Fisheries Dynamics of Modified Floodplains in Southern Asia

Final Technical Report

Project R5953

Fisheries Management Science Programme
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Renewable Natural Resources Research Strategy

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FINAL TECHNICAL REPORT

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1 ODA Summary

1.1 Executive Summary

The purpose of this project was to investigate the life history strategies of floodplain river fish - their spatio-temporal growth, reproduction and survival patterns - and the capture strategies of fishermen, to explain the impacts of hydrological modifications of floodplain rivers, and make recommendations on the management of floodplain river fisheries.

The project was carried out at a hydrologically modified site in Pabna, NW Bangladesh and an unmodified site on the River Lempuing, Indonesia, in collaboration with the Bangladesh Agricultural University, Mymensingh, and the Central Research Institute for Fisheries, Indonesia. Research activities included 2-year surveys of catch/effort data, supported by length frequency, biological and mark-recapture studies on six key species at each site, in addition to six sub-projects on special topics. Comparative analyses were made between study years and among sampling regions, including floodplains inside and outside a flood control (FCD/I) scheme in Bangladesh.

Fish catches were shown to be higher outside the Bangladesh FCD/I scheme, and species compositions to be richer, especially of the larger riverine species. Productive capacity was, however, undiminished inside the FCD/I scheme, with rates of growth, feeding, reproduction and survival all at least as good inside as outside. Lower catches inside the FCD/I scheme were concluded to be due to lower fishing effort (inhibited by agricultural production) and lower fish recruitment, due to reduced accessibility of migrant species. Inside production was mainly due to recruitment from fish surviving over the dry season inside the FCD/I scheme, but biodiversity and yield were also supplemented by fish immigration through sluice gates.

Fishing access was incompletely licensed in Bangladesh, and fishing was intense and competitive at most times. In Indonesia all areas were licensed, and fishing was more efficient, employing ten times fewer people. Mostly due to fishing, mortality rates of fish were so high in Bangladesh, that very few fish were able to survive longer than one year. All the key species except the major carp Catla catla proved able to spawn by this age.

It was recommended that licensing should be maintained at both sites, for its socio-economic benefits. Due to fish mobility, however, licensing holds little inherent value for fish conservation. As a precautionary measure, it was recommended that dry season reserves or fishing restraint should be used in both countries, in several deep waterbodies spread across each river catchment. Such reserves also have strong potential for enhancement of recruitment, for relatively small sacrifices in end-of-dry-season catches. In modified floodplains, catches may also be enhanced by simple management measures at FCD/I sluice gates, taking advantage of natural migratory instincts.

Reserves were found to be traditionally used in Indonesia for the conservation of local fish stocks where waterbodies were clearly associated with communities. It was recommended that future management should encourage community participation, especially at a local level, with higher management agencies taking a coordinating and monitoring role.

This research has made significant contributions to the ecological knowledge of floodplain river fisheries, and provided technical management advice for their conservation and enhancement using simple cost-effective approaches (ODA RNRRS FMSP Purpose 1).

1.2 Background

This study of the dynamics of fish and fisheries in Asian floodplain rivers follows earlier work on this topic funded by ODA as Project R4791 - Poverty and Sustainability in the Management of Inland Capture Fisheries in S. and S.E. Asia. This previous investigation demonstrated the limited catch increases available from four common technical management strategies: fishing effort reductions, gear bans, high water closed seasons and fish/mesh size limits, due to the strong interactions in these multigear fisheries.

It is generally assumed in Bangladesh that hydrological modifications have caused disastrous declines in the inland fish productivity of the country. There is, however, little real evidence of a decline in fisheries due to such modifications. Previous studies conducted under the Government of Bangladesh's Flood Action Plan have produced either non-significant or contradictory results. The knowledge base on which to determine such impacts is also notoriously poor for these multispecies, multigear fisheries in their hydrologically and morphologically complex river environment.

Previous studies of the Flood Action Plan have produced empirical results on the impacts and potentials of different management strategies, sometimes on a large scale over widespread areas, but with little real understanding of the biological processes underlying them. This project has instead chosen to focus in great detail on only two study sites, to give a clear knowledge of the driving forces behind floodplain fisheries.

1.3 Project Purpose

This project was designed to address two key developmental needs:

1. To understand the implications of growth, migration, reproduction and dry-season survival strategies of river fish on the management of inland capture fisheries.

2. To understand the impacts of flood control measures on the fish production potential of modified floodplains in Bangladesh, and make recommendations on the management of floodplain resources for fish production.

1.4 Research Activities

Research activities are described in depth in Chapters 3 and 4 of this report, supported by Appendices A and B. This section provides a brief summary of the project activities.

Fieldwork and project planning was done in collaboration with the Bangladesh Agricultural University, Mymensingh, and the Central Research Institute for Fisheries, Indonesia. After early field visits and the discovery of a highly appropriate 'modified' floodplain site in Bangladesh, collaborations with the initially proposed universities in India were discontinued.

The project was carried out at a hydrologically modified site straddling the Pabna Irrigation and Rural Development Project (PIRDP) in NW Bangladesh, and an unmodified site on the River Lempuing, in South Sumatra, Indonesia. Data were collected under routine surveys (catch/effort, length frequency, mark-recapture, biological and hydrological data), and within several discrete sub-projects, including one PhD study (London university) and three collaborative MSc studies (Bangladesh Agricultural University, Mymensingh).

The routine surveys ran for two full years from January 1995 to December '96 at both study sites, slightly later than planned. Biological data were only collected at the Bangladeshi site to support the detailed comparison of the floodplain regions inside and outside of the FCD/I scheme. Length frequency, mark-recapture and biological data were collected for six ‘key’ species at each site, each selected for their high abundances, as representatives of species 'guilds' of carps, catfish, snakeheads, perches and shrimp, as available.

Data sampling at the Indonesian River Lempuing site was subdivided between three habitat regions: an upstream Forest river region and a downstream Savanna river region, each around 15-20km in main channel length, and a Lake district adjacent to the Savanna river and connected to it by numerous channels, particularly during the flood season. The Bangladeshi PIRDP study site was subdivided into two main study regions including floodplains and associated waterbodies Inside and

Outside the FCD/I embankment (41 and 68km2 respectively). Data were also collected from the adjacent Padma and Jamuna main rivers.

A PhD study was undertaken within the project, based at the University of London, with the objective of providing a quantitative understanding of the effects of FCD/I schemes on the productive capacity of fish stocks at the Bangladesh site. The results of this thesis are included in this main report volume, and written up in detail as Sub-Projects 2, 4 and 6 and one paper (Appendices D, F, H and J): the thesis is expected to be completed by June 1997.

In support of the routine data collection surveys, six additional sub-projects were undertaken to investigate the following specific key research issues:

1. Fishing and fish survival in dry-season waterbodies
2. Density dependence of fish natural mortality rates

Fish migration through flood control sluice gates
Density dependence of fish growth rates
Co-management of Indonesian river fisheries
The utility of visible implant tags for growth studies

Each of these sub-projects was written up as a discrete study, as appended to this report. The results of each sub-project were also fully referred to within the main volume. Sub-projects 2, 4 and 6 were undertaken as components of the PhD study. Sub-projects 1, 4 and 6 were executed in collaboration with MSc students from BAU, Mymensingh. Sub-project 5 was executed in collaboration with senior research staff from CRIF, Indonesia.

Following the shift in focus to the Bangladesh field site, more of the sub-projects were undertaken at that site to quantify the impacts of the FCD/I scheme. Apart from this shift, the experimental approach was essentially achieved as planned in the Project Memorandum.

1.5 Outputs

The outputs of this project, in the form of knowledge gained and recommendations made, are described in Chapters 5, 6 and 7 of this report, and in the volume of appendices. This section provides a brief summary of the main outputs and recommendations. All the main outputs of the project were achieved.

Productivity (catch per unit area) outside the Bangladesh FCD/I scheme was significantly greater than inside in both study years. Fish species communities in Bangladesh were also richer outside the FCD/I scheme, with the larger major carps among those more common outside. It was concluded that the PIRDP embankment reduced the accessibility of the FCD/I scheme, though it did not completely prevent the entry of fish. At the Indonesian site, two of the most valuable River Lempuing species, Notopterus chitala and Osphronemus gurami, previously recorded as rare in 1993 samples were not recorded in any of the 1995 or '96 catches.

Fish recruitment was observed in the early flood season in all study regions. Diets and feeding rates, growth rates, condition factors, lengths at maturity, fecundities and survival rates were all at least as good inside the Bangladesh FCD/I scheme as outside. Due to the lower fish abundances inside the PIRDP in the 1995/96 flood year, fish growth rates and condition factors were actually higher in that region than outside. In Bangladesh, mortality rates were so high that only 0.5-2% of each cohort survived each year, and fish stocks were virtually annual. In Indonesia, mortality rates were lower and far more fish survived beyond their first birthday. Very high tag recapture rates (up to 50% for Catla catla) suggested that the greatest component of the high overall mortality rates was due to fishing, particularly for the most migratory species. Field and experimental analyses on natural mortality rates showed that escapement could be substantially increased by restrictions on fishing at the end of the dry season.

It was concluded that the productive potential of the PIRDP FCD/I scheme is not reduced by its hydrological modification. The lower productivity inside the PIRDP was explained partly by lower fishing efforts, and partly by reduced recruitment inside the scheme, due to the restrictions on access imposed by the FCD/I embankment. Following this result, it was concluded that fish catches in modified floodplains could be enhanced by increasing recruitment either from internal or external sources. Conclusions on the impacts of the PIRDP FCD/I scheme will be strengthened by the final analyses and publication of Ashley Halls' PhD thesis, in June 1997.

Fish migrations included both passive and active phases, and varied strongly between species. Differences between the two sites were explained by their catchment positions and the presence of the vast main rivers in Bangladesh. The ability of some fish to pass through the PIRDP sluice gates was confirmed by the tag recaptures. The mobility of all of the key species was sufficient to take them in between the licensing units of different fishing groups or communities: waterbody licensing clearly does not allocate exclusive rights to floodplain fish. The maximum straight-line migrations observed ranged from 4.7km for A. testudineus in Bangladesh to over 18km for M. rosenbergii in Indonesia. Such mobility clearly stimulates competition between spatially-licensed fishermen, and increases their incentives to catch as many fish as possible while they remain within their areas of control.

Fish survived over the dry season in the most perennial, deepest waterbodies, both beels/lebungs and river pools. Species compositions in dry season waterbodies inside the FCD/I scheme were, however, less rich than those outside, and became progressively less rich towards the end of the dry season. In addition to floodplain habitats, the older specimens of the long-lived major carps survived in the main river region in Bangladesh, and the Indonesian giant prawn M. rosenbergii migrated downstream probably to estuarine zones for the dry season. In the modified floodplains inside the PIRDP, fish surviving in dry season waterbodies were identified as the main source of recruits, while external recruitment and immigration through sluice gates was thought to be responsible for maintaining biodiversity.

Fishing practices at each site were largely determined by the accessibility of the fishing grounds - restricted in Indonesia by complete licensing, and more open in Bangladesh. Significant differences were seen in gear use between the two sites, with most Indonesian catches in 'retaining' barrier traps, and most Bangladeshi catches in actively-fished 'chasing' gear types. Fisherman densities and mobilities were both much higher at the Bangladesh study site, but catches per fisherman were correspondingly lower. The high employment generated by the fishery in Bangladesh and the higher individual catches achieved in Indonesia were in accord with the relative needs of the two countries. It was recommended that the license systems should be maintained at both sites, for their socio-economic benefits. It was also recognised, however, that neither system provides any conservation incentives. In other Indonesian districts, where smaller waterbodies were associated with villages, licensing was restricted to village members, and the sustainability of their local resources was protected by traditional reserves and ceremonies.

Dry season reserves were recommended as the main management tool for floodplain fisheries, accompanied by appropriate sluice gate operations in Bangladesh. Year-round reserves were predicted to have little benefits for floodplain fisheries, unless applied on very large scales, due to the high mobility of their fish stocks. Dry season reserves or partial restraints (eg on dewatering) were recommended instead for their minimal cost to the fisheries, and high potential benefits for stock conservation and recruitment enhancement. Dry season reserves would be best located in several deep, perennial waterbodies spread across each river catchment, including both river sections and beels/lebungs, ideally with each village offering some restraint on its dry season fishing. It was recognised that dry season reserves may not provide adequate protection for the more migratory species, for which barrier controls may be needed in future.

1.6 Contribution of Outputs

1.6.1 Contribution of outputs to project goal

This research has provided knowledge and recommendations of relevance to both Purposes of the Fisheries Management Science Programme. Under Purpose 1, significant advances have been made on the appropriate resource management strategies for capture fisheries in Asian floodplain river fisheries, particularly on the use of riverine reserves and waterbody licensing, and the links between property rights and fish behaviour patterns. Under Purpose 2, additional proposals have also been made for the enhancement of floodplain fish catches in modified and unmodified catchments using simple cost-effective methods.

The dissemination of results from this project is now in process, having been delayed by the late start of sampling activities and site selection in the study countries.

1.6.2 List of publications

One paper has so far been accepted for publication from this report (see Appendix H):

Halls, A.S. & Ekram-Ul-Azim, Md., in press, The Utility of Visible Implant (VI) Tags for Marking Tropical River Fish. Fish. Man. & Ecol.

The following papers have also been submitted up to this time (see Appendices G and I):

Hoggarth, D.D., M. Aeron-Thomas, A.S. Sarnita & Ondara, Spatial Co-management of Indonesian Floodplain River Fisheries, submitted to Indon. Fish. Res. J., February 1997.

Hoggarth, D.D. & A.D. Utomo, A Comparison of Anchor and Streamer Tags for Marking Tropical River Fish, submitted to Fish. Man. & Ecol., September 1995 and returned for modification.

The following theses are also in preparation:

An assessment of the putative impacts of hydraulic engineering on floodplain fisheries and fish assemblages, Bangladesh. Ashley Halls, PhD, Renewable Resources Assessment Group, Imperial College of Science, Technology and Medicine, University of London.

The Utility of Visible Implant (VI) Tags for Marking Tropical River Fish. Md. Ekram-Ul-Azim MSc, Bangladesh Agricultural University, Mymensingh (submitted).

Fishing and Fish Survival in Dry-Season Waterbodies. R. Kumar Dam. MSc, Bangladesh Agricultural University, Mymensingh.

Density Dependent Growth of Puntius sophore. Md. Anowarul Huda. MSc, Bangladesh Agricultural University, Mymensingh

1.6.3 Other dissemination of results

The following presentations have been made:

University Seminar, Mr A.S. Halls, MRAG Ltd.
Methods for the Assessment of Fish Growth in Wild Fish Populations
Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
April 1995

Conference Paper, Md. Ekram-Ul-Azim, BAU, Mymensingh
The Utility of Visible Implant (VI) Tags for Marking Tropical River Fish.
Bangladesh Science Conference, 29-31 October 1996
Bangladesh Association for Advancement of Science (BAAS), Dhaka
Jahangir Nagar University

University Seminar, Dr D.D. Hoggarth, MRAG Ltd
Management Strategies for Tropical Floodplain River Fisheries
Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
14 October 1996

Presentation & Prizegiving to Sumatran Fishing Community, Ondara & A.D. Utomo, CRIFI
Pedamaran Kecamatan Office, December 1996

Presentation & Prizegiving to Bangladeshi Fishing Community, K. Debnath, MRAG Ltd
Talimnagar Village Sluice Gate, December 1996

To assist CRIFI with project planning and research methodologies, the following three-day training workshop was held. This workshop was attended by many CRIFI staff, six of whom went on to practice the techniques for three days in field situations.

Rapid Rural Appraisal Techniques for Inland Fisheries
Dr D.D. Hoggarth, C. Garaway & M. Aeron-Thomas, MRAG Ltd
CRIFI, River Floodplain Capture Fisheries Research Station, Palembang

21-24 August 1996

Two of the project collaborators from each study site also made exchange visits to their counterparts in the other countries, for comparative studies and to develop awareness of regional resource issues.

1.6.4 Planned follow-up actions

Final dissemination workshops for fisheries and water resource managers from both government, donor and NGO backgrounds are now being planned with the project collaborators as follows:

Final Dissemination Workshop in Bangladesh, Dr D.D. Hoggarth, A.S. Halls, MRAG Ltd
Planned for 29 April 1997, BAU, Mymensingh

Final Dissemination Workshop in Indonesia, Dr D.D. Hoggarth, MRAG Ltd
Provisional plans for June 1997, CRIFI, Palembang

1.6.5 Recommended follow-up research

To be of maximum use to inland fisheries managers in developing countries, it is intended that the key results of the project will be published widely in academic and 'soft' publications within the next year.

2 Introduction

2.1 Background

This study of the dynamics of fish and fisheries in Asian floodplain rivers follows earlier work on this topic funded by ODA as Project R4791 - Poverty and Sustainability in the Management of Inland Capture Fisheries in S. and S.E. Asia. This previous investigation demonstrated the limited catch increases available from four common technical management strategies: fishing effort reductions, gear bans, high water closed seasons and fish/mesh size limits. For these strongly interactive, multispecies, multigear fisheries, gains for one species or gear type were nearly always balanced by losses from other ones, and the negligible overall benefits in yield were invariably accompanied by socially unacceptable reallocations in fishing benefits.

Project R4791 concluded that such approaches should generally not be applied for floodplain fisheries, and that fishery reserves should instead be recommended to provide some buffers against overexploitation, as precautionary measures. A major problem with this recommendation was the lack of knowledge currently available on the fish ecology of Asian floodplain rivers, and uncertainties on how such reserves could be applied and the likely magnitude of their protective capacity. The present project has been designed partly to answer such questions.

This research was more directly focussed on providing biological explanations for key uncertainties in recent ODA projects in Bangladesh. It is generally assumed in Bangladesh that hydrological modifications have caused disastrous declines in the inland fish productivity of the country. Such modifications include small impoundments, polders, levees and some very substantial flood control, drainage and irrigation (FCD/I) schemes. There is, however, little real evidence of a decline in fisheries due to such modifications. In the recent World Bank/ODA FAP17 (1994a, b) study, either non-significant or contradictory results were obtained at different study sites on both fish catch rates and hatchling production inside and outside flood control schemes. In the FAP16 study (ISPAN, 1993), it was concluded that “...late or reduced flooding under the controlled flooding management concept of the FCD/I projects would hamper the biological activities of fish by delaying migration, limiting the time for migration, and by shortening the time and area for dispersal, feeding, and growth". In contrast, FAP20 (1994) concluded that a fully functional compartmentalisation scheme may actually increase productivity resulting from an extended flood season, even though hatchling densities may be lower inside the scheme than outside, supporting the notion that FCD/I schemes impair the drift or migrations of hatchlings on to the floodplain.

In general, these projects and other similar ones have produced empirical results on the impacts and potentials of different management strategies, sometimes on a large scale over widespread areas, but with little real understanding of the biological processes underlying them. This project has instead chosen to focus in great detail on only two study sites, to give a clear knowledge of the driving forces behind floodplain fisheries. With such knowledge, it was hoped that the variable impacts of flood control schemes could be better understood, leading to sound recommendations for the enhancement of their catches.

2.2 Project Purpose

This project was designed to address two key developmental needs:

1. To understand the implications of migration, reproduction and dry-season survival strategies of river fish on the management of inland capture fisheries.

2. To understand the impacts of flood control measures on the fish production potential of modified floodplains in Bangladesh, and make recommendations on the management of floodplain resources for fish production.

The first problem is essentially a spatial one. Asian tropical fish stocks in large floodplain rivers are often managed and exploited under some form of area-based licensing scheme. The implications of such management schemes, both for the fish stocks and the fishermen, depend largely on the migration and dispersal patterns of the fish. To understand these implications, the following questions should be asked. How much do the fish move between licence units? Is it possible for fishermen to reduce exploitation rates to conserve or improve resident fish stocks within their own licence area? Are certain migrant fish effectively open-access resources, vulnerable to capture in many different licence units? How much do migration patterns vary between fish species? Do certain habitats serve as nursery areas, or as feeding or breeding areas for adults? Depending on the answers to these questions, could harvest reserves be used to protect fish stocks, and if so, where should they be located?

The second problem reflects concerns on the hydrological modifications currently underway on river systems in Bangladesh and elsewhere, and the uncertain impacts these have on fish production. The absolute impacts of such developments had previously been assessed by other projects, but without consistent results. This project was designed to explain the causes of such impacts by answering two further questions: (1) do fish caught in impounded floodplains migrate in from outside, or survive over the dry season inside?, and (2) what is the relative production potential of impounded versus unmodified floodplains, for those fish present. The answers to these questions determine whether floodplain fish production would best be promoted by controlling water levels, assisting fish migrations with fish passes, or protecting dry season survival, eg. by using reserves.

2.3 Research Study Sites

The research for this project was based at two study sites: a hydrologically modified site in Bangladesh, and a relatively unmodified site in Indonesia. It was originally intended that the modified site would be based at Patna on the River Ganges in India. A Bangladeshi site was selected instead for two main reasons. Firstly, original concerns on the ability and willingness of Bangladeshi fishermen to collaborate with the field study were dispelled by local collaborators. Secondly, a modified floodplain site at Bangladesh was identified which had more extensive floodplains than the Indian site, and a wider range of different flood control measures in place.

