The Use of Sluice Gates for Stock Enhancement and Diversification of Livelihoods (R8210)

Fisheries Assessment Report

Draft

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Cover Picture: A bagnet set directly behind the Baulikhola sluice gate on the Nataubari canal, Pabna Irrigation and Rural Development Project (PIRDP), Pabna, north-west Bangladesh. **Photo by : Ashley Halls**

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1 Executive Summary

1.1 Background

Flood control, drainage and irrigation (FCDI) schemes exist widely in Bangladesh, typically built to control water levels to improve agricultural production based upon high yielding varieties (HYV) of rice that cannot tolerate rapid inundation or require irrigation. These schemes also provide protection from extreme flood events.

The benefits to agricultural sector significant are often significant but at the cost of fish production and biodiversity within the impounded (modified) floodplains as a consequence of lower rates of recruitment of migratory whitefish (rheophilic) species of fish.

Earlier studies demonstrated that fish can enter FCDI schemes via sluice gates and therefore that sluice gates should therefore be recognised as important structures for maintaining biodiversity and productivity of modified floodplains. However, technical guidelines on how best to operate sluice gates during the hydrological cycle to increase the recruitment of fish remained to be developed.

1.2 Study purpose and report scope

The purpose of this study was to improve understanding of the migrations of fish into FCDI schemes through sluice gates, and to identify important hydrological and operational factors affecting passage success that, when combined with improved knowledge and understanding of the strategies, institutions and the decision-making arrangements for managing water resources on the floodplain, particularly from an agricultural perspective could be used to develop protocols or guidelines for operating sluice gates to improve floodplain dependent livelihoods.

Here we report only the findings of the fish migration studies, highlighting the major hydrological and operational factors affecting passage success through gates and making recommendations concerning the operation of sluice gates and fisheries control measures to improve the recruitment of fish to modified floodplains. Companion reports (Sarder *et al* 2005 and Reid *et al* 2005) describe the broader needs and strategies of the floodplain-dependent stakeholders at the study sites and offer guidelines for improved operation of sluice gates from an integrated floodplain management perspective.

1.3 Study Sites and Methodology

Investigations were undertaken at 3 undershot sluice gates, two located at the Pabna Irrigation and Rural Development Project (PIRDP), Pabna, north-west Bangladesh, and the other at the Compartmentalisation Pilot Project (CPP) in Tangail, north central Bangladesh.

Five routine monitoring programmes were conducted during the rising flood and ebb flow in 2003 and during the early phase of the flood in 2004 to provide data to help understand how and why fish migrations and passage success vary in response to an array of hydrological variables and gate operation (Section 3). An *ad hoc* study was also conducted towards the end of the study designed to estimate the significance of removals of fish migrating in channels towards the gates.

1.4 Hydrology and Sluice Gate Operation

The Talimnagar and Baulikhola gates were intermittently opened during the rising flood period to smooth, delay and diminish water heights inside the PIRDP and to allow water levels to rise smoothly and slowly. The gates were fully opened as soon as water levels outside the PIRDP began to fall (October). The Jugini gate remained open throughout the year with small variations in gate aperture to maintain a constant water height of approximately 10.5m (Section 1). Details of how other hydrological variables behaved are given in Section (4.2).

1.5 Magnitude and Timing of Migrations

Talminagar Gate

- During the first year of sampling (June-November 2003), approximately 5t of fish were caught attempting to migrate into the PIRDP through the Talimnagar sluice gate between June and November 2003 (Section 5.1). (Note that these estimates exclude catches from seines, gillnets, traps and other gears whose orientation in relation to the gate is difficult to determine). Total catches including these gears were considerably greater with significant contributions from *Hilsa ilisha*.

- The bulk (~ 4t) of this catch was caught outside the sluice gate, made up of approximately 2t of fish migrating *passively* towards the gate with the rising flood waters and a further 2t *actively* migrating against the ebb as waters drained out of the scheme. The remainder (~1t) was caught inside the flood control scheme divided almost evenly between actively and passively migrating fish (Section 5.1).