The hydrologically 'modified' study site, then, was located in the Pabna Irrigation and Rural Development Project (PIRDP), at the confluence of the Ganges (Padma) and Brahmaputra (Jamuna) river systems, in NW Bangladesh. This site is relatively heavily populated with small villages scattered throughout the study area (Figure 2.1). Two adjacent main sampling areas were selected for study, one inside and one outside the large embankment which protects the PIRDP lands from the flooding Padma and Jamuna rivers. The inside and outside study sites together covered a total of 109km2. Water levels in this part of the PIRDP are controlled by one large and two small sluice gates at intervals along the embankment. This site was the focus of studies on the impacts of flood controls, partially involving comparisons between the ‘inside’ and ‘outside’ sampling areas.

In Indonesia, a 36km section of the River Lempuing was selected within the Ogan Komering Ilir (OKI) regency of South Sumatra province (Figure 2.2). This river section comprises a range of different habitats including savanna floodplains, forested floodplains and adjacent lakes, which are divided into 35 distinct licensing units for spatial management. Outside the local town of Pedamaran (population ~20,000), the site is relatively lightly populated, mainly by the small numbers of fishermen living on their licensed waterbodies. This site was used to investigate fish behaviours and management options in an unmodified, natural floodplain system.

2.4 Research Approach

2.4.1 Comparisons among study sites

The first project purpose was addressed by investigating the spatial and temporal dynamics of both the floodplain fish stocks and the capture fisheries which depend on them, at both study sites in relation to their natural hydrological cycle. Such investigations were made to allow comparisons among the following 'regions' of each study site:

Bangladesh study site regions

'Inside' Floodplains	hydrologically modified by the PIRDP FCD/I scheme
'Outside' Floodplains	nominally similar to 'Inside', but unmodified
Main River	adjacent to Outside floodplains

Indonesian study site regions

Lake District
Upstream Forest River
Downstream Forest River

Of these regions, the Bangladeshi 'Inside' floodplain region is the 'modified' floodplain study site inside the embankment of the PIRDP FCD/I scheme. The productive processes in this region are compared mainly with the nominally similar Outside floodplain region, but also with those at the Indonesian site to provide a broader contrast. Though each region contains different habitat zones (such as floodplains, pools and river sections), the Indonesian site was deliberately divided into three regions with broadly different habitats to determine the impact of habitat on fish production, over and above any inside/outside differences in Bangladesh.

For the second project purpose, the impact of the flood control scheme was investigated by making the most detailed hydrological and biological comparisons within the Inside and Outside regions of the Bangladeshi site. Due to the lack of historical data, it is impossible to confirm whether differences in productivity are really due to the flood control scheme, or whether they also existed prior to its construction. In addition to cautious comparisons of productivities in these regions, greater attention was paid to the underlying processes behind the productivity impacts.

Differences in in/out productivity may be due to two factors: the relative numbers of fish in each region and their relative performance. It was hypothesised that the first factor may be strongly impacted by the effects of FCD/I embankments on fish migration routes, while the second factor depends largely on relative water levels and the resources available for fish production. The accessibility of the inside floodplain to migrant fish was thus investigated through an extensive tagging programme. The dependence of fish production on water levels was also investigated using experiments to determine the relationships between fish growth, mortality, reproduction and recruitment on the density of fish, as determined by water levels. The seasonality of production and migration were also particularly investigated in relation to hydrological differences caused by the flood control scheme.

2.4.2 Dynamics of floodplain fish

Tropical floodplain river fish stocks are comprised of a broad community of fish species, from a range of different taxonomic groups. At each of the study sites, around 30 fish species are commonly found in the catches, while many more rare species are occasionally encountered. The dynamics of these fish communities were investigated as a whole for some analyses, eg. on the relative seasonalities of the overall catch. More detailed explanatory investigations, eg. on migration patterns and growth/mortality rates were made on six key species of fish selected as representatives of fish types or 'guilds' at each site.

For each key species, the following broad areas were investigated to provide a clear understanding of the productive basis of floodplain fish stocks:

Spatial dynamics	Geographic migration cycles, and mobilities (distances)

Key life cycle habitats for feeding, reproduction, and dry season survival

Temporal dynamics Seasonality of migrations, reproduction, recruitment, feeding (rates and preferences), growth and mortality

Population dynamics Age dependent growth, maturation and mortality rates

2.4.3 Dynamics of the fishery

The dynamics of the fishery were investigated by describing the seasonality of the different gear types and their spatial and temporal interactions. Based on an improved knowledge of the resource base, from the above biological studies, particular attention was given to the times at which the fisheries were most effective, and when they particularly threatened the survival of the stocks by harvesting key life history stages. The following broad outputs were investigated, again mainly using data from the five data surveys:

Spatial dynamics Relative exploitation rates by location/habitat
Mobility of fishermen and access to resources
Interactions between fishing gears
Interactions between license units (waterbodies)

Temporal dynamics Seasonality of the fishery
Interactions between fishing gears (linked to mesh sizes and gear selectivity)

2.4.4 Data collection

Data were collected for the above analyses during two full years, 1995 and 1996. As described in Chapter 3, a routine data sampling programme was initiated for the collection of catch/effort, length-frequency, tagging, biological and hydrological data. In addition to this routine sampling, specialised subjects were investigated as discrete sub-projects. Both the routine sampling and most of the sub-projects were undertaken in cooperation with local research staff from collaborating institutes.

2.4.5 Effects of hydrological modifications on floodplain river fisheries

As noted earlier, the effects of hydrological modifications at the Bangladeshi site are considered in two broad areas: (1) the access of fish to the floodplain, and (2) the relative potential production of fish inside and outside flood control schemes.

The main flood control embankment at the PIRDP Bangladesh study site is completely impassable to fish, except at the regularly spaced sluice gates. Fish are caught while attempting to migrate through these sluices, and it was hypothesised that some fish may be able to pass through both the sluice mechanisms and the fishing gears. The floodplain area inside the impoundment dries up almost completely during the dry season, and yet, as shown by the FAP17 project (FAP17, 1994a), fish catches inside are still substantial. The most crucial management issue is whether the fish produced with each new flood pulse derive mainly from stock migrating in through the sluice gates, or from fish which survived inside throughout the dry season. Various outputs from the catch/effort and mark recapture surveys, and from the Bangladeshi sub-projects demonstrate the relative numbers of fish contributing to each year’s production from each source. Comparison of the fish community structures on either side of the embankment, based on data from both FAP17 and this project were also made to determine the degree of isolation of the impounded areas.

Given that fish are present inside impounded areas, from whatever source, the second possible impact of hydrological control depends on the actual alterations made to the water levels, and their effects on the inherent capacity for fish production. In general, impoundments controlled for agricultural purposes have lower and more stable water levels than outside, but may also have a prolonged period of inundation, to allow the aman rice crops to fully develop. Such a hydrological regime may of course also benefit the natural production of fish.

The effect of this second type of impact will be determined using an age-structured 'dynamic-pool' production model based on the relationships between water levels and those biological processes influenced by variations in fish density. These include the growth rate, mortality rates, condition factors, lengths at maturity, fecundity and reproductive activity. Feeding rates and food availability are also investigated as possible underlying causes of any observed differences. This component of the research is investigated qualitatively within this main report, but will be studied more quantitatively in a PhD study funded by the project based at the Renewable Resources Assessment Group, Imperial College of Science, Technology and Medicine, University of London, UK.

2.5 Institutional Collaborations

With a central project base at the Marine Resources Assessment Group, London, UK, collaborations were established with local research institutions at each site to provide the administrative and local field work requirements.

In Bangladesh, the ODA's Bangladesh Aquaculture and Fisheries Resource Unit (BAFRU) provided administrative and logistic support for three Bangladeshi researchers employed directly by the project between November 1994 and December 1996. An educational collaboration was also developed with the Bangladesh Agricultural University (BAU) at Mymensingh, who provided three MSc students to work on sub-projects within the framework of the study (Section 3.11 and Appendices C, F and H). The sub-projects were jointly supervised by the UK project staff and by BAU staff led by Dr M.A. Wahab.

In Indonesia, the Central Research Institute for Fisheries (CRIFI) allocated two full time researchers and one part time assistant to the project, supported by project fieldwork allowances from August 1994 to March 1997. A boat was provided for the fieldwork at the remote Lempuing site, and other basic equipment provided for the CRIFI Research Station for Riverine Capture Fisheries at Mariana, Palembang.

With support from the above institutions, the UK project staff supervised field activities from their London base, via fax/E-mail communication links, and during twelve site visits to Bangladesh and seven visits to Indonesia (see Annual Reports) over the course of the project. During 1996, two of the research collaborators from each of the study countries also visited their counterparts in the other countries, both to extend their experience of Asian river systems, and to gain insights on the comparative results arising at each site.

2.6 Report Structure

In this final technical report, material is presented in this main volume and in a separate volume of appendices.

Chapter 1 of this main volume provides a brief summary of the work, in the format required by ODA for final technical reports.

Chapters 2 and 3 provide an overview and routine methodologies respectively for the research activities and data collection undertaken at each site. Supporting information on the routine surveys and the database developed for the project are given in Appendices A and B. Detailed analytical methods are reported in later sections, as appropriate, to accompany the results.

Chapter 4 reports information on the environmental and hydrological conditions at each study site, and their seasonal and interannual variability.

Chapters 5 and 6 report the main outputs of this work, in the form of research results and conclusion on the dynamics of floodplain fish and fisheries respectively. This material makes reference to data from four of the six sub-projects, written up in depth in Appendices C to F.

Finally, chapter 7 considers the management of floodplain fisheries, based on their biological characteristics, and on the effectiveness of the existing management strategies at each site. The applicability of these results is broadened by a wider study in Indonesia reported as Appendix G.

Each main chapter ends with its own brief summary. Tables and figures are placed at the end of each chapter, and references at the end of each report volume.

In addition to the sub-project reports, the volume of appendices also includes three papers submitted during the project, and one section of the PhD thesis.

2.7 Personnel and Acknowledgements

This research was undertaken by the following personnel:

Marine Resources Assessment Group Ltd, London:

Dr Ian Payne, Project Director
Dr Daniel Hoggarth, Project Officer
Mr Ashley Halls, Research Assistant and PhD student (Imperial College)
Mr Mark Aeron-Thomas, Consultant Economist
Ms Caroline Garraway, Consultant Community Scientist

Central Research Institute for Fisheries, Indonesia, River Capture Fisheries Research Station, Mariana, Palembang:

Mr Ondara, Research Officer (Indonesia)
Mr Agus Djoko Utomo, Research Assistant (Indonesia)
Mr Herman Gim, Field Assistant (Indonesia)
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Marine Resources Assessment Group Ltd, Bangladesh:

Mr Kanailal Debnath, Research Officer (Bangladesh)
Mr Emdad Hossain, Research Assistant (Bangladesh)
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Bangladesh Agricultural University, Mymensingh, Bangladesh:

Dr M.A. Wahab, Academic Supervisor (Bangladesh)
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Mr Ranjan Kumar Dam, MSc Student
Mr Anowarul Huda, MSc Student

This final technical report was written by Dr Daniel Hoggarth and Mr Ashley Halls, with additional inputs to Sub-Project G by Mr Mark Aeron-Thomas. The ideas and conclusions of the report, however, reflect the excellent local knowledge experience of all the above collaborating staff.

For administrative assistance and logistic support, the authors are extremely grateful to Mr Chris Price and his staff at BAFRU, Dhaka; and also to ODA, Bangladesh.

2.8 Summary - Introduction

- This research follows a previous ODA project in S. Asia which found that little benefits were available in total yield from fishing effort reductions, gear bans, high water closed seasons and fish/mesh size limits. It also follows previous inconclusive research in Bangladesh on the impacts of hydrological modifications on the productivities of impounded floodplains.

- The research programme was designed to provide a sound basic knowledge on the life history strategies of floodplain fish, to be able to explain the impacts of flood control schemes, and make recommendations on the management of floodplain river fisheries. Simple management tools were sought which held strong potential for sustaining and potentially enhancing recruitment to fish stocks at minimal costs.

- The project was carried out at a hydrologically modified site straddling the Pabna Irrigation and Rural Development Project (PIRDP) in NW Bangladesh and an unmodified site on the River Lempuing, Indonesia. Fieldwork and project planning was done in collaboration with the Bangladesh Agricultural University, Mymensingh, and the Central Research Institute for Fisheries, Indonesia.

- The research approach involved comparisons among regions of the study sites defined both inside and outside the FCD/I scheme in Bangladesh, and in broad habitat categories, as available at each site. Regional comparisons were made between the various sub-components of the fish production process, including recruitment, growth, reproduction and survival. This compartmentalisation enabled the overall impact of FCD/I schemes on floodplain fisheries to be determined and also provided a detailed understanding of the mechanisms behind such impacts. These broadly included the accessibility of modified floodplains and their productive capacity, dependent on floodplain water levels.

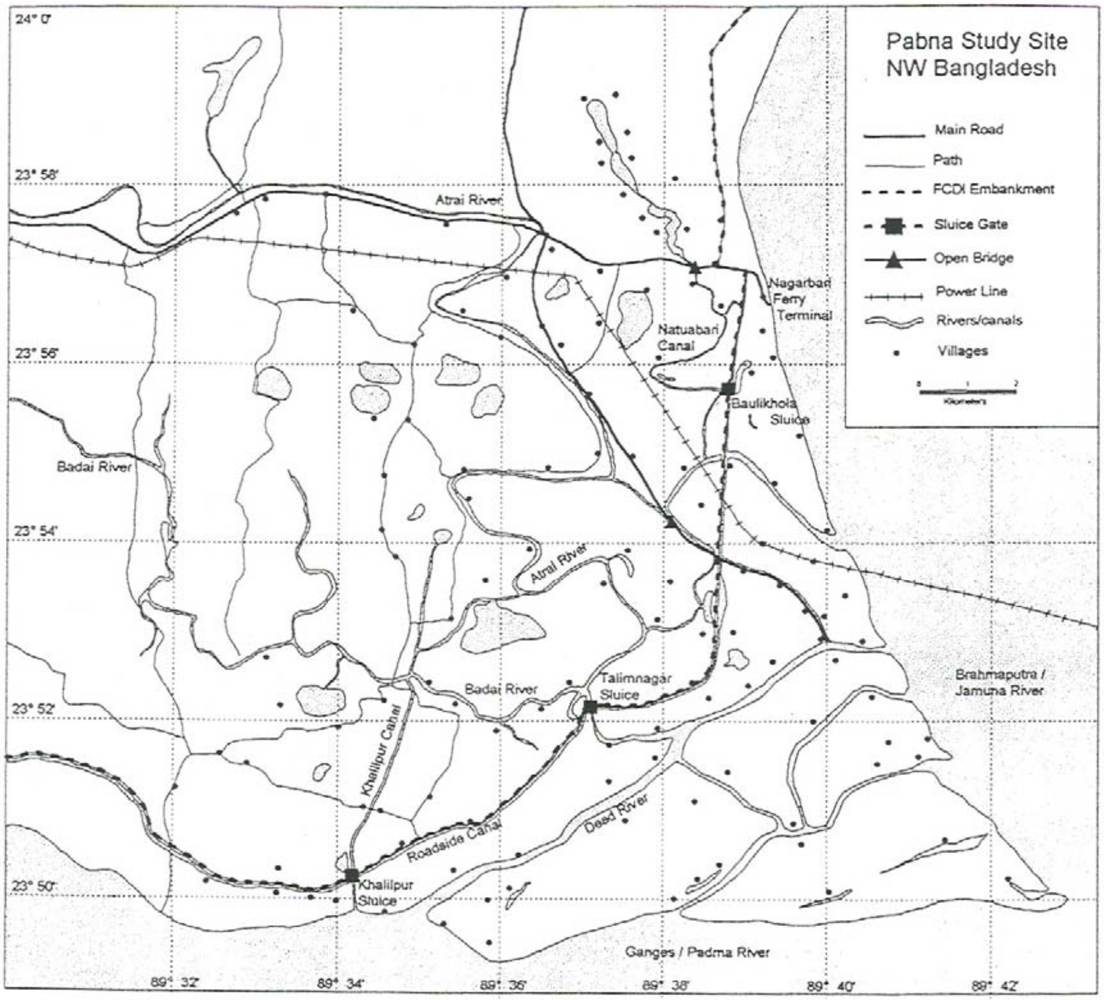


Figure 2.1 The Bangladeshi study site, straddling the south-east boundary of the Pabna Irrigation and Rural Development Project (PIRDP) flood control scheme.

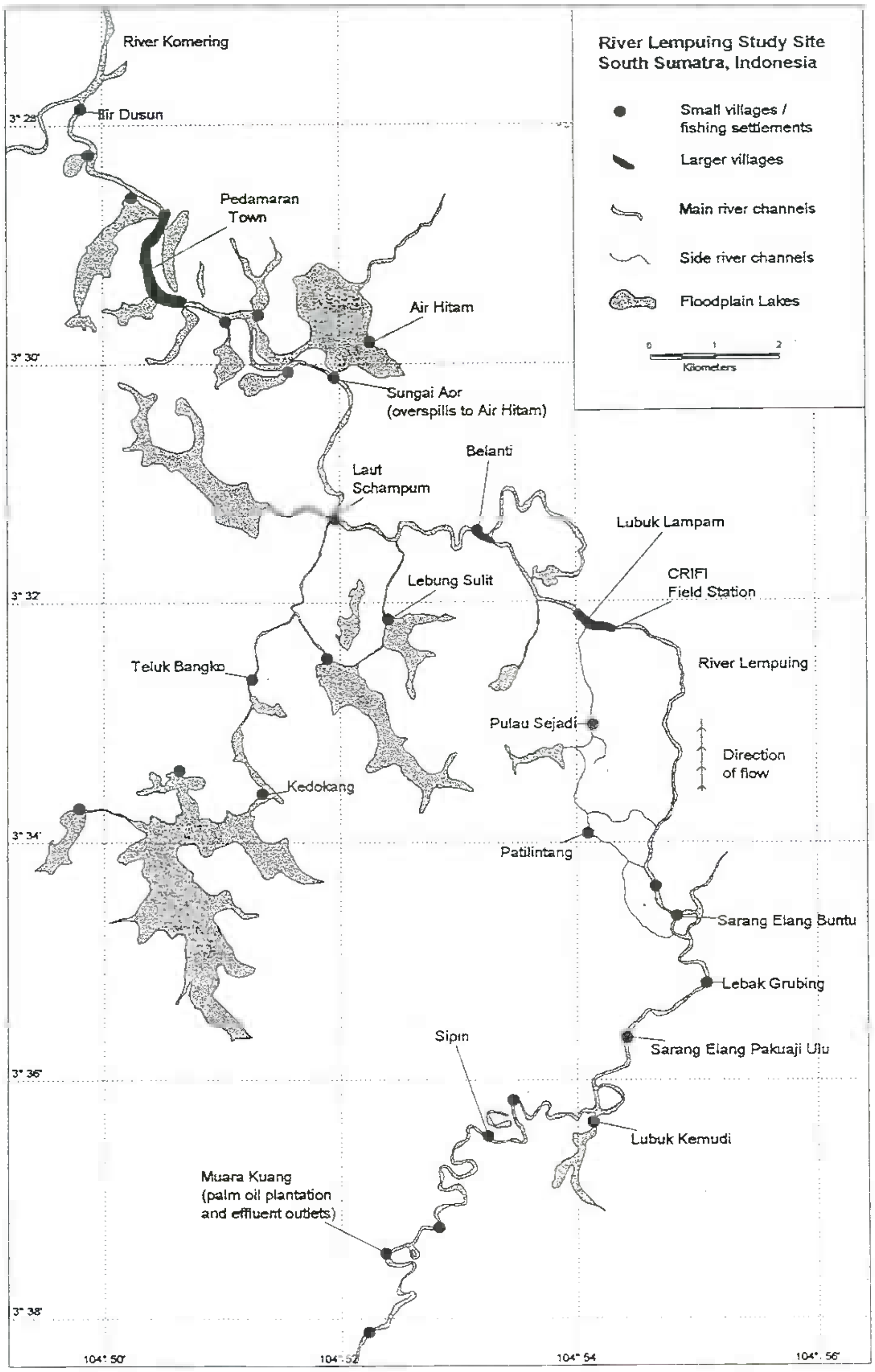


Figure 2.2 The Indonesian study site, showing the River Lempuing main channel and its associated lakes, in Ogan Komering Ilir province, South Sumatra.

3 Data Collection

3.1 Introduction

Data were collected during this three-year project under a number of different mechanisms. Firstly, routine data collection surveys - for catch/effort data, length frequencies and so on - were established at each study site to provide the baseline data for the project. Such data contributed to several separate components of the study. Secondly, a PhD programme was undertaken to specifically examine the impacts of hydrological modification on the productive capacity of impounded floodplains. Finally, an additional suite of discrete sub-projects (three of them as sub-components of the PhD) was undertaken to answer concise questions within the general research area. Four of these sub-projects were carried out as joint exercises with the collaborating institutions, three of them as MSc projects.

This chapter provides details on each of these data collection activities. Analysis methodologies are generally described in later sections of the report, as appropriate, to accompany each component of the investigation.

3.2 Routine Data Collection Surveys

The primary field data for this project were collected by the local project officers under the supervision of the MRAG staff. The following data were sampled for two full years, 1995 and 1996, at the frequencies given:

Catch/effort	Twice-monthly interviewing of randomly selected respondents
Length frequency	Bi-monthly sampling from non-selective gear types
Mark (tag) releases	Opportunistically, depending on seasonal availability of fish
Mark recapture	Daily reception of tags returned by fishermen
Hydrology	Daily water heights, and weekly water velocities
Biology	Monthly sampling to target n for defined fish length classes

The first five data types were collected at both study sites. Biological data (maturity and reproductive state by sex, feeding activities and hard parts for age determination) were only collected at the Bangladeshi site, to support the development of the production model for comparing the areas inside and outside the flood control scheme (see Chapter 5).

Parameter outputs, survey objectives, planning considerations and routine sampling methodologies for each survey were described in the Survey Methodologies document (Appendix A).

3.3 Biological studies of 'key' species

Tropical floodplain river fish stocks are comprised of a broad community of fish species, from a range of different taxonomic groups. At each of the study sites, around 30 fish species are commonly found in the catches, while many more rare species are occasionally encountered. The dynamics of these fish communities were investigated as a whole for some analyses, eg. on the relative seasonalities of the overall catch. More detailed explanatory investigations, eg. on migration patterns and growth/mortality rates were made on six 'key' species of fish at each site, selected as representatives of the following taxonomic guilds:

Taxonomic group	Bangladesh	Indonesia
Carps	Catla catla	Osteochilus hasselti
	Puntius sophore	
Snakeheads	Channa striatus	Channa striatus
Catfish	Wallago attu	Mystus nemurus
Perches	Glossogobius giurus	Helostoma temmincki
	Anabas testudineus	Anabas testudineus
Shrimp	Macrobrachium rosenbergii	

The above key species were selected as representatives for their high abundance, both due to their importance to the fisheries, and to their potential for obtaining good samples. The six Bangladesh key species, especially P. sophore and W. attu, were responsible for 35% of the 1995-96 catches at the PIRDP site. The six Indonesian key species contributed 48% of the total 1995-96 catches at the Lempuing site. The shrimp M. rosenbergii is no longer common in Indonesia, but was selected as a previously economically important species.

3.4 Spatial Location Coding Systems

Spatial location coding systems were developed at both sites for accurate recording of the positions of fish captured or sampled in each of the separate data surveys. The location codes comprised a maximum of seven letters, subdivided into two parts, separated by a comma. The first three letters of each code indicated the waterbody name. The letters after the comma indicated the sub-section of the waterbody (upstream, downstream; left/right bank; section 1/2/3 etc), and the habitat type (main river, secondary river, canal, floodplain or lake). This coding system was primarily developed for the mark-recapture survey, for identifying the release and recapture locations of tagged fish. The use of the codes in the other surveys, however, enabled the analyses of the different data types to be subdivided by any region of interest, in addition to habitat type.

The codes used for the Bangladeshi field site are illustrated in Figure 3.1. The area represented by each location code was defined by reference to landmarks (such as schools, mosques, river confluences, bridges, roads etc) well known to the local fishermen. This enabled easy allocation of fish capture locations to a single location code. The actual positions of the location were quantified for mapping purposes by recording the latitudes and longitudes of the landmarks using a hand-held GPS meter. At the Bangladesh site, locations identifying floodplains and beels covered an average area of 1.13km2, while locations in secondary rivers and canals had an average length of 1.18km.

In Indonesia, the waterbody names for location coding were taken from the auction unit names used by the local administration for licensing the River Lempuing fishery (see Chapter 7). At the Lempuing site, the outer limits of floodplain locations could not be recorded using the GPS meter due to the difficulties of transport in this remote floodplain region. Only the boundaries between the auction units on the main river could be reliably positioned from the project boat (Figure 3.2). Several location codes were however created for each waterbody, to distinguish catches from each of the different habitats and any sub-divisions. Riverine location codes at this site were an average 2.55km in length. Lake location codes were of a similar size to Bangladesh, ranging in size from a few hectares up to the largest Danau Besar lake (DBL location, Figure 3.2) at 3.9km2.

3.5 Mark Recapture Programme

Details on the practicalities of the Mark-Recapture programme are given in the Survey Methodology document (Appendix A); sample sizes and recapture rates etc are provided in Chapter 5. Additional supporting information only is provided in this section.

In preparation for the tagging programme, an experiment was performed at the Indonesian site during 1994 to determine the mortality rates and tag loss rates resulting from the use of different types of tag on the different key species of fish. Based on the results (Appendix I), 5,500 anchor tags, and 5,000 streamer tags were supplied to the two sites. The anchor tags were used to tag the larger, round-bodied fish species, and the streamer tags for the smaller, narrow-bodied species and the

Macrobrachium rosenbergii prawns (large streamer tags) in Indonesia. The tags were supplied by Hallprint Pty Ltd of Australia, in the following sizes:

Anchor, TBF	15mm filament + 10mm marker
Small Streamer, PST 12P	42.5 x 2.5mm (cutout 12.5 x 1.2mm)
Large Streamer, PST 7S	57 x 2.7mm (cutout 20 x 1.4mm with locking flaps)

The mark recapture programme was supported by publicity activities at each site, including the use of posters, handouts (Figure 3.3) and verbal announcements in villages and at fishermen's meetings up to approximately 60km away from the main tag release area (see Figure 3.4 for Indonesia). To increase the tag return rate, rewards were given for each tag returned to the project. In Indonesia, either a project T-shirt or Rp7,000 (~£2) was given as a prize, while in Bangladesh, Tk100 (~£1.60) was awarded. When tagged fish were returned in addition to the tag itself, the market value of the fish was also paid. Lotteries were also held at the end of each fieldwork year with attractive prizes. In Indonesia, the programme publicity also received a boost when the local Independence Day Boat Race in October 1995 was won by a 10-man team wearing the project T-shirts given as rewards!

3.6 Catch / Effort Sampling Strategies

The objectives and survey planning notes for the catch / effort sampling programmes were described in the Survey Methodologies document (Appendix A). Briefly, at each site, a panel of respondent fishermen was randomly selected within regional strata, to provide twice-monthly data on the total catch weights and fishing efforts for each of their different gear types. Separate market samples were then taken by project staff to estimate catch compositions by region and geartype. The product of these two data sources provided estimates of total fish catches subdivided by month, region, gear type and fish species for the two full sampling years 1995 and 1996.

Appendix A gives the background and overall approach for this sampling strategy, in addition to the practical aspects of the routine interviews and data collection. The following sections give additional details on the selection of respondent fishermen at each site, and the frame survey data used to raise the sampled catches to the totals within the regional strata. Slightly different sampling strategies were used at the two study sites, as summarised in Table 3.1. The main difference in the sampling strategies was that the Indonesian frame survey was based on a complete census of fishermen within the licensed Lempuing waterbodies, while the Bangladeshi frame survey was based on random subsampling, firstly of villages, then of interviewees drawn from voter lists.

3.7 Catch / Effort Sampling Strategy - Indonesia

3.7.1 Waterbodies, licensing units and general sampling approach

The catch/effort sampling strategy for the Indonesian site was much simplified by the fact that all waters in this locality are licensed for fishing by the local authorities, and that licensed fishermen fish almost exclusively in their own waterbodies. A complete census of fishermen numbers could thus be easily undertaken, by interviewing the leaseholders of each of the different waterbodies. To assist the explanation of the Indonesian sampling strategy, brief details are first given in this section on the River Lempuing licensing system.

The River Lempuing is divided up into 35 licensing waterbodies. One of the waterbodies is restricted from fishing by the local Department of Fisheries as a reserve (Teluk Rasau, Figure 3.2). The other 34 waterbodies are auctioned for fishing in November/December each year, using one-year leases running from January 1 to December 31. The waterbodies are generally leased by either a financier or a well-off group of fishermen, perhaps a family unit. Large waterbodies may then be split up into smaller geographical sub-units and sub-leased to other groups of fishermen. Decisions on the sub-division and exploitation of a waterbody are made by the new head-licensee at the beginning of each new year, and the waterbody may be split into different sub-units in different years. Each sub-unit, then, is usually fished by one group of fishermen, and also by a number of sub-licensed individual fishermen, generally using different gears. Various types of credit arrangements exist between the different levels of sub-licensees.

Each fishing waterbody thus has a small community of up to around 20 fishing households, whose members change from year to year. Fishermen's families sometimes live with them on their waterbodies, and sometimes remain at the main family homes, mostly in the main town of Pedamaran (Figure 2.2).

While nearly all fishing is done by the licensed fishermen in their own waterbodies, unlicensed fishermen are allowed to fish in any waterbodies in the traditionally open-access month of January. During this month, most licensees are busy constructing their large barrier traps ready for the forthcoming drawdown and low-water seasons. The sampling programme, based only on licensed respondents, did not record the activities of such 'free' fishermen in January: the resulting downward bias is, however, considered to be negligible due to the small numbers of free fishermen, and the low efficiency of fishing at this time.

3.7.2 Catchment geography and sampling regions

The 35 River Lempuing licensing waterbodies are spread out along a ~50km section of the river. The main study site included the 29 downstream license units spread over a 36km stretch of the river between the main local town of Pedamaran, and a palm oil plantation upstream at Muara Burnai (Figures 2.2, 3.2). Between these points, the river and its floodplains may only be easily accessed by boat.

The study site includes braided stretches of main river with side channels, in addition to their adjacent floodplains and lakes. Licensing waterbodies may be comprised of one or more different habitat types, which often form the divisions for the different licensing sub-units. The floodplain habitat may be classified as either lebak flooded grassland, or rawang flooded forest.

For this study, the Lempuing catchment was divided into three sub-regions; a downstream section of 'savanna river' bounded mostly by lebak floodplain; an upstream section of 'forest river' bounded mostly by rawang; and a region of large lakes to the SW of the main river, and connected to it only by side channels during the high water period (Figure 3.5). Catch data were raised separately for these three sub-regions to enable comparisons of fish behaviours between the different overall habitat types.

3.7.3 Frame survey of fishermen numbers

A ‘frame survey’ estimate the total numbers of fishermen, boats, or other fishing effort 'units' within a sampling region. At this study site, the total numbers of group and individual fishermen in each sub-division of each waterbody were simply collected using a complete census approach, by interviewing the group leaders of all the sub-units in each of the 35 waterbodies. This exercise was repeated for each of the 1994, '95 and '96 fishing seasons.

In 1994, all of the unrestricted 34 waterbody units on the R. Lempuing were fished, subdivided into a total of 58 sub-units (Table 3.2). In 1995 and 1996, however, some of the waterbodies were not licensed, and the numbers of fishing sub-units and fishermen fell accordingly. The total numbers of fishermen, for example, dropped from a high of 587 in 1994 to only 324 in 1996 (Table 3.2).

3.7.4 Two-stage random selection of catch / effort respondents

To estimate catch and effort rates, a panel of catch/effort respondents (CERs) was selected using a two-stage sampling design with stratification. At this site, the primary sampling units were the waterbodies, while the secondary units were the fishermen selected as CERs.

- **First-stage sampling of waterbody sub-units**

Sixteen waterbody sub-units were selected for catch/effort data collection on the R. Lempuing, spread over the three sub-regions (Figure 3.5). The waterbodies were selected within double strata of sampling region plus habitat type. For this purpose, each of the waterbodies was assigned by CRIFI staff to one of the four main habitat types: lebak floodplain, rawang floodplain, river and lake), or, where appropriate, to a combination of two habitats. In general and where possible, within each double strata, two waterbody sub-units were randomly selected, with probabilities proportional to their total numbers of active fishermen (both groups and individuals). Over and above this ideal sampling strategy, the following constraints were applied.

1) All three of the Lubuk Lampam waterbody sub-units (LLL, LLR and LLS, Figure 3.5) were forcibly included in the sample, to enable comparison with CRIFI's long time series of data for this waterbody.

The important 'DBT' channel section between the lake sub-region and the main river channel was also included to ensure that fish movements between these two regions were monitored.

2) Several waterbody units, including those in the upper part of the Forest region, were excluded from the selection process due to their inaccessibility. In the lake sub-region, the three sub-units were eventually selected mainly on grounds of accessibility.

3) The waterbody sub-units entered into the 'draw' were those chosen by the leaseholders of the 1994 season. When a selected sub-unit was found to be sub-divided differently in 1995 or '96, compared to 1994, the new sub-unit(s) was(were) selected which contained (was contained in), the chosen 1994 sub-unit.

As intended, the number of waterbody sub-units thus selected in each sub-region proved to be approximately equal percentages (27-29%) of the numbers of sub-units fished in 1994 (table 3.3). The number of sub-units selected in each habitat strata, however, varied between 17 and 100% of the 1994 numbers available. With hindsight, it was also observed that many of the original habitat classifications were not particularly reliable (eg a 'river' sub-unit also contained a substantial floodplain section). For this reason, therefore, the habitat strata were dropped from the raising process for these data (see below).

- **Second-stage sampling of catch / effort respondents**

In the second stage of sampling, three CER fishermen were selected, where available, in each chosen waterbody sub-unit. One CER (usually the group leader) was chosen to report the total catches for the fishing group, while two other individual fishermen were randomly selected as respondents, from all the individuals available. Fisherman type (group/ individual) thus provided a third level of stratification, applied in the second sampling stage.

Due to variations in the sub-licensing arrangements (one sub-unit contained two groups, and one sub-unit had no individuals), 17 groups and 30 individuals were eventually sampled in the 16 selected sub-units (Table 3.3). In comparison with the numbers of fishermen determined in the 1995/96 frame surveys (Table 3.2), the number of fishermen selected as CERs represented an overall 47% of the group fishermen, and 22-24% of the individual fishermen.

- **Routine sampling of Catch & Effort Data**

As described in the project Survey Methodologies document (Appendix A) the selected CERs were interviewed twice each month on random days for information on their catches and efforts on the preceding day (and earlier days where memory permitted) for each different gear type that they used. Separate 'CE3' data was also collected by the project staff on the species composition of catches from different gear types in each month. The CE3 data was then used to sub-divide the estimated total catches by species, as shown in the following section.

- **Estimation of total catches / efforts**

This section gives the formulae used to calculate total catches and fishing efforts for the three geographic regions at the Indonesian study site from the twice-monthly CER data in the CE2 forms (Appendix A).

The following equations were used to calculate the total catches and fishing efforts in each geographic sub-region, month and gear-type. These three stratification variables are not sub-scripted in the following equations, but are implied from this point on.

- **Total catch, by geographic sub-region, month & gear type**

At the Indonesian site, group CERs reported the full catch of the whole group, while individual CERs reported only their own catches (except when fishing with one or more other fishermen). When an individual was fishing as part of a small team (assumedly with other individuals, not with the group), the reported catch was then divided by the team size to give only that fraction or share kept by the CER. Furthermore, since the important dry season ngesek and ngesar gears used by the groups were only used occasionally (and could easily have been missed by random sampling), their catches were recorded using a complete census approach. In the following formulae then, slightly different raising factors are used for group and individual fishermen and for ngesar/ngesek censused gears and other sub-sampled gears. The raising processes used allow for the fact that CERs reported a variable number of day's catches (usually between one and three depending on their memory), during each half-month interview period.

The mean monthly catch, $\overline{C}_g$, of a single group fishermen, in the G CER groups (Table 3.3) in the sampling stage 1 selected waterbodies was thus estimated as:

$$\overline{C}_g = \sum_{r=1}^{G} \left(\frac{\sum_p C_{rp}}{\sum_p R_{rp}} \right) \frac{D}{N_{g'}}$$

for sub-sampled non-ngesar/ngesek gears; and for censused ngesar/ngesek gears as:

$$\overline{C}_g = \sum_{r=1}^{G} C_{rp} \;/\; N_{g'}$$

where Crp = the CE2 catch of CER group r, in recall period p,
Rrp = the number of days in CER group r’s recall period p,
D = the number of days in the month,
and N’g = the total number of group fishermen in the G groups selected as CERs in sampling stage 1 selected waterbodies (Table 3.2).

The mean monthly catch, $\overline{C}_i$, of one of the N'i individual fishermen selected as CERs in the sampling stage 1 selected waterbodies (Table 3.3) was estimated as:

$$\overline{C}_i = \sum_{r=1}^{N_{i'}} \left(\sum_p \frac{C_{rp}}{N_{rp}} / \sum_p R_{rp} \right) \frac{D}{N_{i'}}$$

where Nrp = the number of fishermen fishing with CER r during recall period p (usually equal to one when fishing alone).

The total monthly catch, C, of all fishermen was then given by:

$$C = \overline{C}_g N_g + \overline{C}_i N_i$$

where Ng = the total number of group fishermen,
and Ni = the total number of individual fishermen,

as recorded in the fisherman census (frame survey, Table 3.2) for the appropriate year.

- **Total effort, by geographic sub-region, month & gear type**

Fishing effort measures vary between gear types depending on how they are fished. The fishing efforts, Erp, of CER r, in recall period p, were thus estimated as:

Erp = Urp . Hrp for standard-sized, continuously effective gears,
Erp = Urp . Hrp . Lrp for gill nets (JR),
and Erp = Urp for occasionally used, active seine gears (NK, NL, NP and NR; Urp usually equal to 1),

where Urp = the number of gearunits used by CER r, in recall period p,
Hrp = the soakhours of CER r, in recall period p,
Lrp = the length of the gill nets used by CER r, in recall period p.

As for the catch estimates, the mean monthly fishing effort, $\overline{E}_g$, of a single group fishermen in the G CER groups in the sampling stage 1 selected waterbodies was then given by:

$$\overline{E}_g = \sum_{r=1}^{G} \left(\frac{\sum_p E_{rp}}{\sum_p R_{rp}} \right) \frac{D}{N_{g'}}$$

for sub-sampled non-ngesar/ngesek gears; and for censused ngesar/ngesek gears by:

$$\overline{E}_g = \sum_{r=1}^{G} E_{rp} \;/\; N_{g'}$$

The mean monthly fishing effort, $\overline{E}_i$, of one of the N'i individual fishermen selected as CERs in the sampling stage 1 selected waterbodies was given by:

$$\overline{E}_i = \sum_{r=1}^{N_{i'}} \left(\sum_p \frac{E_{rp}}{N_{rp}} / \sum_p R_{rp} \right) \frac{D}{N_{i'}}$$

The total fishing effort, E, of all fishermen was then given by:

$$E = \overline{E}_g N_g + \overline{E}_i N_i$$

- **Total catch, by geographic sub-region, month, gear type & species**

The total fish catch weights estimated as above from the CE2 data were subdivided by species using the species composition data recorded in the CE3 survey (Appendix A).

Firstly, the estimated percentage, Ps, of species s (in the catches of gear type x, in month y and sub-region z...) was given by:

$$P_s = \sum_{k=1}^{K} P_{sk} \;/\; K$$

where	Psk =	the percentage of species s in CE3 sample k,
and	K =	the number of CE3 samples taken.

Secondly, the estimated catch, Cs, of species s was simply estimated as:

$$C_s = C\, P_s / 100$$

Due to the difficulties of finding unbiased CE3 samples, CE2 data were sometimes recorded in some strata (regions, months, geartypes) without any supporting CE3 data on their species compositions. In these cases, the catch data were subdivided by the Ps data from the nearest available month, within the same region and gear type.

- **Statistical problems**

The statistical raising procedure given above differs from that originally intended (Appendix A) due to a number of problems encountered during the sampling procedure. Firstly, since the habitat classifications proved to be inaccurately applied, this strata was dropped from the raising process even though it had been used in the first stage (waterbody) selection process. Assuming that many of the waterbodies were correctly classified, this means that the sample should have a good coverage of all the main habitat types but may underestimate the catches from the most common habitats.

Secondly, since the selection of waterbodies was based on the 1994 frame survey numbers, while the respondents and the numbers of fishermen for raising the total catches were taken from the 1995/6 seasons, the true probabilities of a respondent's selection cannot be easily specified. The intended statistical formulae could not therefore be used. While this was unfortunate, it was necessary to select the waterbodies before the 1995 season (to enable the sampling to start at the beginning of the year), and the 1995 frame survey could not be achieved until some time into the season when all the fishermen were resident in their waterbodies. The process used above thus simply assumes that the fishermen selected as CERs are representative of the average behaviour of Lempuing fishermen, and multiplies up their average catches by the total numbers of fishermen in all the waterbodies of a region.

Thirdly, since the waterbodies selected for the survey were not randomly selected, due to the constraints placed on sampling by accessibility and the need to cover certain key areas, it is inappropriate to estimate statistical confidence intervals based on the normal distribution. The catch / effort results are thus presented without error estimates, and should be interpreted with some caution, though as the best available estimates from a statistically complicated situation.

3.8 Catch / Effort Sampling Strategy - Bangladesh

3.8.1 Fishermen behaviour and general sampling approach

At the Bangladesh site, fish resources in the main rivers and inundated floodwaters are generally common property, while access rights to many of the beels (floodplain lakes), secondary rivers, and canals, are leased on a yearly or three-yearly basis. In some leased beels, certain areas remain available as open access fishing, especially to the poorest subsistence fishermen. A small number of beels are completely open access resources due to their low productivity. Rivers are generally leased out in segments of variable size up to ten miles in length.

Leaseholdings are generally owned by businessmen who obtain revenue in a number of different ways, such as:

- sub-leasing all or part of the water body to interested parties,
- employing fishermen at a daily rate, and selling the catch,
- allowing fishermen to harvest the fish within the waterbody in return for a proportion of their catch (10%-50%).

In comparison to the Indonesian licensing system, where fishermen only fish in their own licensed waterbody, the Bangladeshi system has great flexibility over the year. Individual, unlicensed fishermen may thus fish several different waters as the seasons progress, while the group used to harvest the dry season resources may not be decided until the last few months. This seasonal flexibility of licensing means that catch and effort data from a single water body may only be monitored by on-site, gear-based sampling, as used by the FAP17 programme. Such an approach was too expensive for this research project, and a respondent-based approach was used instead, as at the Indonesian site. In contrast to the Indonesian survey, though, since Bangladeshi waterbodies do not have any clear association with particular fishermen, the frame survey and the first stage sampling was based on villages instead of waterbodies. The fishermen were also not stratified by habitat type before selection, as the majority of fishermen fish in a variety of habitats during the course of the year. The catch and effort data collected from the respondents, however, were categorised by capture region and habitat to enable the respondents' catches and efforts to be subdivided appropriately.