- Active inward migrations against the ebbing (outflowing water) between October and November contributed marginally more (~2.8t) to the overall catch of inwardly migrating fish compared with passive inward migrations (~2.3t) caught during the flood period June-September (Section 5.1).

- During the second year, when sampling was restricted to a much shorter 3 month period (June-August), about 1 t of fish were caught attempting to migrate into the PIRDP through the gate, most (600kg) of which were caught inside the gate. Most (~800kg) were fish migrating passively with the flow of water into the scheme.

Baulikhola

- Fishing activity at Baulikhola was geared to take advantage of fish attempting to migrate out of the flood control scheme rather than those attempting inward migrations (hydrological conditions outside the gate during the rising flood period prevented the use of LN, BN and JT outside the gate). However, during the first year, just over 1t of inwardly migrating fish were caught inside the PIRDP with these three gears compared with nearly 3t of fish caught migrating out of the gate towards the main river (Section 5.1.2).

- During the second year, 700kg of inwardly migrating fish were caught, again, almost all taken inside the gate.

Jugini

- Fishing activities at Jugini focussed upon catching fish passively migrating into the CPP with the rising flood waters using nets set inside the scheme facing towards the gate. During the first year only 300kg of inwardly migrating fish were caught compared to 500kg in year 2 (Section 5.1.3).

- Overall, more fish were found to immigrate into the FCDI schemes than emigrate. The biomass of passively immigrating fish was approximately equal to the biomass of actively immigrating fish. Whilst these two migrations are therefore equally important in terms of biomass, they are not in terms of the numbers of fish (potential recruits).

1.6 Species compositions

- Consistent with earlier work reported by Halls *et al.* (1998), catches of both passively and actively immigrating fish caught *outside* the sluice gates were dominated by *rheophilic whitefish* species that undertake lateral migrations from the main channel to the floodplains to spawn or feed but typically return to the main river during the dry season to avoid the harsh environmental conditions that exist in any remaining floodplain water bodies during this period. These species included *Cirrhinus reba, Cirrhinus mrigala, Catla catla, Hilsa ilisha,* and *Labeo rohita* (Section 5.2).

- Whilst passively immigrating fish caught by interceptory gears set inside the schemes during the flood season also included *whitefish* species in addition to *blackfish* species, suggesting that passage into the scheme via the sluice gates is possible during this period, species belonging to this whitefish group were often conspicuously absent from catches taken by these gears during the ebb when fish must swim against the flow. This suggests that passage during the ebb flow may be more difficult or not possible at all for some species. This is consistent with findings from the mark-recapture study (Section 1.10).

- The proportion of passively immigrating whitefish species caught inside the gate increased significantly at Talimnagar during the second year of sampling when the gate was opened more frequently during the rising flood period (Section 5.2).

- At Jugini, where the gate remained opened and flow was only in an inward direction, a similar mix of species was caught both inside and outside the gate during both sampling years implying high inward passage success during this period.

1.7 Timing of Migrations

- The timing of migrations through the sluice gate was examined on the basis of plots of daily catches recorded from the three main interceptory gears: liftnets, bagnets and jump traps. This approach does not take account of changes to fishing effort or gear catchability and therefore provides only an approximate indication of the relative strength of fish migrations with time.

- At Talimnagar, catches were not recorded outside the gate until mid July, simply because gears were not set in this location until then. Thereafter, catches increased rapidly, reaching a peak in October as was waters began to ebb. Catches were recorded inside the gate from June onwards with peak catches also recorded in October. At Baulikhola, virtually no catches were taken outside during the rising water period because gears could not be set in this location because of the adverse hydrological conditions. Catches taken inside were highly variable with little discernable pattern. Catches at the Jugini gate showed considerable variation with little discernable trend (Section 5.3).

1.8 Differences in recruitment potential during the flood and ebb periods.

- Examination of length frequency distributions (Annex A) indicate that fish are significantly larger during the ebb compared to the early flood reflecting rapid growth during between these periods. This implies that the passive migration phase is of more significance in terms of potentially augmenting the number of recruits (the number of 0+ fish) to fisheries inside the flood control scheme compared to the active phase.

- For example, based upon length weight relationships reported by Halls *et al* (1999) and estimates of modal length from length frequency data (Annex A), the mean weight of marbled gobies *Glossogbius giuris* during the early passive migration phase (July) is estimated to be approx 1g (corresponding to a 5cm fish) compared to 8g (for a 10 cm fish) during the active migration phase (October). One tonne of passively migrating fish caught during July would comprise nearly a million individuals, compared to 125,000 individuals during October. In other words, per unit biomass of fish, the numbers of fish migrating during the ebb may be 10 times that migrating during the ebb.

1.9 Reproductive strategies of migrating fish

- Monthly comparisons of the gonadosomatic index (GSI) indicate that the species selected for sampling tend to spawn during the ebb (rising water period), around June or July (Section 6.1) which compares well with results for the same and other species reported by Halls et al (1999).

- Combining available estimates of length at maturity (Lm_{50}) (Section 6.2) with length frequency data (Annex A) indicates that fish passively migrating into the PIRDP via the Talimnagar or Baulikhola gates during the flood period comprise both immature and mature individuals. However, by the time the waters begin to ebb and flow out of the scheme almost all the individuals of sampled species were found to be sexually mature.

1.10 Passage Success and Factors Affecting Passage Success

- The influence of a wide range of hydrological and sluice gate operational factors on passage success through the three sluice gates was examined including sluice gate aperture, current velocity, water pressure, turbulence and volumetric flow.
- Passage success into the flood control schemes via the sluice gates varied from <5% to 100% at Talimnagar and Baulikhola, but was consistently above 40% at Jugini were the sluice gates remained open throughout the study (Section 1).

- Whilst passage success was positively correlated with sluice gate aperture at both Talimnagar and Baulikhola, passage success was found to be significantly dependent ($p<0.05$) upon only the *flow* of water entering the scheme (m^3s^{-1}) as measured inside the scheme. Passage success was found to increase linearly with increasing flow (Section **Error! Reference source not found.**).

- At Jugini, sluice gate aperture was not significant ($p>0.05$) in determining passage success, but then the gate aperture consistently exceeded $7m^2$ without considerable variability (Section 4.2.1). It may be that beyond some threshold, sluice gate aperture becomes unimportant, and that other factors such related to gate aperture such as flow and turbulence become more important. Greater contrast in the data set for this gate may have helped reveal those to be important.

- Passage success at Jugini was found to be significantly dependent ($p<0.05$) upon only the *turbulence* of water measured outside the scheme. Passage success increased as turbulence decreased. A similar but not significant trend ($p>0.05$) was also found at Talimnagar gate (Section **Error! Reference source not found.**).

- Marked fish were released twice during the ebb flood at Talimnagar. The results indicate that whilst a number of fish that were released inside the scheme were re-caught, none of those released outside the scheme were re-caught within the first 7 days and less than 5% were recaptured within three weeks of their release. This would suggest that passage success is currently negligible during the ebb flood even when the gates are often fully open but when flows outwards from the scheme are very high. It is likely that fish are unable to swim against the strong outward flows during this period (Section **Error! Reference source not found.**).

- Differences in species composition caught inside and outside the Talimnagar gate support this conclusion. Whilst a similar group of species were caught inside and outside the gate during the flooding period, during the ebb, several whitefish species (that typically return to the main channel during the dry season) caught outside the gate where conspicuously absent in the catches taken inside the scheme. Similar sets of species were also caught both inside and outside the Baulikhola and Jugini gates during the rising water period (Section 5.2).

- Rheophilic whitefish species were more abundant during the first year of sampling compared to the second. This may reflect the greater frequency at which the gate was opened during the first compared to the second year of sampling (Section 4.2.1) and/or differences in the duration of the sampling period.

- Examination of the sampled size structure of migrating fish suggests that passage success is independent of fish size.