3.8.2 Catchment geography and sampling regions

The Bangladesh study site was based on floodplain lands at the confluence of the Padma (Ganges) and Jamuna (Brahmaputra) rivers (Figure 3.6). In this locality, the PIRDP flood control embankment is routed well inland from the banks of the main rivers, leaving substantial floodplain lands outside the flood control scheme. The embankment has remained unbroken in this locality since its completion in 1974, and three flood control sluice gates control water flows and fish movements across the embankment. The site was therefore selected to enable a comparison of the adjacent floodplains on either side of the flood control embankment, and the effect of the embankment on fish movements between them.

For sampling purposes, four main capture regions were defined within the Bangladesh study site (Figure 3.6):

‘Inside’ Waterbodies and floodplains inside the FCDI scheme (area 4108 ha)
‘Outside’ Waterbodies and floodplains outside the FCDI scheme (area 6773 ha)
‘Adjacent’ Waterbodies and floodplains inside the FCDI scheme, further inland and adjacent to the ‘inside’ region (area undetermined, and catch underestimated due to the undetermined contribution of fishermen further inland)
‘Main River’ Main river waters only, outside the FCDI and adjacent to the ‘outside’ floodplain region (area undetermined due to due to unknown distances from shore line of waters fished)

As noted above, areas could only be estimated for the two main study regions, Inside and Outside; and relative productivities and fishing efforts etc. are therefore only compared between these two regions. Catch compositions and seasonalities, however, are compared among all four study regions. The Adjacent sampling region was primarily needed to estimate the catches in the main Inside/Outside sampling regions from fishermen living outside those regions, and vice versa. Such catches occur at this site (and not in Indonesia) due to the high mobility of the Pabna fishermen (Section 3.8.1). It is likely that some fishermen from even further inland than the adjacent region also fish in the main study region, but it is assumed that such contributions decrease to a negligible level beyond the sampled adjacent region. Due to its boundary position (and the catches taken by fishermen from even further inland), the Adjacent catches are expected to be most underestimated. They are also probably least precise due to the relatively small number of CE respondents in that region (Section 3.8.4).

The fourth Main River region was distinguished from the Outside region to enable the Inside and Outside floodplain catches to be compared, without the extra catches taken outside the FCDI scheme in the main river habitat (not present in the Inside region).

The high-water flooded areas were estimated for the Inside and Outside floodplain regions, on the assumption that all lands within the study boundary were floodable. While this is broadly correct within a normal flood year, these lands do include pockets of high ground in villages, roads, levees etc. The given areas thus overestimate the true flooded areas by a small amount. It is provisionally assumed that the Inside and Outside regions are sufficiently similar, in habitat terms, for comparison of their productivities (catches) and fishing efforts scaled by their areas. Since the boundary between the Adjacent and Inside regions runs along (and includes) the Atrai and Badai rivers (Figure 3.6), the catches from the Inside region may be expected to contain a relatively greater contribution from secondary river habitats. These rivers were selected as the boundary to ensure that capture locations could be easily distinguished and reported by the fishermen even when the whole area was inundated during the flood season.

3.8.3 Frame survey of fishermen numbers

As mentioned previously, the frame survey of total fishermen numbers at the Bangladesh site was based on a random selection of villages followed by interviews with randomly selected respondents in each village.

- **Identification of villages and population sizes by region**

The names and locations of villages in each of the Adjacent, Inside and Outside regions were identified through the Pabna Election Committee Office, categorised by local government administration units: districts, tannas, and unions. For each village, population sizes were obtained, based on the most recently available (1988) census data. Population numbers in this case show the number of males over 18, eligible to vote. Such numbers were not corrected for population growth since 1988, nor for any overall migration of people into or out of the regions. Assuming that retirement rates approximately balance the entry of young fishermen into the fishery, the catch estimates still relate to those taken by males over 18. Women generally do not fish in the Pabna area, but the catch estimates exclude the contribution of young men and children under 18 years old.

- **Qualitative interviews on fishing activities**

To begin the frame survey, a qualitative survey was first undertaken on the spatio-temporal aspects of fishing activities within the study site. Thirty three villages were randomly selected from the census village lists for this purpose (8, 12, and 9 in the subsequently chosen Adjacent, Inside and Outside regions respectively, with a further 4 on boundary locations). Group interviews at each of these villages were then used to assess the fishing activities of village members (using CE1a data forms, Appendix A). These qualitative interviews led to the understanding of the fishermen mobilities in Bangladesh, and the subsequent selection of the two main sampling regions, supported by the Adjacent region to estimate the catches from fishermen further inland.

- **Quantitative interviews on fisherman numbers**

To estimate the numbers of fishermen in each of the defined regions, 10 villages were first randomly selected from either side of the FCDI embankment. Four and six villages were selected from the Adjacent and Inside regions respectively. Villages straddling the embankment boundary between the Inside and Outside regions were not selected. Voter lists containing the names of all males >18 years old (the 'population size') were then obtained for each of the selected villages, and 5% samples of the village names were selected for the quantitative interviews.

The quantitative interviews (using the CE1b data forms, Appendix A) were designed to assess the proportions of the village populations (males >18 years old) occupied as full-time, part-time and subsistence fishermen, and the types of fishing gears they used. The following definitions were used for the different fishermen types:

Full-time fishermen fished >300 days/year, for profit, and had no other occupation,
Part-time fishermen fished <300 days/year, for profit, in addition to other occupations,
Subsistence fishermen fished only for home consumption.

The 5% sampling proportion gave at least 10 names for each of the 20 villages selected, and a total of 527 respondents were interviewed (Table 3.4). When a selected respondent could not be interviewed (eg. due to death, emigration, or refusal to take part in the survey), further names were randomly selected from the voter lists to meet the 5% target.

The results of the survey indicated that there were relatively more full-time fishermen outside the flood control scheme, and more part-time fishermen in the Adjacent region (Table 3.4). This suggests a slightly greater dependence on agriculture inside the flood control scheme and a greater dependence on fishing outside the scheme. The proportions of subsistence fishermen differed little between the regions though, and, in overall terms, the proportions were similar between all three of the regions.

To estimate the total numbers of fishermen in each region, the proportions of each type of fishermen were raised by the total population numbers from the village census data (Table 3.4). Scaled by the regional areas, the densities of full and part-time fishermen together were higher in the Inside region (47/km2) than in the Outside one (36/km2). Such observed densities are between the densities previously observed at other sites in Bangladesh (Third Fisheries Project beels: 59/km2, Hail Haor: 32/km2, MRAG, 1994a).

3.8.4 Two stage random selection of catch / effort respondents

- **First stage sampling of fishing villages**

Since the voter lists had already been obtained, the 20 villages randomly selected for the quantitative frame survey interviews were again used as the first stage sample for the selection of catch / effort respondents.

- **Second stage sampling of catch / effort respondents**

For each of the 20 villages, two names were randomly selected as CERs from the lists of full-time and part-time fishermen identified in each village. Preference was generally given to full-time fishermen where they had been detected in a village subsample. This process produced a sample of respondent fishermen (Table 3.5), in which each region had a ratio of full-time respondents to part-time ones approximately the same as the overall ratios found in the quantitative village surveys (Table 3.4).

Though subsistence fishermen were present in all the villages, sometimes fishing up to 3 months per year, no such fishermen were selected as CERs. This exclusion was made to minimise the sampling effort required for the twice-monthly interviews of CERs. With 40 full/part-time fishermen scattered throughout 20 villages, this sampling commitment was already substantial for the small team available. Observations by the Pabna field staff during the 1995/96 sampling have subsequently shown that the catches taken by subsistence fishermen from their low-efficiency gears are small compared to those of the professional fishermen. Furthermore, since subsistence fishermen comprised very similar proportions of the total fishermen numbers in each of the three regions (Table 3.4), their exclusion should not bias the in/out comparison to any great extent.

- **Statistical Problems**

The sampling procedure outlined above is a simplified version of the rather complex procedure actually used! As explained in this section, and similarly to the Indonesian sample selection, some sub-strata were used during the sampling which were subsequently dropped from the raising process. The calculations used thus assume that the fishermen selected (done randomly, but within additional substrata) were representative of the average behaviour patterns within the three regions, and simply raise the average catches of the selected CER fishermen by the total numbers of fishermen in the region.

The first difficulty was encountered during the course of the frame survey. It then became apparent that the numbers of fishermen within any given village were not proportional to the size of the village, as had been assumed in the original survey instructions (see Sampling Methodologies Report, Appendix A). In view of this, villages were not selected 'probability proportional to their sizes' in the first stage of the frame survey. Instead, the villages were randomly selected within double strata of region plus a three-level index of fishing intensity, as determined from the proportions of full and part-time fishermen in the summarised results of the qualitative village interviews. This strategy was adopted during the field period, since it was suspected that villages with different fishing intensities may have used different gear types, or achieve different efficiencies or 'catchabilities' for their gears.

On returning to the UK, the hypothesis that the villages differed in their gear use was tested using non-parametric multivariate analysis on the data recorded from both the group interviews conducted during the first stage of the frame survey (qualitative information), and the individual interviews conducted during the second stage of the frame survey at the 20 selected villages (quantitative data). In the first case, data was of the form of group estimated numbers of full and part time fisherman and gears used by members of the village, the second in the form of the number of FT and PT fishermen interviewed from the random selection of voters and the gears used by them. In both cases population size used to calculate fishing intensity was based upon the number quoted on the voter lists. Data took the form of a matrix of gear type data (presence and absence) and village replicates represented by the low, medium or high fishing intensity category. The information was used to calculate similarities between every pair of replicates to form a triangular similarity matrix. Multi-Dimensional Scaling (MDS) was then applied to this similarity matrix to produce an ordination such that the distance between replicates reflects the rank (dis)similarity between them. For each data set the null hypothesis (H0 : no difference between replicates) was tested using a randomisation test on the 'global statistic' (Clarke & Warwick, 1994). This is based on the difference in average rank (dissimilarities) between and within sites. In both cases the null hypothesis could not be rejected at the 5% level, implying that gear use was after all independent of the fishing intensity of the village. In view of this finding, the fishing intensity classes were not used as strata in the eventual raising of the catch and effort data.

A second problem was encountered with the classification of fishermen as full-time or part-time respondents. On examination of the 1995 data, for individual respondents, it became clear that at least six of the 40 respondents were probably misclassified (ie. 'full-time' fishermen who actually only fished part-time, or vice-versa). Furthermore, in a comparison of the mean catches-per-unit-effort achieved by the different respondents within gear-month categories, 'part-time' and 'full-time' fishermen were found to take the greater catches in exactly half of the 42 pairs compared. In view of these additional findings, fisherman type (part-time/full-time) was also dropped from the raising process.

3.8.5 Routine sampling of catch and effort data

Catch and effort data from the CERs were sampled as described in the Survey Methodologies document (Appendix A). At the Bangladesh site, the fishing locations of the catches were recorded particularly carefully to enable the catches of fishermen from each of the three CER regions to be subdivided between the four capture regions. During the course of the two-year sampling period, a small number of CERs dropped out of the sampling programme (due to emigration, death etc.). Such respondents were immediately replaced by new CERs randomly selected from the voter lists, within the same region and fishermen-type categories.

3.8.6 Estimation of total catches / efforts

- **Total catches, by CER region, fishing region, habitat, month & gear type**

The mean monthly catches of the CERs at the Bangladesh study site were calculated using the formulae previously given for individual fishermen at the Indonesian site (Section 3.7.6). The Bangladesh data, however, were raised separately in categories of region, month and gear type, as for the Indonesian data, and also with additional strata for the origin region of the CERs, and for the habitat type. CER origin regions were included for this data set to demonstrate the mobility of Bangladeshi fishermen; they were not used in Indonesia because fishermen only fished their own waterbodies. Habitats were not specifically included in the Indonesian sample, but were represented by the three habitat-based geographic regions, and by the fishing gears, whose use was largely correlated with habitat type.

All the Bangladeshi CERs were thus sampled as individual fishermen, and were asked to recall a sub-sample of their most recent and fully remembered fishing days (ie. not a complete census). When the Bangladeshi CERs fished as part of a group, the full catch of the group was reported, and the share taken by the respondent was calculated by dividing by the group size, as with the Indonesian individual CERs.

As noted above, fisherman type (full-time/part-time) was dropped from the Bangladeshi raising process, and total catches were therefore raised using the ratios of the combined numbers of full-time and part-time fishermen in the regions (Table 3.4) and in the CER sample (Table 3.5). The same frame survey numbers were used to raise the total catches for both the 1995 and the 1996 study years, since the frame survey could not be easily repeated at the Bangladesh site.

- **Total effort, by CER region, fishing region, habitat, month & gear type**

Total fishing efforts were also calculated using the Indonesian formulae for individual fishermen (Section 3.7.6), but with the additional CER origin region and habitat strata.

Fishing effort measures for some of the Bangladeshi gears were, however, calculated differently to the equivalent Indonesian gears. In Bangladesh, fishing gears were more often fished in an active way involving the constant attention of the fishermen. In such cases, fishing effort measures need to include the time spent by the fishermen attending their gears. This time should equal the 'soakhours' for such gears: the distinction is made because 'CER Hours Fishing' was recorded separately on the CE2 form (Appendix A) for such active gears, while 'soakhours' was recorded for unattended gears. The fishing efforts, Erp, of CER r, in recall period p, were thus estimated in Bangladesh as:

	Erp = Urp . Hrp	for standard-sized, passive / unattended gears,
	Erp = Urp . Jrp	for standard-sized, active / attended gears,
	Erp = Urp . Hrp . Lrp	for passive / unattended fixed gill nets,
	Erp = Urp . Jrp	for active / attended drift gill nets
and	Erp = Urp	for occasionally used, active seine gears (eg katha and kua, with Urp usually equal to 1),

where	Urp =	the number of gearunits used by CER r, in recall period p,
	Hrp =	the soakhours of CER r, in recall period p,
	Jrp =	the hours actively fished by CER r, in recall period p,
and	Lrp =	the length of the gill nets used by CER r, in recall period p.

- **Total catch, by CER region, fishing region, habitat, month, gear type & species**

The species compositions of the Bangladesh catches were also estimated as for the Indonesian site (Section 3.7.6), using the CE3 species composition data to subdivide the CE2 catch weight data. The additional habitat and CER region strata used in Bangladesh were retained for this final subdivision, though the average species compositions were only calculated from the CE3 data within region, month and gear type strata (ie. not including habitats). The inclusion of habitat for the CE3 data would have reduced the sample sizes to undesirable levels, and still left many CE2 data combinations without matching CE3 data for their subdivision. As for the Indonesian data, when species composition data were not available for a particular region/month/gear-type combination, the catch data were subdivided by the species composition estimates from the nearest available month, within the same region and gear type.

3.9 Project Database

The data collected in the routine surveys were entered and stored in specially created databases, written in MicroRim RBase software, and held at each site. These databases enabled entry of the data in compatible formats at both sites, using rule-checking entry-forms. Facilities were included for automated reporting of sampling activities, for the transfer of the data to London from the remote machines, and for unloading of selected data for local analysis. The structure and operation of the database was described in a Database User Manual (see Appendix B).

3.10 PhD Study - Modelling In/Out Fish Production in Bangladesh

This project funded a PhD investigation based at the Renewable Resources Assessment Group, Imperial College of Science Technology and Medicine, University of London, UK. The work was undertaken by research student Mr Ashley Halls, under the academic supervision of Drs Ian Payne and Geoff Kirkwood of Imperial College, and under the project leadership of Dr Daniel Hoggarth. This section describes the background and approach of this thesis. Most of the work described here is also included in this report, either directly within this volume, or as sub-project reports (Appendices D, F, H and J) referred to within the main text.

A dichotomy exists in Bangladesh between the need for hydraulic engineering to control the annual inundation of the floodplain in order to maximise agricultural production, coupled with the demand for effective protection against extreme floods, and the potential impact that hydraulic engineering has upon fish production and species assemblages. From a fisheries perspective, this problem is compounded by the fact that the majority of fish production is directly or indirectly dependent upon the floodplain component of the floodplain-river system and upon the timing, extent and duration of the flood pulse; all of which can be severely modified by hydraulic engineering.

This thesis attempts to help resolve this dichotomy by first identifying the effects of hydraulic engineering structures on the biological processes that influence the dynamics of the fish populations and their species assemblages, and then by developing a detailed understanding of the influence of the extent, duration and timing of floodplain inundation upon fish yields through simulation modelling.

The production of fish (P) is defined as the "...total elaboration of fish tissue during any time interval..." (Ivlev, 1966) and is a function of growth (G), natural mortality (M) and recruitment (R):

$$P = f(G, M, R).$$

The yield (Y) from a fishery is a function of P and of fishing mortality (F):

$$P = f(G, M, R, F)$$

where F is a function of fishing effort (f) and catchability (q).

There are two approaches by which the impact of hydraulic engineering (modification of the hydrological regime) on fish production within an exploited fishery can be assessed. The first approach is to compare estimates of fish yields recorded from modified and pristine locations after removing the effects of fishing mortality. The second approach is to compare estimates of each component of the yield function recorded for populations sampled in modified and pristine locations.

One of the major obstacles to the first approach is the need to remove the effects of fishing mortality; a process which involves standardising fishing effort across the different gear types employed in the fishery. This task is made particularly difficult when dynamic hydrological conditions dictate the gear types in operation at any given time, the amount of fishing effort deployed and gear catchability. According to (FAP 17 1994a) this "......is one of the major problems in conducting comparative surveys of floodplain fisheries". Nevertheless, it is argued that even if this approach could be applied successfully, the underlying biological processes governing the observations would not be understood, making it difficult to develop measures to mitigate against any impacts.

The second approach, selected for this research, overcomes the need for complex catch rate standardisation procedures and although inherently more simplistic, potentially offers a much greater understanding of the impacts of hydraulic engineering on the individual elements which determine fish production and yield. By developing a greater understanding of these elements and the behaviour of fish populations in respect to the hydrological regime, not only can appropriate mitigating measures be developed and effectively targeted if they are required, but the dynamics of the fishery may also be modelled, providing a powerful tool to assist in the design of adaptive management policies.

A number of previous studies indicate that levees and polders (FCD/I schemes) may impact fish and fisheries both directly and indirectly. The direct impacts result from the modification of the hydrological regime, or from the physical presence of the FCD/I creating obstacles to fish movement. The indirect impacts may be less obvious. These may include changes in land use or more intensive agricultural practices involving greater use of pesticides and fertilizers which may affect the physiology or behaviour of fish. Flood control schemes may also attract higher human population densities than unmodified locations, such that their fish populations experience greater levels of fishing effort and correspondingly higher mortality rates. To answer these uncertainties, the aims of this thesis were identified as follows.

1. Assess the direct impact of FCD/I schemes by comparing species assemblages inside and outside the schemes using robust statistical methodology.

2. Assess the direct impact of modifications to the hydrological regime on the growth and mortality rates, and the reproductive behaviour and capacity of a selection of key species, based on comparisons of populations sampled inside and outside FCD/I schemes.

3. Based upon the findings of (2) and anecdotal evidence, attempt to evaluate any indirect impacts of FCD/I schemes on the fish and fisheries of Bangladesh.

4. For one key species, develop a stock-recruitment relationship and density dependence models to describe the influence of hydrology on growth and mortality rates.

5. For the same key species, develop a simulation model to examine the dynamics of the population in relation to hydrological conditions and exploitation, in order to provide guidelines for adaptive management policies.

3.11 Sub-Project Portfolio

The routine data collection surveys described above provided much of the data required for the project analyses. In addition to this data collection, five key sub-projects were also undertaken to reinforce certain important analyses. A sixth sub-project was undertaken during 1995 for planning purposes. The sub-projects are briefly described here, and written up in detail as Appendices C to H.

The first four of the sub-projects were carried out at the modified Bangladesh site, either by project staff or by MSc students provided under the BAU collaboration. Work outlines were written for each sub-project by MRAG staff, and discussed with the BAU collaborators where appropriate. The first two sub-projects coincided with the 1995/96 dry season, and the second two with the 1996 flood. These sub-projects were broadly designed to determine the effects of flood control schemes on fish production via (1) the access of fish to the floodplain, and (2) the effects of different water levels inside and outside impounded areas. Sub-projects 2. and 4. represent the final versions of the experiments originally envisaged for the Indonesian site (section 9.9 of the Project Memorandum).

3.11.1 Sub-Project 1: Fishing and fish survival in dry season waterbodies

Duration: Oct. ‘95 - Apr. ‘96. BAU Student: Ranjan Kumar Dam.

This sub-project investigated (1) what dry season waterbodies are available in Bangladeshi floodplain river systems, (2) what relative catches are taken from each, and (3) how many fish survive throughout the dry season in each type of waterbody in the presence of normal fishing activities.

3.11.2 Sub-project 2: Density-dependence of fish natural mortality rates

Duration: Nov. ‘95 - Apr. ‘96. MRAG project staff.

This sub-project investigated the density dependence of natural mortality rates in dry season waterbodies, with restrictions on fishing activities. The results were used to (1) develop a mortality sub-model for assessing the impact of flood regimes on fish production rates, and (2) determine the potential dry season survival rates of fish in waterbodies set aside as reserves (for comparison with sub-project 1). The study was undertaken in natural floodplain waterbodies, both kuas and mathel household ponds. The main analysis was based on the abundant key species P. sophore, but the effects of biological interactions (particularly predation) on the observed mortality rates were also considered.