1.11 Conclusions and recommendations

- This study supports the conclusion of earlier workers that fish can successfully migrate through sluice gates. Sluice gates should therefore be recognised as important structures for improving the recruitment of fish to modified floodplains within FCDIs.

- Fish attempt to migrate into FCDIs throughout the year. Most immigrating species are rheophilic whitefish including prized Indian major carp species.

- During the early flood (June-July) immigrating fish largely comprise small juvenile fish but are also accompanied by sexually mature individuals that have either recently spawned or will spawn imminently.

- So **when** and **how** should sluice gates be operated during the hydrological cycle?

When?

- Per unit biomass, the numbers of fish migrating during the early flood may be 10 times greater than during the ebb. So while, in terms of weight, catches of fish during the early flood appear small, they are very significant in terms of the numbers of potential recruits that could enter flood control schemes.

- The reproductive studies showed that fish spawn in May-July before ebb (Section 6.1). Sluice gates should be operated to ensure fish can enter schemes during the rising flood period *before* they spawn to maximise recruitment.

- Few (if any) fish appear able to penetrate the sluice gates during ebb flow period (Section 8.2) apparently because current speeds exceed their max swimming speeds in most cases (Section 8.3). During the flood period however, fish can passively migrate with in-flowing current and pass apparently unhindered through the gates (ie up to 100% passage success) in some cases.

- The main conclusion we can draw from this evidence is therefore that **sluice gate management practices during the rising flood are likely to have the greatest positive impact.**

- Opening sluice gates earlier than current practice would also provide more irrigation water early in the year. This would help to reduce the pressure that is being increasing placed upon dry season water resources for the purposes of *boro* crop irrigation (see Shanker *et al.* 2004).

How?

Sluice gate managers should aim to:

1. **Maximise the flow of water (volume of water per unit time) into the flood control scheme during the rising flood period.** In effect, managers should attempt to maximise the transport of water (and therefore fish) through the gates (Section 8.2).

2. **Maximise the frequency of gate openings.** Anecdotal evidence presented here and reported by Hoggarth et al (1999) suggests that both biodiversity and fish production benefits from more frequent gate openings, particularly during the rising flood period (Section 1.6). Monitoring catch rates (biomass indices) of immigrating fish outside sluice gates to determine the best times to open gates during the rising flood period is not recommended because these catch rates will, themselves, be dependent upon the sluice gate operation (Section 7.2). Procedures therefore need to be developed to provide guidance on the timing of gate opening possibly based upon monitoring fish abundance in main channel including the *savar* net fishery.

3. **Minimise the turbulence of water outside the gate.** In some cases, turbulence appears to act as an obstacle to the induction and smooth passage of fish through the

gate (Section 8.2). The advice from hydrologists or engineers should be sought on how best to operate gates to minimise turbulence.

4. **Ensure that ebb flow velocities do not exceed the maximum sustainable swimming capacities of fish**. These velocities can be easily calculated from empirical formulae using estimates of the mean length and weight of sampled fish immigrating during the ebb flow period (Section 8.3).

5. **Attempt to create ebb flows that attract the most fish to towards the sluice gate**. These optimal attraction velocities can be easily estimated by sampling liftnet catch rates and corresponding water velocity estimates during the ebb flow period (Section 8.4.1).

6. **Control fishing activities along channels connecting the gate to the main rivers.** With more than 50% of fish potentially being caught before they even reach the entrance of sluice gates in some cases, controlling fishing activities along channels connecting gates to main rivers is likely to be equally, if not more, important as fine tuning sluice gate operations, particularly for gates which typically remain are permanently open like the Jugini (Section 9.3). Such interventions might offer a first step towards improving the recruitment of fish to modified floodplains that is acceptable to farmers and other stakeholders who might be disadvantaged by increased flows of water into flood control schemes during the rising flood period.

- Closing the fishery in channels connecting sluice gates during the flood period should also benefit the local fishery. Activities during this period exploit sexually immature fish that are still growing rapidly. Reducing the effort during this period could potentially increase the size of spawning stocks thereby improving overall yield, as well as yield-per-recruit both inside and outside flood control schemes.

- Fishing activity along these channels might be permitted to resume during the ebb flood when (i) passage success through gates into flood control schemes such as the PIRDP appears insignificant (Section 1.3), (ii) most fish have reached sexual maturity (Section 1.4), (iii) and seasonal rates of growth have slowed (Annex A and Halls *et al.*, 1999).

1.12 Recommendations for further work

- More tagging studies of the type described here are required particularly during the ebb flood period to confirm the extremely poor rates of passage success observed during this period. Further releases during the flood period accompanied by hydrological measurements might also help to further elucidate the relationship between passage success and other hydrological variables.

- Guidance needs to be developed on the timing of gate openings during the rising flood period when pressure to keep the gates closed is likely to be most intense. Brief but regular opening might be possible, the timing of which guided by abundance monitoring programmes in the main channel including the *savar* net fishery.

2 Introduction

2.1 Background

Simple but extensive flood control schemes, polders or impoundments have been constructed widely in Bangladesh and elsewhere to protect agricultural land against the effects of extreme flooding. In some parts of Bangladesh, elaborate flood control, drainage and irrigation (FCDI) schemes have also been built, with pumping stations and sluice gates capable of controlling water levels at optimum heights for agricultural production, over much of the year. While such flood control schemes provide significant benefits to the agricultural sector and protect human lives and livelihoods, workers have shown that they may also reduce the productivity of the country's significant floodplain fishery resources (ISPAN 1993; FAP17 1995) upon which millions depend for their income and major animal protein source. The agriculture and fisheries sectors must now compete to control the availability of water on the floodplain to meet their often-conflicting requirements (Shanker *et al.* 2005).

Halls *et al* (1999) reported reductions in annual fish yields of up to 50%. Flood control schemes also impact significantly on species assemblages caught within modified floodplains. Halls *et al* (1998) found that up to 25 species were absent or less abundant inside FCDI schemes compared to outside. The majority of these species were found to be conspicuous members of the highly prized *whitefish* category. These species typically undertake lateral migrations from the main channel to the floodplain to spawn and feed during the flood season, but return to the main channel before the onset of the dry season to avoid the harsh environmental conditions that exist in residual dry season water bodies. Evidence presented by Halls *et al* (1999 and 2001) indicates that obstructed migrations of whitefish species are largely responsible for the diminished floodplain fishery yields inside FCDI schemes.

Tagging and migration studies reported by Hoggarth *et al* (1999) and Halls *et al* (1998) have demonstrated that fish can enter FCDI schemes through sluice gates throughout the hydrological cycle and therefore they should be recognised as important structures for maintaining biodiversity and productivity of modified floodplains. Whilst these workers provided anecdotal evidence that species richness and productivity increases when sluice gates are opened more frequently during the rising flood period, guidelines on how best to operate sluice gates during the annual hydrological cycle to maximise the recruitment or the passage of fish through them to modified floodplains remain to be developed.

Effective and sustainable implementation of such guidelines requires that they take account of the needs and interests not of only fishers, but also other stakeholders dependent upon the floodplains for their livelihoods, particularly farmers.

Rice production, increasingly concentrated in the Rabi (winter dry season), characterises the main productive use of floodplain lands. Traditionally, lower elevation land, including beels (perennially flooded floodplain waterbodies), did not come under cultivation and provided habitat for over wintering fish that would spawn with the arrival of the first rains at the end of the Rabi dry season (Ashar – May–June), ensuring adequate fish 'recruitment' for the coming hydrological year. Over the last two decades, however, this habitat has been rapidly eroded as even the lowest lying lands are often drained after flood drawdown (Poush – November–December) and planted to high-yielding Boro production. This expansion of irrigated Boro has placed great demands on dry season water sources, whilst simultaneously encouraging delayed and controlled flooding inside FCDIs through sluice gates. These issues are examined further in accompanying reports (see Section 2.2).