3.11.3 Sub-Project 3: Fish migration through flood control sluice gates

Duration: May - Dec. '96. MRAG project staff.

This sub-project examined the timing and direction of fish movements through the two flood control sluice gates within the Bangladesh study site, based on the catches of fishing gears used at these locations. Migrations had previously been observed at these sites which contradicted the generally accepted floodplain patterns. This sub-project ran for the duration of the 1996 flood season, since both sluice gates dry out completely during the drought. The results supported the tagging data on fish movements across the flood control embankment, and measured the potential contribution of immigrating fish to each year's production, for comparison with that from floodplain-resident fish (sub-project 1).

3.11.4 Sub-Project 4: Density dependence of fish growth rates

Duration: June - Oct. '96. MRAG project staff + BAU student: Md. Anowarul Huda.

This sub-project estimated the density dependence of floodplain fish growth rates, to provide a further sub-component of the floodplain fish production model. A controlled experiment was set up in 16 holding ponds, at BAU, with fish held for 3 months at different densities over the flood (growth) season. The study was based on the abundant key species P. sophore.

The fifth sub-project researched the generality of the management recommendations arising from the work at the Indonesian site:

3.11.5 Sub-Project 5: Co-management of Indonesian river fisheries

Duration: May '96. MRAG project staff + senior CRIFI researchers.

Human population densities, fish exploitation rates and cultural traditions all vary greatly between the many Indonesian islands. In this sub-project, a multi-disciplinary MRAG/CRIFI team undertook fact-finding missions to determine the co-management approaches currently used in three river catchments in Kalimantan, Java and central Sumatra. The purpose of this sub-project was to consider whether the project recommendations on the 'scientific co-management' of the R. Lempuing site could (or should) be extended as a nationwide policy for Indonesian rivers in general.

The sixth sub-project was undertaken and completed in 1995 at the BAU facilities in Mymensingh, Bangladesh, primarily to assist in planning the research programme. The results from this sub-project led to the development of sub-project 4. described above.

3.11.6 Sub-Project 6: The utility of visible implant tags for growth studies

Duration: April - Oct. '95. MRAG project staff + BAU student: Md. Ekram-Ul-Azim.

This sub-project confirmed that VI tags could be used to measure the growth rates of certain species of fish, having no significant effects on tagged specimens. Tag loss rates, however, were extremely high for the most important and smallest key species Puntius sophore and Glossogobius giurus. Following this result, an alternative methodology was developed to determine the growth component of the Bangladesh floodplain production model.

3.12 Summary - Data Collection

The data for this project were collected under routine surveys (catch/effort, length frequency, mark-recapture, biological and hydrological data), and within several discrete sub-projects. Three of the sub-projects were undertaken as part of the PhD study (London university), and three as collaborative MSc studies (Bangladesh Agricultural University, Mymensingh).

The five routine surveys ran for two full years from January 1995 to December '96 at both study sites. Biological data were only collected at the Bangladeshi site to support the detailed comparison of the floodplain regions inside and outside of the FCD/I scheme. Routine survey methodologies were outlined for field officers in an instruction manual attached as Appendix A.

Length frequency, mark-recapture and biological data were collected for six 'key' species at each site, each selected for their high abundances, as representatives of species 'guilds' of carps, catfish, snakeheads, perches and shrimp, as available.

Data sampling at the Indonesian River Lempuing site was subdivided between three habitat regions: an upstream Forest river region and a downstream Savanna river region, each around 15-20km in main channel length, and a Lake district adjacent to the Savanna river and connected to it by numerous channels, particularly during the flood season.

Data sampling at the Bangladeshi PIRDP study site was subdivided between two main study regions on floodplains and associated waterbodies Inside and Outside the FCD/I embankment (41 and 68km2 respectively), and also in an Adjacent floodplain region further inside the FCD/I scheme (from which some fishermen fished in the main Inside region), and in a Main river region lying alongside the Outside floodplains.

Spatial location coding systems were developed for accurate recording of fish capture and sampling positions. Location codes included habitat types and waterbody locations, referenced to well-known local landmarks. Coded floodplain and lake locations covered average areas of around 1km2, while riverine locations were an average 1.2km long in Bangladesh, and 2.5km long in Indonesia.

Catch / effort data were provided by panels of 40-47 respondents at each site, randomly selected using two-stage sampling within regional strata. Data were provided for one or more days in each half-month period by each respondent. Separate market samples were taken by project staff to determine catch compositions by region and geartype. Frame surveys were used to determine total numbers of fishermen within full-time/part-time/subsistence and group/individual categories respectively in Bangladesh and Indonesia. One frame survey was done in Bangladesh, with subsampling of both the many villages and fishermen; annual frame surveys were done in Indonesia using complete censuses of fishermen in licensed waterbodies. These three data sources were combined to provide estimates of total fish catches and efforts subdivided by month, region, gear type and fish species (the latter category for catches only).

Length frequency data were collected on a bimonthly basis (6 samples per year) from the least selective gears to target sample sizes of 2-300 fish per gear type per region per sampling period. Target sample sizes often were not achieved due to seasonal variations in the availability of fish.

A mark-recapture programme was used to study fish migration patterns and mortality rates. The larger fish were tagged with small sized anchor tags, while smaller fish and prawns were tagged with streamer tags. This programme was supported by extensive publicity, and by the continuous presence of project staff at the field locations. Tags were returned to project staff by fishermen, and rewards were given for each tag returned, and prizes given at annual lotteries.

Data collected under the routine surveys were entered and stored in project databases at each site, as described in a Database User Manual (Appendix B).

A PhD study was undertaken within the project, based at the University of London, with the objective of providing a detailed understanding of the effects of FCD/I schemes on the productive capacity of fish stocks at the Bangladesh site. The results of this thesis are included in the main report volume, and as Sub-Projects 2, 4 and 6 (Appendices D, F and H), and one complete chapter (Appendix J).

In support of the routine data collection surveys, six additional sub-projects were undertaken to investigate the following specific key research issues:

1. Fishing and fish survival in dry-season waterbodies
2. Density dependence of fish natural mortality rates

Fish migration through flood control sluice gates

Density dependence of fish growth rates

Co-management of Indonesian river fisheries

The utility of visible implant tags for growth studies

Each of these sub-projects was written up as a discrete study, as appended to this report. The results of each sub-project were also fully referred to within the main volume. Sub-projects 1, 4 and 6 were executed in collaboration with MSc students from BAU, Mymensingh. Sub-project 5 was executed in collaboration with senior research staff from CRIF, Indonesia.

Table 3.1 Summary of Cath/Effort data sampling strategies for each study site

Detail	Indonesia	Bangladesh
Site Name	River Lempuing, South Sumatra	Pabna Irrigation & Rural Development Project (PIRDP), NW Bangladesh
Licensing	All waterbodies licensed, in 35 main units for 1 year licence periods. Auction open and administration accessible. Units often split into different sub-units each year. Free fishing access in January	Only selected beel and river habitats licensed for 1-3 year licence periods. Auction closed and not easily accessible Free fishing access in high water season
Fishermen	Fishermen usually only fish in own license unit Group fishermen lease sub-units & use large gears Individual fishermen sometimes sub-lease, & use smaller gears	Fishermen not restricted to one location Professional fishermen use large gears full-time Part-time fishermen mostly use cheaper gears Subsistence fishermen use cheaper gears and do not sell catch
Geographic Regions (Sampling Strata)	Downstream savanna river (mostly lebak) Adjacent lake region, isolated in dry season Upstream forest river (mostly rawang)	Inside embankment, adjacent to sampling area Inside embankment, inside sampling area Outside embankment, inside sampling area Outside embankment, main river
Accessibility	Some waterbodies too remote to visit Some waterbodies difficult to get to in dry season	Some villages difficult to get to
Habitats	River channel (sungei) Savanna floodplain (lebak) Floodplain pools (lebung) Forest floodplain (rawang)	Main river channels Secondary river channels Canals Floodplain Floodplain pools (beel)
Gear Types	~9 group gears ~14 individual gears Gear use correlated with fisherman type and habitat	~6 mostly 'professional' gears ~15 mostly 'part-time' gears Some gears used by both fishermen categories
Frame Survey	Based on 1994 complete census of all 58 waterbody sub-units	Based on '94/'95 sub-sample of villages with census data from 1988 voter-lists
First Stage CE Respondent Selection	16 out of 58 waterbody sub-units selected Sampling stratified by geographic sub-regions and habitats Selections constrained by accessibility and practicality Up to 2 sub-units randomly selected in each region-habitat strata, probability proportional to size of combined number of group and individual fishermen (in '94 sampling frame)	20 out of 85 identified villages selected Sampling stratified by geographic sub-regions 4-10 villages selected in each region strata probability proportional to number of villages
Second Stage CE Respondent Selection	Total of 47 CERs selected All groups included as respondents in selected sub-units (usually only one group per sub-unit, one group = one CER) Two individual fishermen randomly selected as respondents in each sub-unit	Total of 40 CERs selected Two fishermen randomly selected in each village, from those identified as full-time or part-time fishermen Subsistence fishermen not selected: catch estimate excludes subsistence catches
Catch Estimation	Catches estimated by month, region (respondents only fish in own region), geartype (correlated with habitat) and species	Catches estimated by month, catch-region, respondent-region, geartype, habitat and species

Table 3.2 Numbers of waterbody sub-units selected for catch/effort sampling, and resulting numbers of group and individual fishermen fishing, in the three River Lempuing sampling regions, in 1994, 95 and 96

	Savanna Region	**Lake Region**	**Forest Region**	**Totals**
1994				
Waterbodies Leased	18	6	10	34
Subunits fished	26	11	21	58
Number of Group Fishermen	115	38	134	287
Number of Individual F'men	128	81	91	300
1995				
Waterbodies Leased	18	5	10	33
Subunits fished	22	6	18	46
Number of Group Fishermen	93	28	100	221
Number of Individual F'men	85	29	20	134
1996				
Waterbodies Leased	15	3	10	28
Subunits fished	19	4	18	41
Number of Group Fishermen	82	18	101	201
Number of Individual F'men	66	30	27	123

Table 3.3 Numbers of waterbody sub-units selected for catch/effort sampling, and resulting numbers of group and individual fishermen catch/effort respondents (CERs) at the Ricer Lempuing study site, by sampling region and year

	Savanna Region	**Lake Region**	**Forest Region**	**Totals**
Subunits selected	7	3	6	16
1995				
Group CERs	7	3	7	17
Number of F'men in Group CERs	42	19	42	103
Individual Fishermen CERs	12	6	12	30
1996				
Group CERs	7	3	7	17
Number of F'men in Group CERs	37	16	41	94
Individual Fishermen CERs	12	6	12	30

Table 3.4 Frame survey details and estimated numbers of fishermen, in the three sampling regions of the Pabna study site

Region	Adjacent	Inside	Outside
Number of >18 year old male voters (1988 census)	12,125	16,978	17,292
Number of interviewees, of which:	107	157	263
Full time fishermen (%)	2 (1.9%)	4 (2.6%)	11 (4.2%)
Part-time fishermen (%)	17 (15.9%)	14 (8.9%)	26 (9.9%)
Subsistence fishermen (%)	34 (31.8%)	54 (34.4%)	101 (38.4%)
Estimated total numbers of:			
Full-time fishermen	227	433	723
Part-time fishermen	1,927	1,514	1,710
Subsistence fishermen	3,853	5,840	6,640

Table 3.5 Numbers of fisherment selected as catch/effort respondents (CERs), in the three sampling Pabna study site

Region	Adjacent	Inside	Outside
Number of full-time CERs	1	3	6
Number of part-time CERs	7	9	14
Number of subsistence CERs	0	0	0

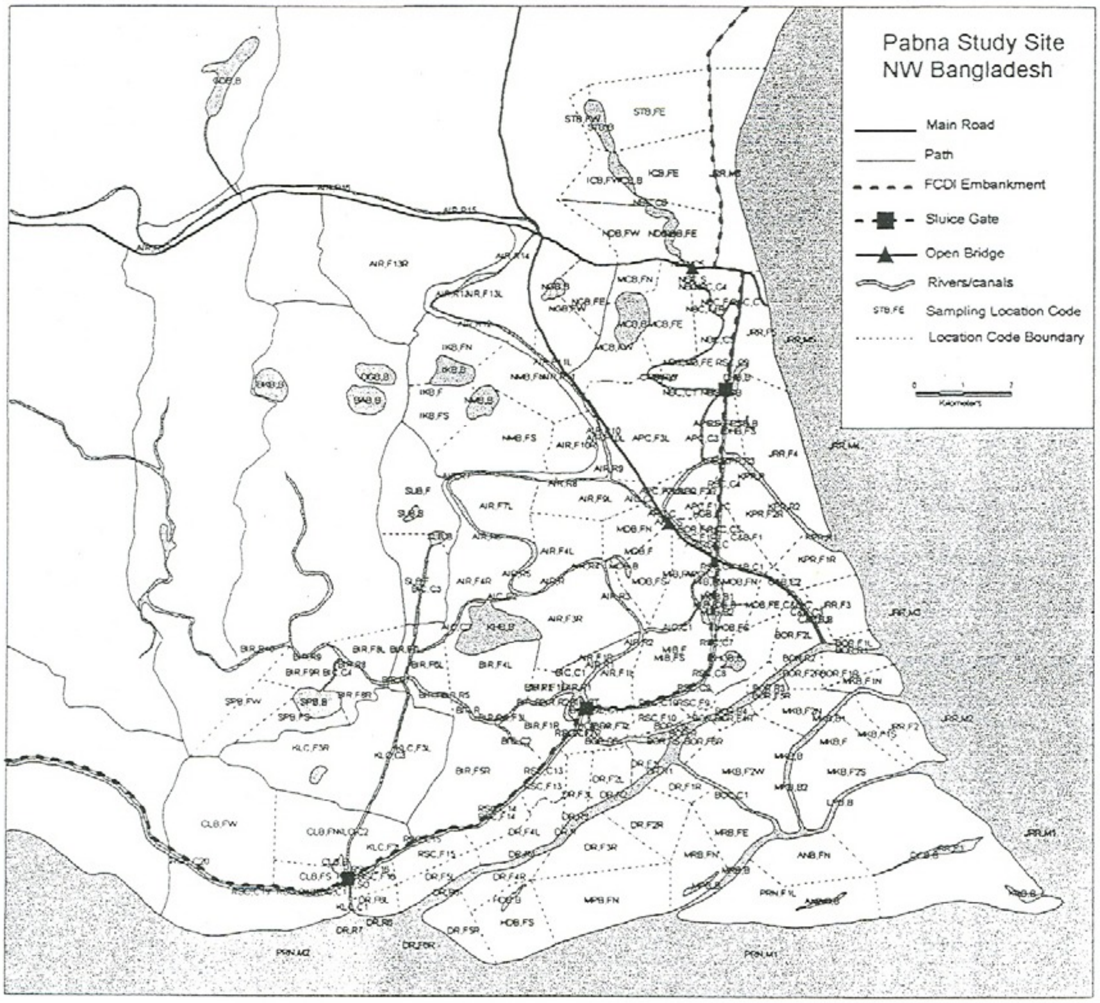


Figure 3.1 Spatial location codes used for data collected at the Bangladesh field site.

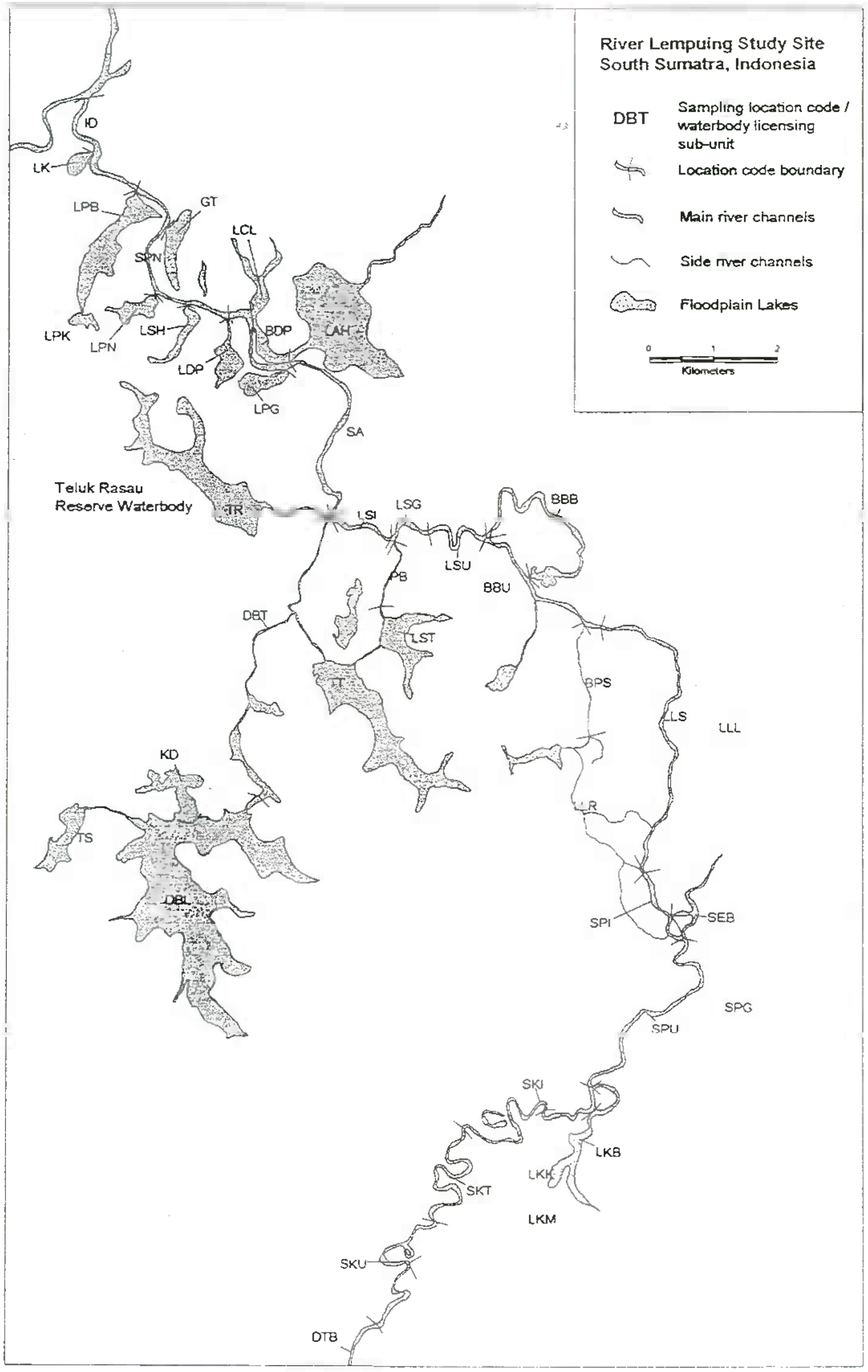


Figure 3.2 Partial spatial location codes used for data collected at the Indonesian field site (not including habitat type or sub-division extensions), based on waterbody licensing sub-units.

CRIFI / MRAG Fish Tagging Experiment

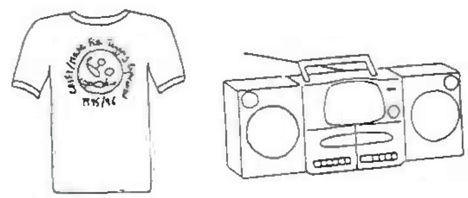
In 1995 and 1996, the Central Research Institute for Fisheries, Indonesia and the Marine Resources Assessment Group, UK will be tagging and releasing fish and prawns in the Lempuing River to monitor their movements and growth rates.

If you catch a tagged fish or prawn, and return the tag to CRIFI, we will send you a project T-shirt, and enter your name in two lotteries, with a chance to win a Grand Prize of a Hi-Fi system!

To qualify for the reward, you must return the tag to CRIFI along with the following information:

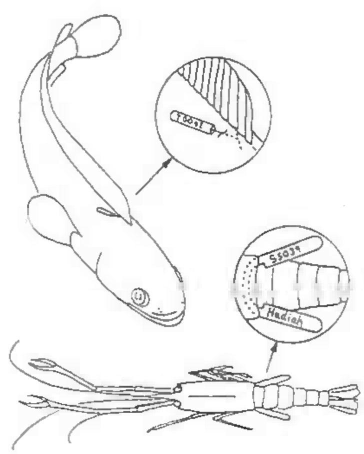
- *Tag number*
- *Species*
- *Date caught*
- *Location caught (river, waterbody*
  + description of exact location)
- *Fish/prawn length: Total length (mm)*
  + Fork length (mm)
- *Captor's name and full address*

Return Tag for REWARD

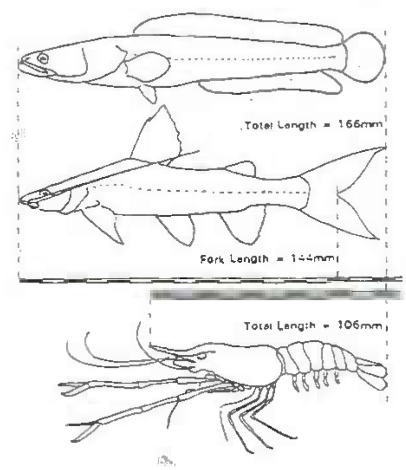


Project T-shirt
+
Entry to Grand Prize Draws
1st Prize: Rp500,000 Hi-Fi system
2nd Prize: Personal Stereo (5 prizes)
Draws at 1995 / 1996 auctions

Tag Positions



Length Measurements



If you catch a tagged fish or prawn:

- If possible, tagged fish/prawns should be delivered, alive or in good condition, with the above information, to the CRIFI Field Research Station at the Lubuk Lampam waterbody on the Lempuing River. If you return the fish/prawn in good condition, with the tag still in position, you will be paid 150% of its market value in addition to the reward.
- If delivery is not possible, send the tag and the above information to Ondara, Sub Balitkanwar, Jln. Rajawali 491A, Post Box 1125, Palembang 30113.

Figure 3.3 Mark-Recapture programme publicity handout for Bangladesh (translated into Indonesian before distribution)

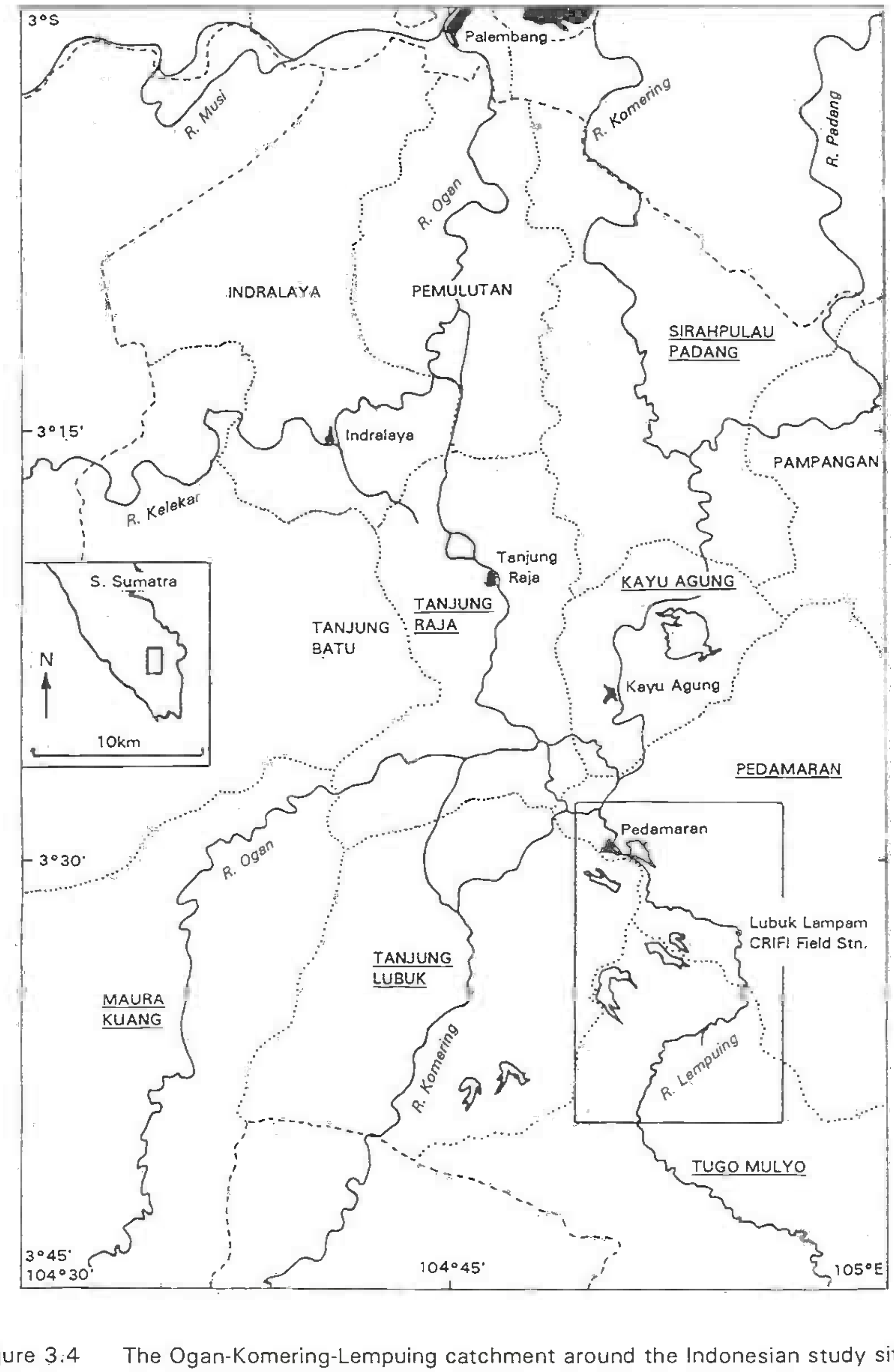


Figure 3.4 The Ogan-Komering-Lempuing catchment around the Indonesian study sit (boxed) showing the main river channels (solid lines) and administrativ boundaries (dashed/dotted lines). Tag releases were made within the boxe area and tagging publicity announcements were made in the seve underlined districts of the Ogan-Komering-Lempuing catchment.

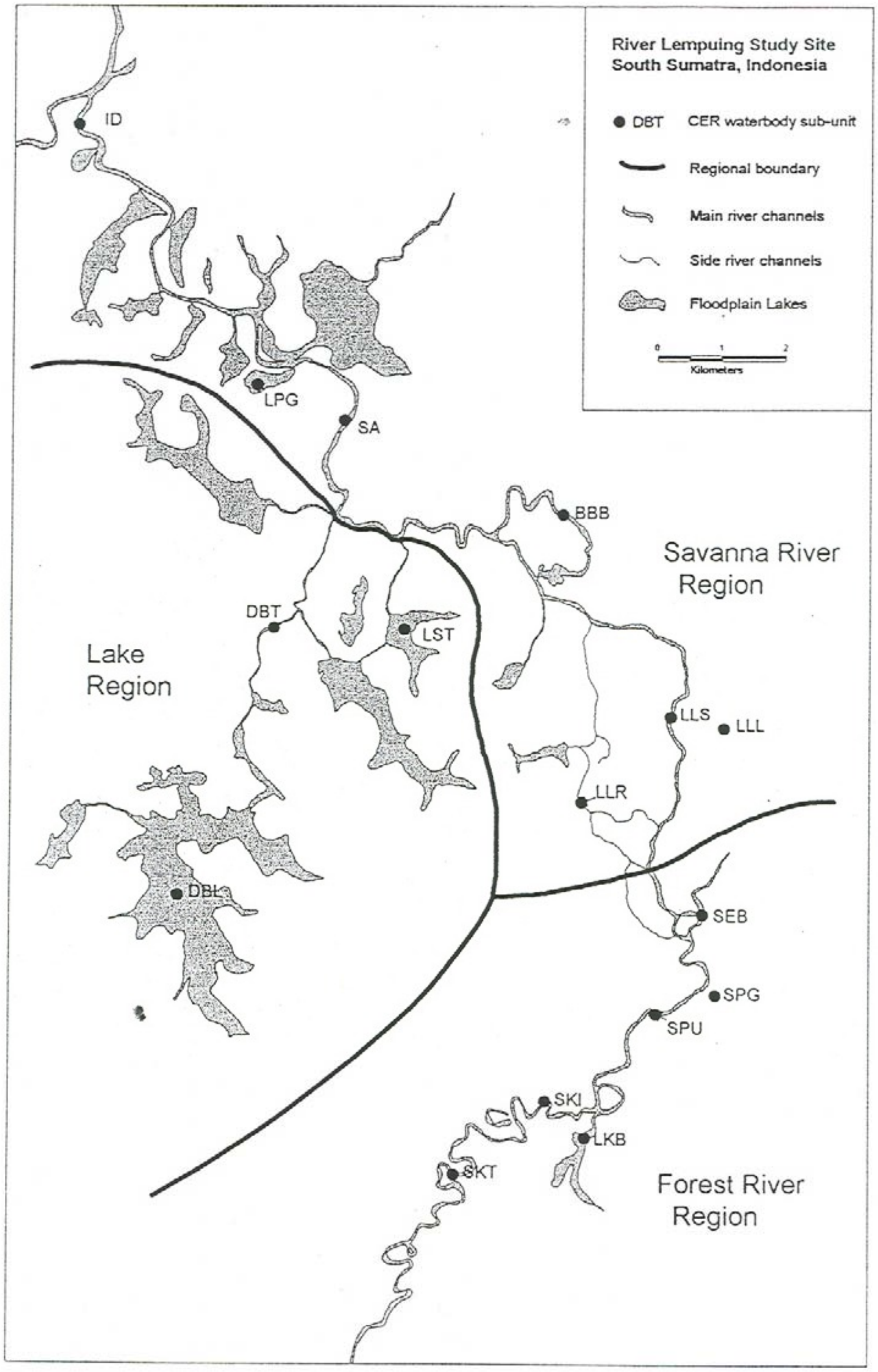


Figure 3.5 Sampling sub-regions at the Indonesian River Lempuing study site, and the licensing waterbody sub-units randomly selected in the first stage sampling of catch/effort respondents (CERs).

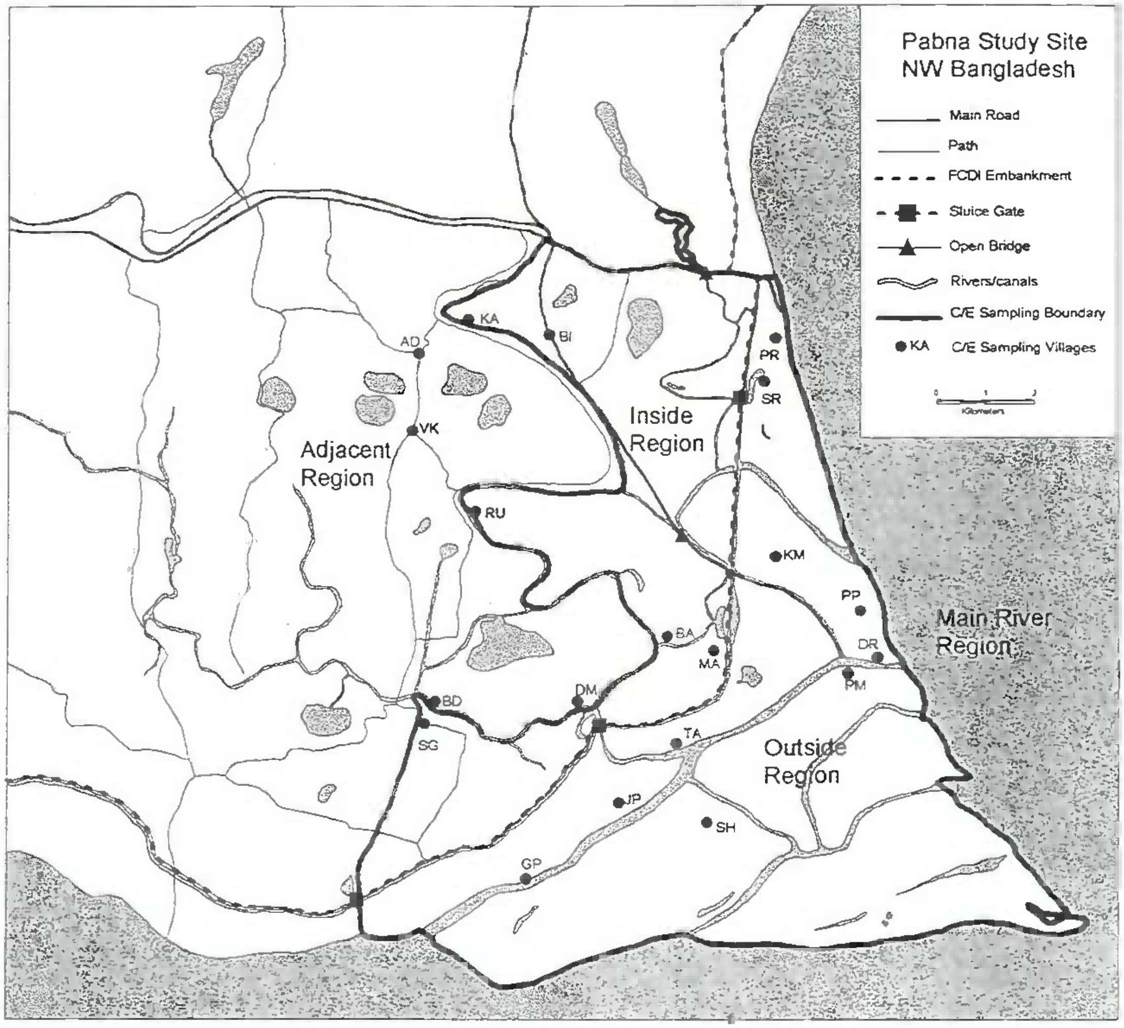


Figure 3.6 Sampling sub-regions at the Bangladeshi Pabna study site, and the villages randomly selected in the first stage sampling of catch/effort respondents (CERs).

4 The Floodplain Environment

4.1 Introduction

This chapter describes the environmental characteristics and the most important differences between the two study sites in Bangladesh and Indonesia. In the simplest terms, the Bangladeshi site is hydrologically 'modified' from its pristine condition by the PIRDP flood control scheme, while the Indonesian River Lempuing site is hydrologically unmodified. In addition to these basic differences, there are a number of other important differences between the two sites, which may influence their productive capacity and management requirements. As described in the following sections, these include their relative catchment positions, their flood seasonality and variability and the relative impacts of human settlement.

4.2 Comparative catchment positions of study sites

The hydrologically 'modified' study site in Bangladesh was selected at the confluence of the Padma (Ganges) and Jamuna (Brahmaputra) rivers, in NW Bangladesh (Figure 4.1). At this position, 150km inland from the coast, with a floodplain altitude of around 25ft (7.6m), the Padma and Jamuna have average widths of around 2 and 7km respectively, far larger than any rivers in Indonesia. The main focus of the Bangladesh study, however, was on the Badai and Atrai secondary rivers, and their floodplains and lakes, both inside and outside the Pabna Irrigation and Rural Development Project (PIRDP, see Section 4.5.2). These secondary rivers and their floodplains lie in between the two main rivers and have comparable sizes (20-50m widths) to the Indonesian River Lempuing study site. Farming is the primary occupation within the PIRDP floodplains, but fishing is an important source of income for many people.

The 'unmodified' study site in Indonesia was located at a relatively upstream position in the Lempuing-Komering catchment, though at a similar altitude and distance from the coast (Figure 4.2). In South Sumatra, the three rivers Ogan, Komering and Lempuing run parallel to each other from the western Barisan Mountains to join the large Musi River near the provincial capital of Palembang. These rivers interconnect with each other via three side channels just below the Lempuing study site. In this vicinity, the Ogan River is by far the largest, with widths of up to 500m, while the Komering and Lempuing are smaller rivers with widths up to around 50m. The River Lempuing, however, is associated with a substantial floodplain lake system, known as the Marga Danau or Lake District (see Figure 2.2), which provides some of the richest inland fishing grounds in South Sumatra. Agricultural production is mainly at a subsistence level in this lightly populated and deeply flooding area.

4.3 Floodplain morphology and terminology

Apart from the proximity of the main Padma and Jamuna rivers to the PIRDP study site, the two selected floodplain systems are nominally similar. Both sites thus contain a mixture of habitats including secondary rivers, floodplains and natural depressions. The Bangladeshi site is, however, far more heavily populated than the Indonesian one, producing the following significant differences in its floodplain characteristics.

The PIRDP study site is subdivided artificially (in addition to the main embankment) by many roads and footpaths, with the larger roads having canals alongside them. At the River Lempuing site, most transport is still by motorboat or canoe, even in the dry season. In Bangladesh, the floodplain is also nearly all converted to agricultural use (see section 4.5.6), and the natural floodplain waterbodies are supplemented by many smaller excavated fish pits and household ponds. In Indonesia, in contrast, the River Lempuing floodplains are still mostly in their natural condition. Two types of floodplain are also distinguished on the Lempuing: savanna grassland and forested types. The latter forested floodplains have now largely disappeared from the Bangladeshi river catchments, due to human overexploitation.

The following habitat types were thus recognised in this study, and generally referred to using the following names in this report:

Habitat type	Bangladesh	Indonesia
Floodplain	Savanna	Lebak
Forested		Rawang
Agricultural	Floodplain	
Secondary river	River	Sungei
Canal	Khal	
Natural depression	Beel	Lebung
Excavated fish pit	Kua	
Household pond	Mathel	

4.4 Flood seasonality and variability

4.4.1 Bangladesh

At its confluence position, the PIRDP study site receives flood water from both the Jamuna and Padma rivers, and also from local rainfall. In most years, the Jamuna River begins flooding a month or more before the Padma, usually in April or May. During the rainy season, the waters rise around 20 feet (6m) to reach a peak flood in July or August. The high water may then be sustained for around three months before waters begin to fall in September or October.

With the lowest PIRDP floodplains at an altitude of approximately 25ft, the floodplains outside the embankment are covered by up to 8.6ft (2.6m) of water in the flood season (Figure 4.3, Table 4.1). Due to the embankment, flood depths inside the PIRDP flood control scheme do not reach the peak levels experienced outside, and have a smoother flood curve with water depths of up to 6.5ft (2.0m) (see Section 4.5.4). Virtually all the lands within the project study site, except those raised by man for roads or housing, both inside and outside the flood control scheme become inundated in a normal flood.

Flood magnitudes have varied significantly over recent years, with the first study year, 1995, having a particularly high and long flood compared to 1993 and '94 (Figure 4.3, Table 4.1). In the second study year, 1996, the flood began very early in April, but did not reach the floodplain height until the end of June, giving a relatively short, though still high flood. Measured as a 'flood index' (Welcomme, 1979) calculated as the integral of the daily water depths over the 25ft floodplain height, the 1995 flood may be seen as 86% larger than the lowest 1994 season, and 19% larger than the 1996 flood (Table 4.1).

Table 4.1 Comparative flood indices for the 19 93 to 1996 floods at the Bangladesh study site (water depths measured outside the Talimanagar sluice

Year	1993	1994	1995	1996
Flood Index (foot-days inundated)	536	339	632	532
Maximum Floodplain Depth (ft)	7.0	6.8	8.6	8.3
Days Floodplain Inundated	136	117	129	115

In comparison with the Indonesian study site, and based on limited data from 1995 and '96 only (see following sections), it is possible that the Bangladeshi flooding pattern shows greater variability in its high water, flood levels than in its low water, dry season levels. The dry season water levels only dropped to a relatively stable 15ft in both 1995 and '96 (Figures 4.6, 4.7) while high water flood levels fluctuated far more dramatically. This observation may be explained by the buffering effect of the huge Gangetic delta, and the closeness of the PIRDP site to the water tables at this point.

4.4.2 Indonesia

In its position on the eastern side of South Sumatra, the Indonesian River Lempuing receives its floodwaters during the NE monsoons, which usually arrive in September / October to produce peak water levels by December (Figure 4.4). The flood seasons at the two study sites are thus approximately six months out of synchronisation with each other.

The 1994/95 Indonesian flood was high and relatively long, with a pronounced peak in March, and a long drawdown split by a temporary reflooding in June/July (Figure 4.4a). In the following year, the 1995/96 flood reached similar heights but was divided by a false drawdown in early March (Figure 4.4b). The 1995 dry season was relatively dry, while the '96 dry season was shortened by an unusually early flood in August. These variations produced significant impacts on fish productivities and fishing success in the two years (see Chapters 5 and 6).

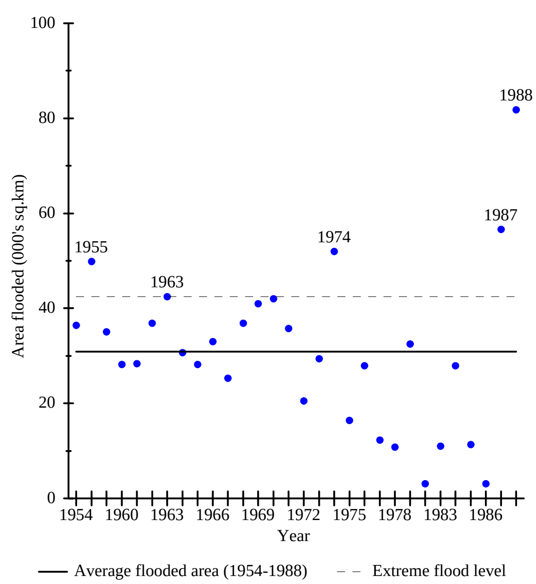
In the long term, the two study years were quite average in their flood patterns (see data for preceding years presented in MRAG, 1994a). The 1994 dry season, just before the start of the study, was, however, the driest ever recorded, with water levels being below the gauge datum (a nominal 0cm) for the first time ever for three full months from mid July to mid October!

In contrast to the Bangladeshi site, there is some evidence that the flood pattern at the Indonesian study site is more variable in its dry season depth, than in its flood season heights. This pattern of variability may be explained by the relatively large size of the Marga Danau inland delta, compared to the Lempuing River (so that high water floods spread out laterally instead of vertically), and to the lack of a stable water table at this catchment position. Whatever the cause, this strong variability has important implications for the conservation and management of the Indonesian fishery.

4.5 Hydrological modification of the Bangladesh study site

4.5.1 'Extreme' flooding and its effects in Bangladesh

The extent of annual flood inundation in Bangladesh is extremely variable and unpredictable resulting from spatial, and interannual variations in the amount of rain falling in the upper catchment areas of the main rivers flowing through the country. Occasionally, the peak flows of both the Padma and the Jamuna rivers are synchronized, creating ‘drainage congestion’. In these years, ‘extreme’ or 'catastrophic' flooding may occur as shown below.



Area inundated by flooding in Bangladesh, 1954-1988.
Data source: Ahmad (1989).

The periodicity of these floods is approximately every 10 years. Many authors including Matin & Husain, (1989), Ahmad (1989), and Pramanik (1994) have blamed deforestation within Bangladesh and its neighbouring countries for higher discharge rates and increased silt loading leading to shallower rivers. These two factors combine to make the rivers more prone to flooding.

Extreme floods disrupt transport and communication systems and damage infrastructure such as roads, railways, bridges, embankments and buildings. In the most severe cases, many lives are lost and people are left homeless. For example, in the catastrophic flood of 1988, 30 million people were made homeless: between 1960 and 1980, approximately 800,000 lives are thought to have been lost (Temple & Payne, 1995). Given that much of Bangladesh's population live at agrarian subsistence level, damage to crops caused by extreme flooding presents a serious threat to the welfare of the people and to the economy as a whole. Rice, jute, sugarcane and vegetable crops are all susceptible to damage caused by flooding. Furthermore, the very unpredictability of extreme floods may have an indirect negative effect on crop production as farmers appear unwilling to risk investing resources in an attempt to increase yield. Drinking water supplies can also become contaminated during extreme floods, which are invariably followed by diseases such as cholera, diarrhoea and dysentery.

4.5.2 The Pabna Irrigation and Rural Development Project (PIRDP)

The Pabna Irrigation and Rural Development Project was constructed during the early 1970s to protect Pabna communities from extreme flooding and provide controlled irrigation for agriculture. A total area of 1,845km2 is now protected from the floodwaters of the Padma and Jamuna rivers by an embankment of over 200km in length (Figure 4.5; SWMC, 1994). A smaller area of 219km2, including the catchments of the Chiknai, Sutikhali and Kageswari rivers in the north east corner of the scheme, is supplied with irrigation water from a pumping station at Bera via the Ichamati canal (Figure 4.5). Water levels inside the PIRDP are controlled by the Bera pump and a second pump at Koitola, and by the opening of 15 sluice gates spaced at intervals around the embankment.

The irrigation area lies adjacent and to the north of the project study site on the other side of the main road between Pabna town and the ferry terminal at Nagarbari (compare Figure 4.5 with Figure 2.1). Irrigation waters in the Ichamati canal may eventually flow to the south of the irrigation area, via the Atrai River and go under the Kashinathpur road bridge into the south east study site. The study site is not specifically targeted for controlled irrigation, though, and the Atrai sluice gates are often closed to keep water within the NE irrigation area. Though it is not irrigated, the study site is completely protected from the main river floods by the embankment.

4.5.3 PIRDP hydrological management - overall strategy

The PIRDP includes three independent drainage systems: the Chiknai-Tarapasha-Ratnai-Sutikhali system in the northern part of the PIRDP draining through the Demra and Bera sluices, the small Kageswari River to the east leading to the Koitola Sluice, and the Atrai-Badai system draining the southern lands including the project study area via the Talimnagar sluice (Figure 4.5).

The PIRDP also has 14 major depressions or beels, in which water is stored over the dry season for irrigation. Thirteen of these beels are in the main irrigation areas in the Chiknai and Kageswari systems, while only one is located in the south east study site region (the Gandhahasti Beel complex, between the Badai and Atrai rivers, coded as beels BGB, BAB, IKB, NMB in Figure 3.1).

Water inside the PIRDP is supplied mainly by local rainfall, supplemented by water pumped in by the Bera station, or allowed to drain in through the sluice gates. The pumping stations and sluice gates are managed to produce a moderate and controlled flood for the high water aman rice production without threatening local communities, and to provide further irrigation water during the dry season. The operation of the pumps and gates varies between the years, depending on the local rainfall levels and the resulting water heights inside the PIRDP.

The pumping stations at Bera and Koitola sluices may thus both be used to supplement the gravity drainage inside the irrigation area during the flood season if high water levels begin to threaten crop production or communities. Later, in the dry season, the bi-directional Bera pump may also be reversed to provide irrigation. The 42km Ichamati canal is maintained throughout the year by the Bera pump at a height of 35ft (above mean sea level), to feed the many secondary and tertiary canals inside the irrigation area (Figure 4.5). Frequently spaced drainage regulators on these canals then control the water levels in different flood cells. However, due to breaks in the internal embankment and the poor condition of some of the regulators, some flood cells are inadequately supplied (E. Rahman, Pabna WDB Executive Engineer, pers. com., 1994).

The 15 perimeter sluice gates are generally closed during the rainy season due to the dangers of excessive overspill from the main rivers. The gates are then opened at the end of the high water season, after the aman rice matures to allow the floodplain waters to drain to the main river. The PIRDP sluice gates may therefore be used to prolong the aman rice season to ensure a successful crop. The sluice gates vary in size from 3 to 15 vents, with each vent having an aperture of between 1.5x1.8m and 6.1x2.6m. The six-gate Talimnagar sluice, on the Badai river within the project study site (Figures 2.1, 4.5), has the largest maximum aperture of all the PIRDP gates, at 94.6m2.

The PIRDP irrigation and flood control mechanisms are controlled by officers of the Bangladesh Government's Water Development Board (WDB), using telephone links to monitor water heights in different parts of the scheme. The WDB is advised about water requirements in each year, in response to the development of the crops, by a committee of landowners and farmers. Fishermen are not represented on this committee.

4.5.4 PIRDP impact on local hydrology

The impact of the PIRDP flood control structures has been modelled by the Surface Water Modelling Centre for the FAP17 project (SWMC, 1994). Without the flood control structures (particularly the disconnection of the Badai river from the Padma at its western, upstream end, see Figure 4.5), the SWMC model predicts that internal flood magnitudes in the Badai system would be substantially higher, especially in years of major floods such as 1987 and '88. In the two other catchments to the north with their many beels acting as internal drainage structures, the flood control system appears to have little overall effect on flood heights, though the waters are now retained longer for irrigation purposes. The large Talimnagar sluice in the study site thus allows relatively fast drainage of the southern catchment, and the project study site is recognised as a sub-region particularly affected by the PIRDP flood control scheme. These predictions are confirmed in the following section, by water height data collected by this project.

4.5.5 Sluice gate operation and in/out water levels at the study site

The project study site in the south east of the PIRDP is drained by the main Talimnagar sluice gate on the Badai river, and also by two smaller gates, one at Baulikhola, 8km northwards along the embankment, and the other at Khalilpur, 6km to the south west (Figure 2.1). Water levels were monitored by the project both inside and outside the Talimnagar and Baulikhola sluice gates on a daily basis for both study years 1995 and '96. Sluice gate apertures were also recorded every day at both sites to observe the detailed management of water resources in this vicinity by the WDB.

As noted earlier, the Talimnagar sluice on the Badai River is the largest of all the PIRDP gates, with six 6m-wide gates, having a combined maximum aperture of 94.6m2. The Talimnagar sluice base or sill is positioned at an altitude of 17ft AMSL and the PIRDP 'inside' rivers become separated from the outside Badai and Jamuna river when water levels fall below this height.

The much smaller Baulikhola gate on the Natuabari canal, in contrast, has only three 1.5m-wide gates and a maximum total aperture of 8.1m2. Due to the smaller size of the Natuabari canal, the sill of the Baulikhola sluice has an altitude of a relatively higher 21ft. The Natuabari canal dries out completely around the Baulikhola sluice when water levels fall below 20ft, though pockets of water remain in the deeper canal sections both inside and outside.

The overall effect of the PIRDP flood control structures is to delay and smooth the flood curve inside the scheme compared to that outside (Figures 4.6, 4.7). The high flood levels up to almost 35ft recorded outside the sluice gates, produced by flood pulses of the Jamuna / Padma rivers, are thus avoided inside, where water levels rose and fell more gradually up to a maximum of only 31.5ft. Such conditions enable the maximum high water aman rice production as the crop has time to grow with the gently rising water levels, without being submerged.

Due to the delay in the inside flood, the duration of the floodplain inundation is shorter inside than outside (Table 4.2). Due to their relative sizes, the Baulikhola sluice drains its vicinity more slowly than the Talimnagar one, and the inside flood is slightly extended at the former site. Overall, the inside floods were thus 10 days shorter at Baulikhola and 20-25 days shorter at Talimnagar (Table 4.2).

Combining the water heights and flood durations as the integral flood index (foot-days of inundation over the average floodplain depth of 25ft), the inside flood magnitude was substantially reduced in both years, at both sites. In 1995, inside flood indices were 68% of outside ones at Baulikhola, and 66% at Talimnagar. In 1996, the inside flood rose to a higher level than in 1995, and inside flood indices were a higher 81% and 75% of those outside (Table 4.2).

Table 4.2 Comparative flood indices inside and outside the Talimnagar and Baulikhoa sluice gates in 1995 and 1996

Sluice Gate	Baulikhola		Talimnagar	
Position	Inside	Outside	Inside	Outside
Year: 1995				
Flood Index (foot-days inundated)	454	667	420	632
Maximum Floodplain Depth (ft)	5.9	9.6	5.8	8.6
Days Floodplain Inundated	111	121	109	129
Year: 1996				
Flood Index (foot-days inundated)	435	535	398	532
Maximum Floodplain Depth (ft)	6.5	8.6	6.4	8.3
Days Floodplain Inundated	97	107	90	115

As shown in the following sections, the observed differences in flood patterns may be partly explained by the operation of the Talimnagar and Baulikhola sluice gates. These two gates were managed in broadly similar ways, though with significant differences particularly in 1995.

- **1995 Sluice gate operation and water levels**

In 1995, both sluice gates were kept closed at the beginning of the flood season during both May and June. At this time the PIRDP experienced much local rainfall and the inside water levels rose at a rate where any extra floodwater from outside could have pushed water levels dangerously high. The flood pulses flowing down the Jamuna and Padma in these months were thus largely excluded from the PIRDP by the closed gates (Figure 4.6). Water levels reached the outside floodplains (altitudes around 25ft) in mid June, but did not inundate the inside floodplains until early July.

From July 1995 onwards, the two gates were operated quite differently (Figure 4.6). As water levels continued to rise to their maximum levels outside, water was only allowed into the PIRDP through the Talimnagar gate for four days in mid-July and three days in mid-August. Apart from these times, the sluice gate was only opened when the inside water heights either equalled or exceeded the outside heights. The gate was thus first opened to a large aperture in early August, when the water levels were equal inside and out. Local staff report that the gate was opened at this time following requests from fishermen to encourage fish migration into the PIRDP. The Talimnagar gate was then mostly closed again when outside water levels rose in August and again in late September. The sluice gate was finally fully opened in early October when outside water levels began to fall, and both inside and outside water levels dropped at a similar rate due to the large aperture of the gate.

In contrast, the Baulikhola gate was opened far more often over the 1995 flood season, particularly during the July and August late flood pulses. Local staff reported that the Baulikhola gate was less rigorously controlled by the WDB than the Talimnagar gate (where the WDB gate officer resided). Local fishermen were then able to open the Baulikhola gate themselves during these periods to allow fish inside the PIRDP waters. The Baulikhola region also drained more slowly than the Talimnagar region during the October drawdown presumably due to the smaller aperture of the former gate.

- **1996 Sluice gate operation and water levels**

In 1996, the two sluice gates were managed in more similar ways, suggesting that both gates were more tightly controlled by the Talimnagar WDB officer. As noted in Section 4.4.1, the 1996 flood started early but then rose very slowly so that mid June water heights were around 10ft lower than in 1995 (Figure 4.7). Due to the low local rainfall levels, the Talimnagar sluice was opened in early May and both gates were opened from mid June onwards to attempt to raise water levels inside the PIRDP up on to the floodplains. Even with the gates opened this way, the 1996 floodplain inundation was still some two weeks later than in 1995 (Figure 4.7). Like 1995, however, the gates were still only partially opened during most of July, until the main flood pulse had passed and water levels began to fall. The gates were then opened to their maximum extent, as requested by fishermen when in/out water levels became equal in August. Having achieved an inside flood of some 31-32ft by mid August, the sluice gates were then closed again until mid September when outside water levels began to fall. At that time the sluice gates were again opened only partially to allow the water out gradually and prolong the aman growth season inside the PIRDP. As in 1995, the gates were fully opened again half way through October to allow the floodplains to drain.

4.5.6 PIRDP floodplain agriculture

The particular purpose of this study is to determine the impact of FCD/I schemes such as the PIRDP on floodplain fish production. Recognising the wider demands on river catchments, this section briefly describes the agricultural systems practised in the Bangladesh site, and shows the positive impacts of the PIRDP for these sectors.

The traditional crop in the Pabna deepwater floodplain regions is broadcast, long-stem aman rice, planted at the start of the flood and harvested during the drawdown, as the floodplains become accessible again. The more controlled flooding resulting from the PIRDP irrigation is designed to allow high-yielding varieties (HYVs) of rice to be produced year round over three crop seasons. In the 1st 'carif' season, from March to June (dry/early flood season), aus rice (eg IRRI II variety) is planted. In the 2nd high water carif, July to October, the traditional aman rice is still grown. Finally, over the dry or 'ribbi' season, IRRI short stem rice, along with jute, wheat, mustard and other vegetables are all now grown successfully. Before the PIRDP, mainly only the high water Aman rice was grown at a cropping intensity of 118%[1]. Cropping intensities inside the PIRDP are now reported to be 190% in some flood cells, approaching the final target figure for production of 212% overall (E. Rahman, Pabna WDB Executive Engineer, pers. com., 1994).

Within the study site corner of the PIRDP (outside the NE irrigation sector), dry season production is similar inside and outside the embankment. Local farmers report, however, that overall crop production inside the PIRDP is generally at least double that outside. Furthermore, while inside production is relatively reliable, the outside crops - particularly the main aman rice crop - may occasionally be completely destroyed when the unregulated floods rise dramatically and submerge the crops. Paradoxically, this impact may now be even more frequent precisely because of the increased areas of empoldered schemes, and the reduction in land available to absorb extreme floods.

On balance, then, Pabna farmers inside the FCD/I scheme are supportive of flood controls. To see the broadest picture, it should be acknowledged that the relatively high importance of farming in Bangladesh, compared to fishing, does to some extent justify the construction and maintenance of flood control schemes. The farmers interviewed were, nevertheless, aware of the difficult position of the poorest landless fishermen, and agreed that simple changes could be made to sluice gate operations to benefit the fishing community.

4.6 Hydrological Modification of the Indonesian Site

Though the Indonesian River Lempuing study site has no deliberate hydrological modifications like those in Bangladesh, there is some evidence that hydrological conditions are changing in the catchment. A long-term decline in water levels was mentioned in Section 4.1, presumed due to upstream modifications to the Lempuing catchment and increasing demands for water resources. In addition to this decline, local project staff also reported changes to the management of the canal sluices controlling water flows between the Lempuing and the larger Ogan river downstream of the study site (see Figure 4.2). Though data on sluice gate openings are not available, the relatively high 1996 dry season (and the poor catches which resulted) were reported to be at least partly due to the closure of these sluices, and the prevention of the normal draining patterns. Such observations call strongly for a catchment approach to the management of the River Lempuing fisheries and its wider water resource demands.

[1] Cropping intensities over 100% indicate some land producing more than one crop per year

4.7 Summary - The Floodplain Environment

- The hydrologically modified study site in Bangladesh and the pristine site in Indonesia were both based on secondary river systems having widths of 20-50m. The Bangladesh study site floodplains lay between the confluence of the Padma and Jamuna rivers and straddled the embankment of the Pabna Irrigation and Rural Development Project (PIRDP) flood control scheme. The Indonesian study site included the rivers and lakes of the south Sumatran River Lempuing fishery, some 10km upstream of the larger River Ogan.

- In addition to the deliberate hydrological modifications, the high human population levels in Bangladesh have produced further changes in floodplain morphology. In contrast to the relatively pristine Indonesian site, the Bangladesh floodplain is subdivided by roads and paths, has many excavated fish pits and household ponds, and is fully utilised for agriculture throughout most of the year.

- The two study sites have similar flood curves though at the opposite monsoon seasons. The Pabna site is generally flooded from June/July to September/October, while the Lempuing site is flooded for slightly longer from November/December to March/April. It is possible that the Bangladesh site has greater variability in its flood season water heights, with relatively constant dry season depths; while the flood pattern at the Indonesian site is most variable during the drought season.

- At the Bangladesh site, the 1995 flood was particularly high and long. The 1996 flood arrived around two weeks later after a false early start, but eventually rose to a similarly high level.

- At the Indonesian site, both the 1994/95 and the 1995/96 floods were high and reasonably long. The 1995 drawdown was split by an unseasonal reflooding pulse, while the 1995/96 flood was divided by an unseasonal small drought. The 1995 dry season was relatively dry, while the 1996 dry season was ended prematurely by an early flood in August. Just before the study period, the 1994 drought was the most extreme ever recorded on the Lempuing.

- The Bangladesh PIRDP provides protection from extreme flooding and pumped drainage for a 1,845km2 area, and controlled year-round irrigation for a 219km2 sub-area. The Pabna study site straddled the boundary of the flood protection area in the vicinity of the largest drainage sluice at Talimnagar, but lay completely outside the irrigation sub-area.

- The PIRDP flood control structures are managed by the Bangladesh Government's Water Development Board (WDB). Advice about seasonal water requirements and gate opening times is provided by a committee of landowners and farmers with the primary aim of maintaining conditions for the aman rice crops. No formal consideration is given to the needs of fishermen or fish migrations, though the sluice gates may be opened at the request of fishermen (or without permission sometimes) when this does not threaten agricultural conditions.

- The main effect of the PIRDP flood controls is to delay, shorten and smooth the flood curve inside the scheme, avoiding the dangerously high peaks occurring outside, and producing the optimum conditions for rice production. Resulting flood magnitudes inside the scheme were 66-68% of those outside in 1995, and 75-81% in 1996, when the gates were opened for many days in August.

- In 1995, the two sluice gates in the vicinity of project study site were both closed during the early flood to reduce the danger of excessive flooding after high levels of local rainfall inside the PIRDP. The primary Talimnagar sluice gate remained closed for most of this high flood year, except to let water drain from the inside floodplains when possible. In the drier 1996, however, the Talimnagar sluice gate was opened during early May and much of July and August to boost flood levels inside the PIRDP.

- According to the WDB managers and to local farmers, the PIRDP scheme has been successful in producing better conditions for agricultural production. Rice and other crops are now produced year round, including high yielding rice varieties, and without the occasional crop losses caused by extreme floods outside the scheme.

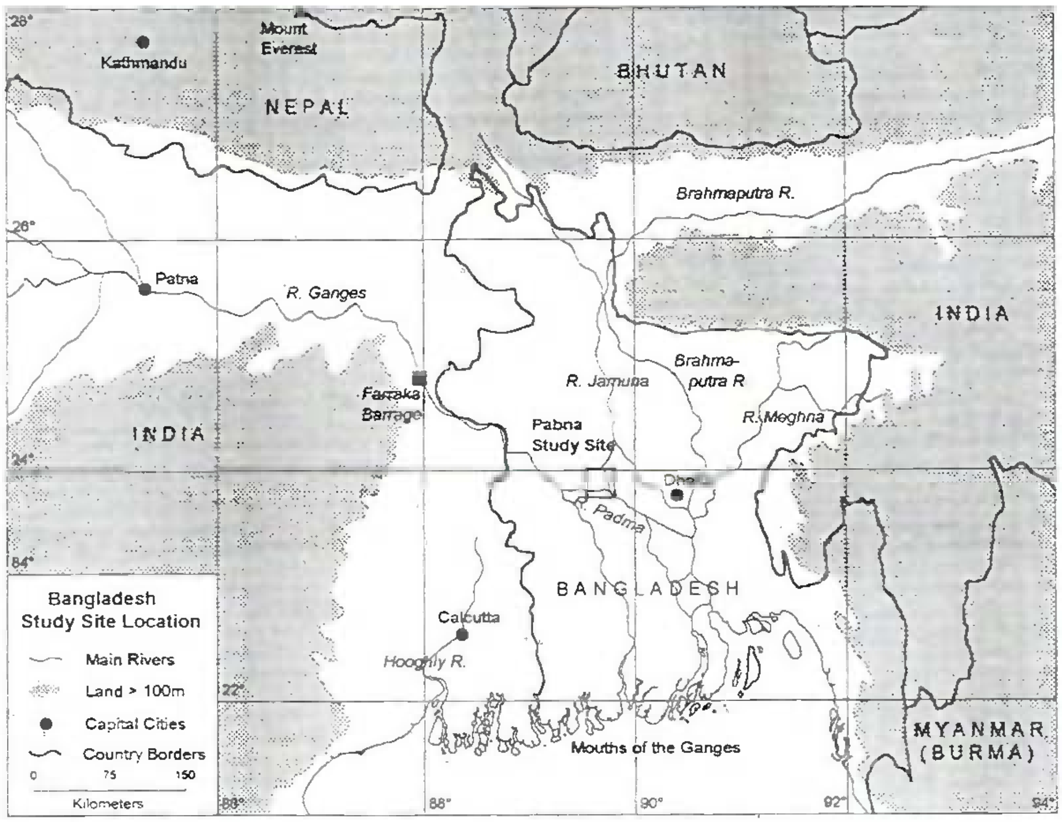


Figure 4.1 The catchment position of the Bangladeshi study site at the confluence of the Padma and Jamuna rivers.

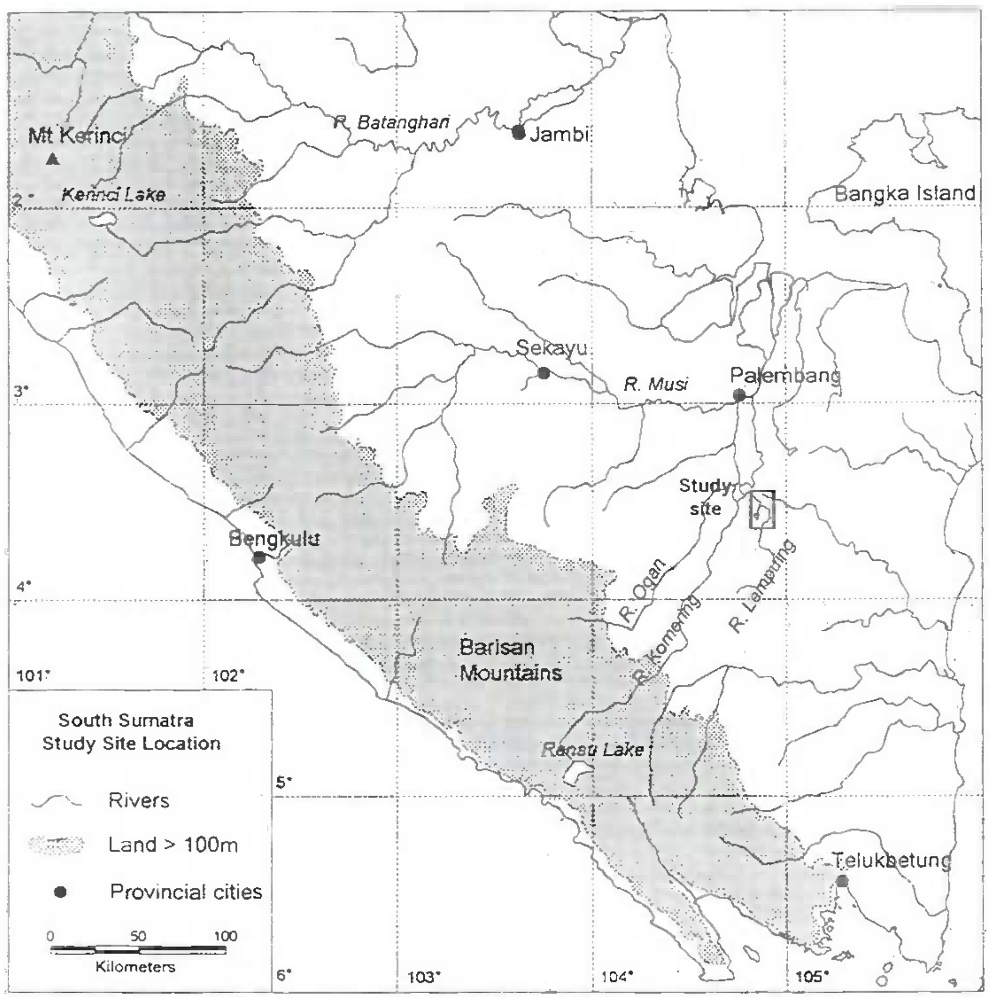


Figure 4.2 The catchment position of the Indonesian study site, in Ogan Komering Ilir province, South Sumatra.

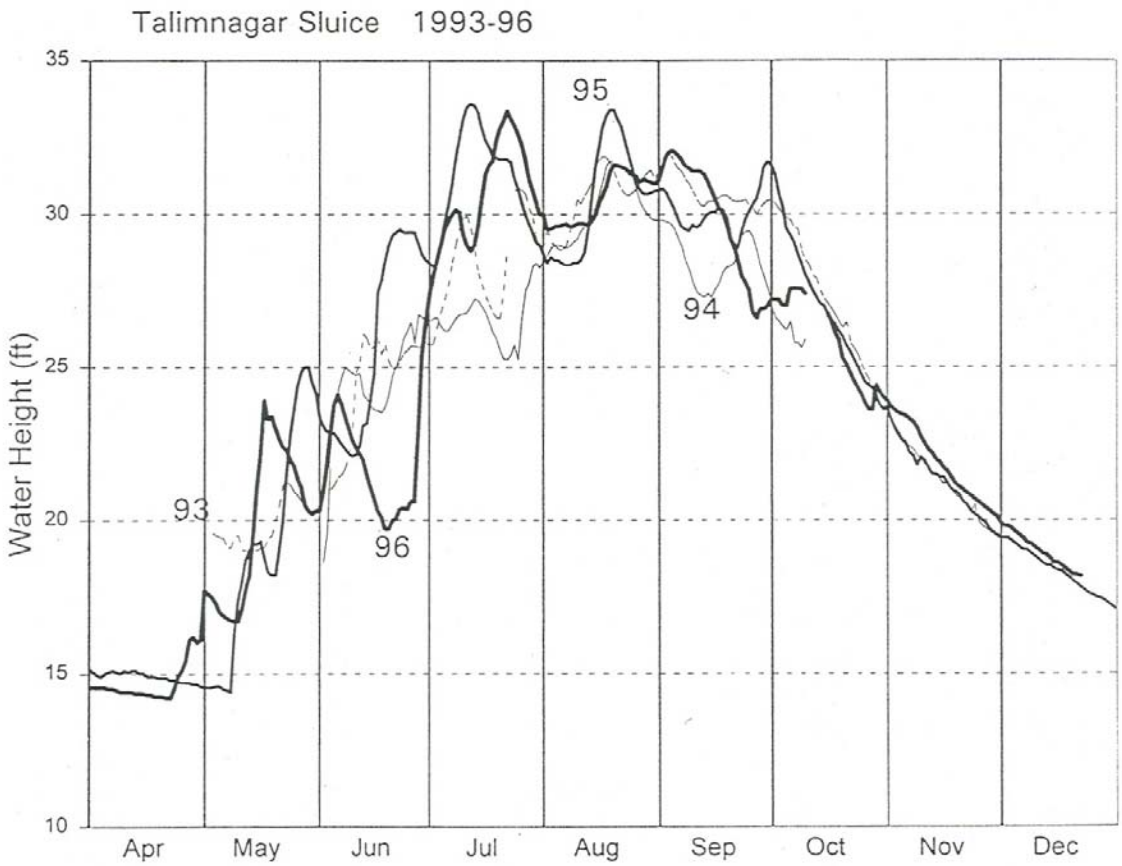
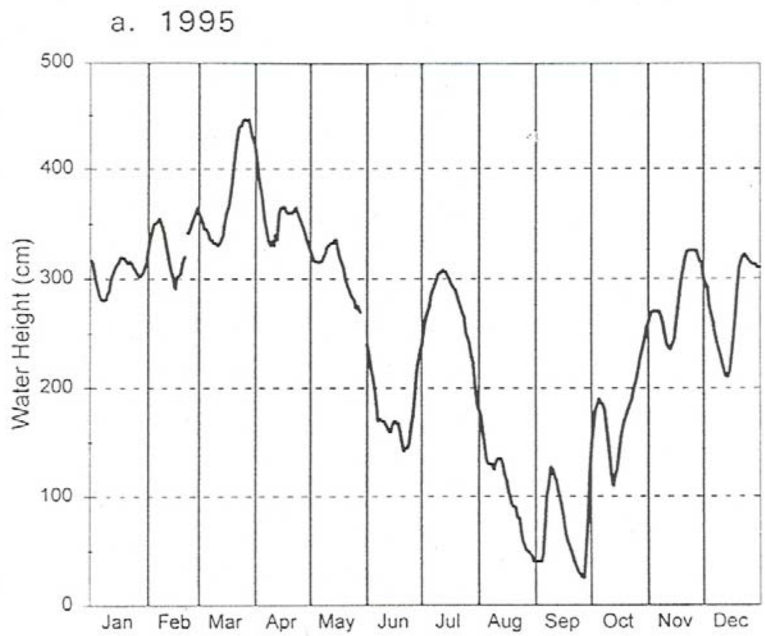


Figure 4.3 Water heights at the Bangladeshi study site for years 1993-'96, measured outside the Talimnagar sluice gate.



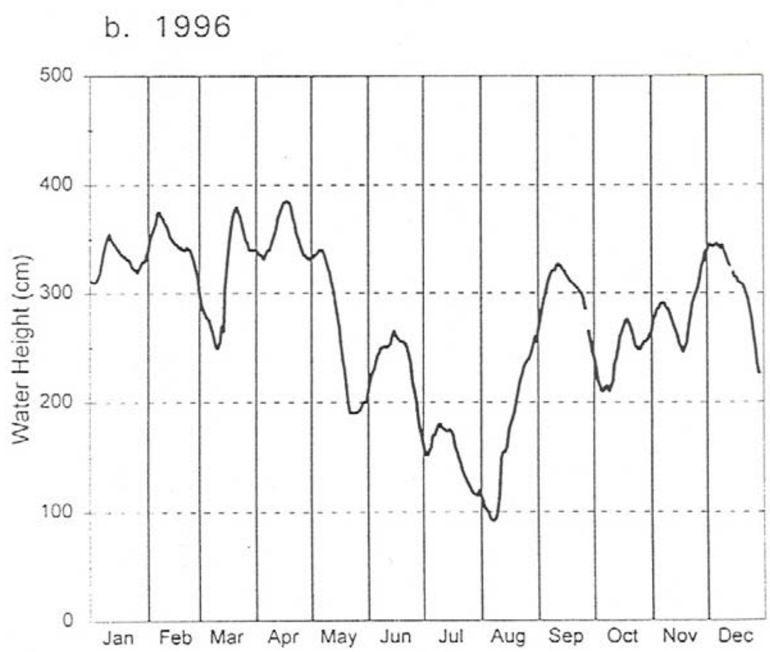


Figure 4.4 Water heights at the Indonesian study site in years 1995 and '96, measured the CRIFI Lubuk Lampam research station.

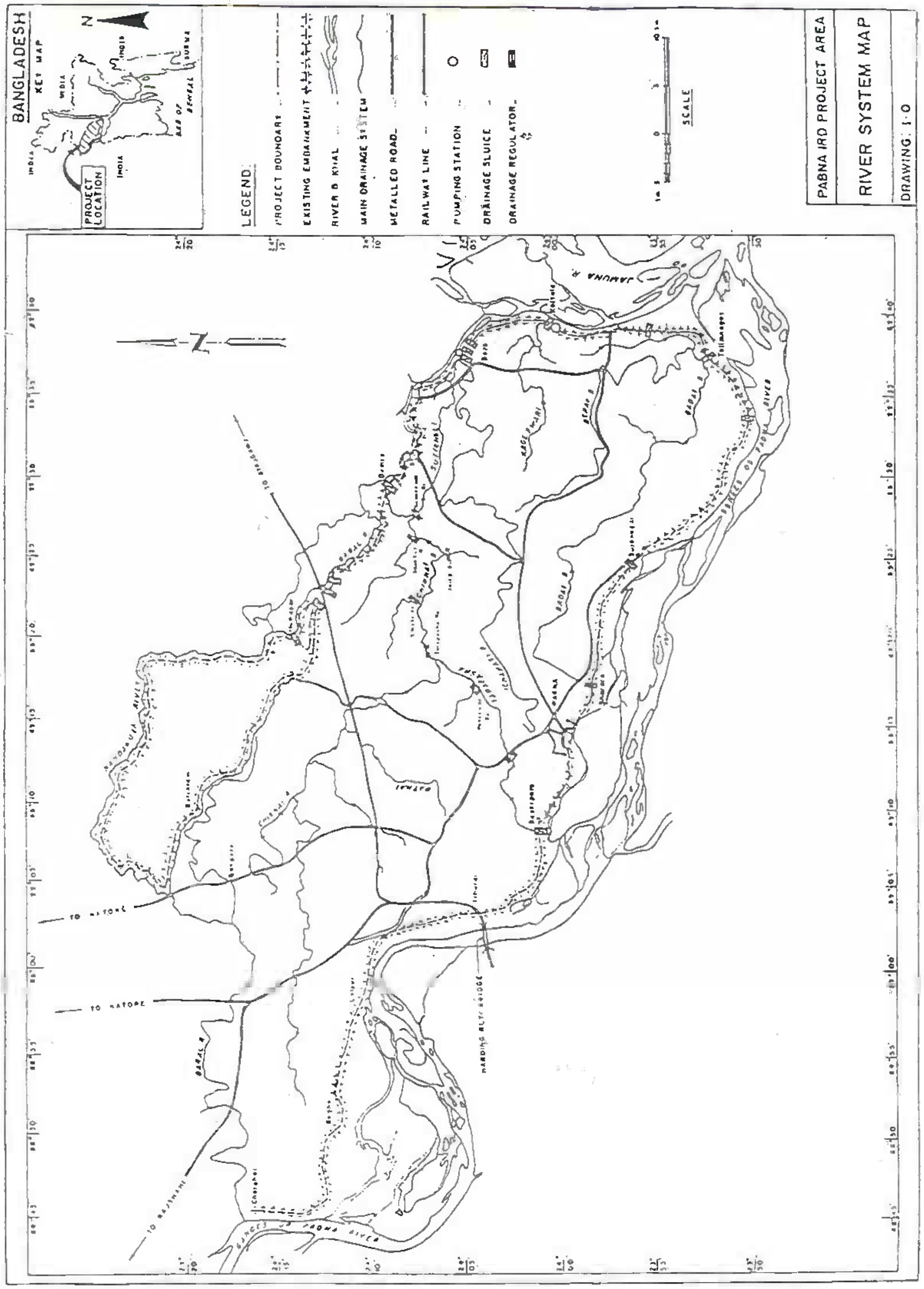
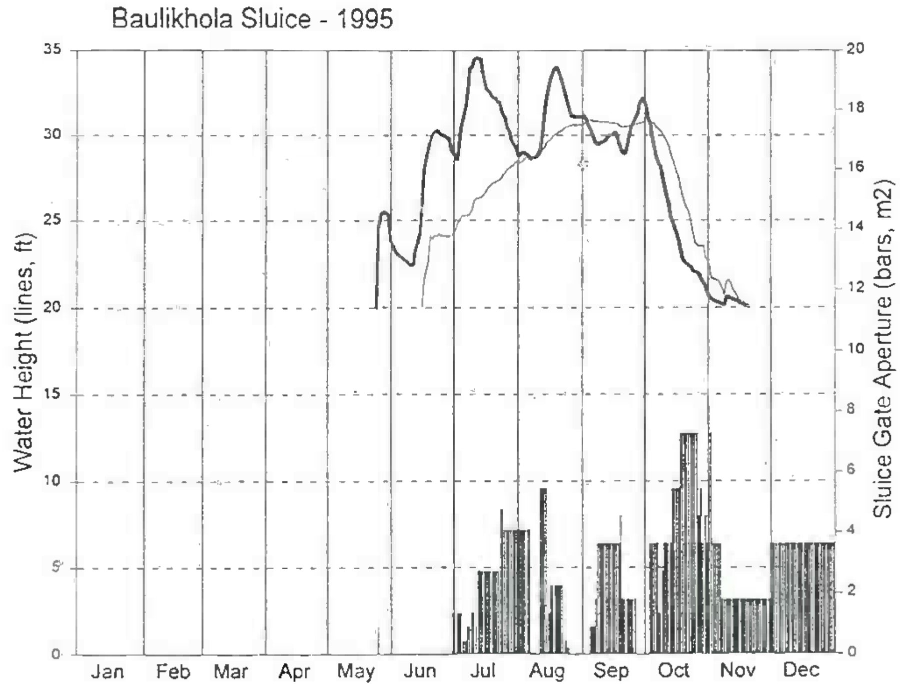


Figure 4.5 Rivers, main roads and the flood control embankment of the Pabna Irrigation and Rural Development Project (PIRDP) area (reproduced from SWMC, 1994). The Pabna study site straddled the embankment in the south-east of the PIRDP area (see Figure 3.6).



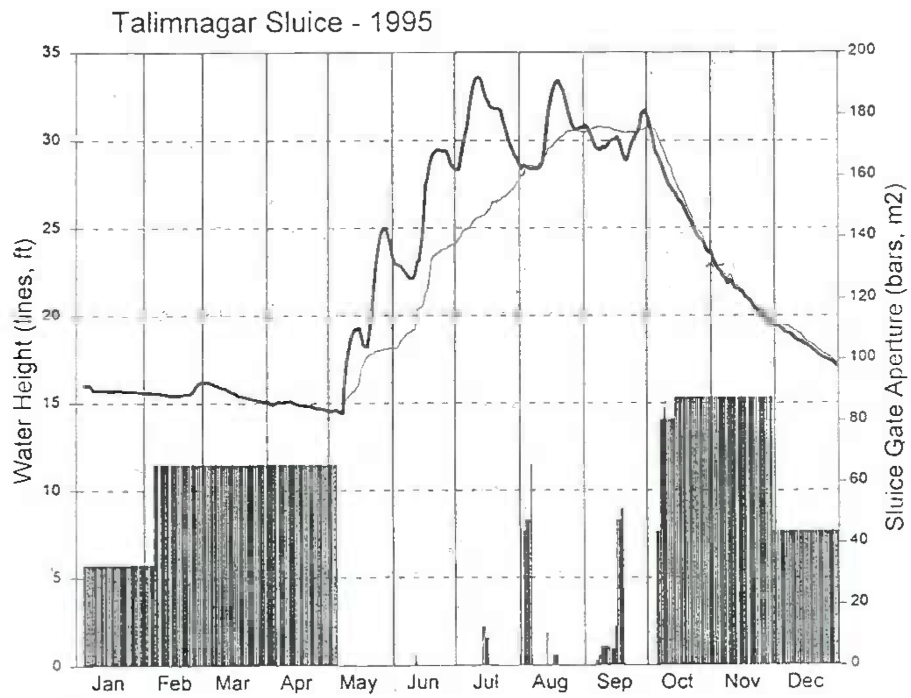


Figure 4.6 Daily water heights at the Bangladeshi study site in 1995, measured inside (thin lines) and outside (thick lines) the Baulikhola and Talimnagar sluice gates; and total apertures of each sluice gate (bars).

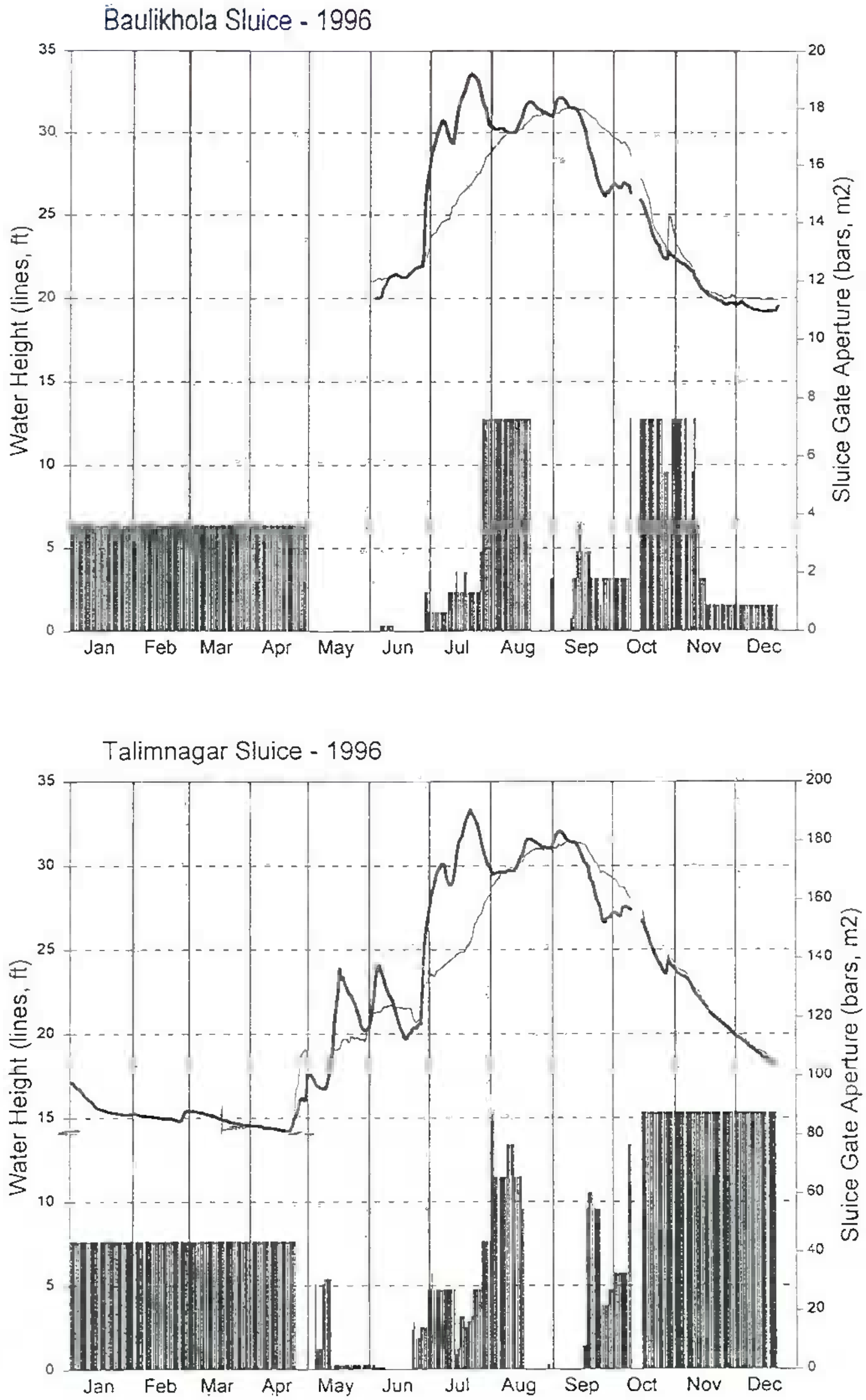


Figure 4.7 Daily water heights at the Bangladeshi study site in 1996, measured inside (thin lines) and outside (thick lines) the Baulikhola and Talimnagar sluice gates; and total apertures of each sluice gate (bars). Data not collected during mid-October 1996.