2.2 Study Purpose and Report Scope

The purpose of this study was to improve understanding of the migrations of fish into FCDI schemes through sluice gates, and to identify important hydrological and operational factors affecting passage success that, when combined with improved knowledge and understanding of the livelihood strategies, and the institutions and the decision-making arrangements that exist for managing water resources on the floodplain, particularly from an agricultural perspective, could be used to develop protocols or guidelines for operating sluice gates to improve floodplain dependent livelihoods.

Here we report only the findings of the fish migration studies, highlighting the major hydrological and operational factors affecting passage success through gates and make recommendations concerning the operation of sluice gates and fisheries control measures to improve the recruitment of fish to modified floodplains. The floodplain dependent livelihood strategies, together with the institutions and decision-making arrangements for controlling and managing water resources on the floodplain at the study sites are described in a companion study by Sarder *et al* (2005). The overall study conclusions, together with the guidelines for the improved operation of sluice gates are reported by Reid *et al* (2005).

2.3 Research Study Sites

The Fisheries Assessment focussed upon three sluice gates. Two, the Talimnagar and Baulikhola gates control water levels inside the Pabna Irrigation and Rural Development Project (PIRDP) flood control drainage and Irrigation (FCDI) scheme located in Pabna District, NW Bangladesh, at the confluence of the Padma and Jamuna Rivers (Figure 1and Figure 2). The third, the Jugini Gate on the Lohajang River in Tangail, NC Bangladesh, controls inflowing water from the Jamuna river into the Compartmentalisation Pilot Project (CPP) (Figure 1).

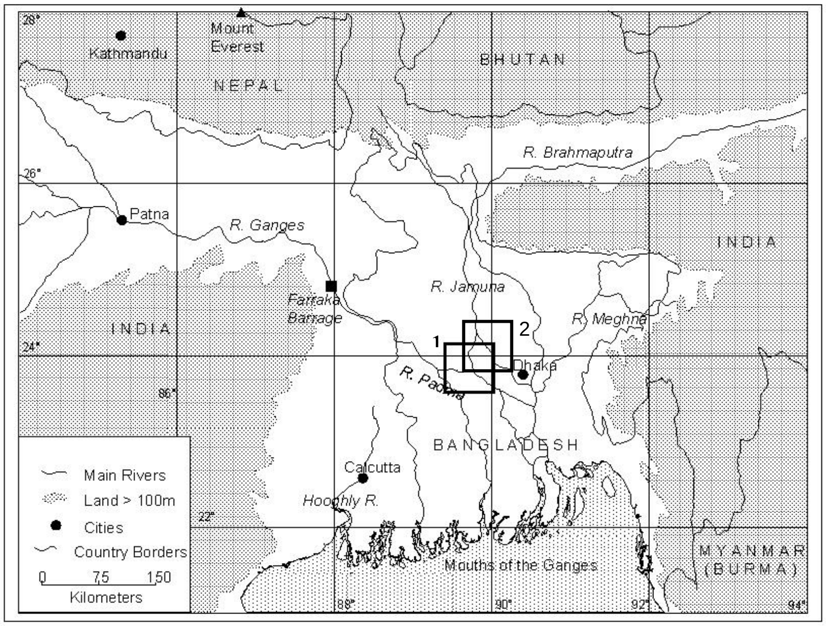

Figure 1 The catchment positions of the two study sites at (1) Pabna and (2) Tangail.

2.3.1 The PIRDP

The PIRDP was constructed during the early 1970s to project local communities from extreme flooding events and to provide controlled irrigation for agriculture. A total area of nearly 2000 km^2 is protected from the floodwaters of the Padma and Jamuna Rivers by an embankment of over 200km in length. Water levels inside the PIRDP are controlled by the Bera and Koitola pumps and by 15 sluice gates, Talimnagar being the largest of these. The gates are infrequently opened during the rising flood period (June-September), but all are often fully opened at the end of the high water season (October) to allow the floodplain waters to drain back to the main river channels. The water level control strategy inside the PIRDP in the context of the agricultural sector is described further by Sarder *et al* (2005).

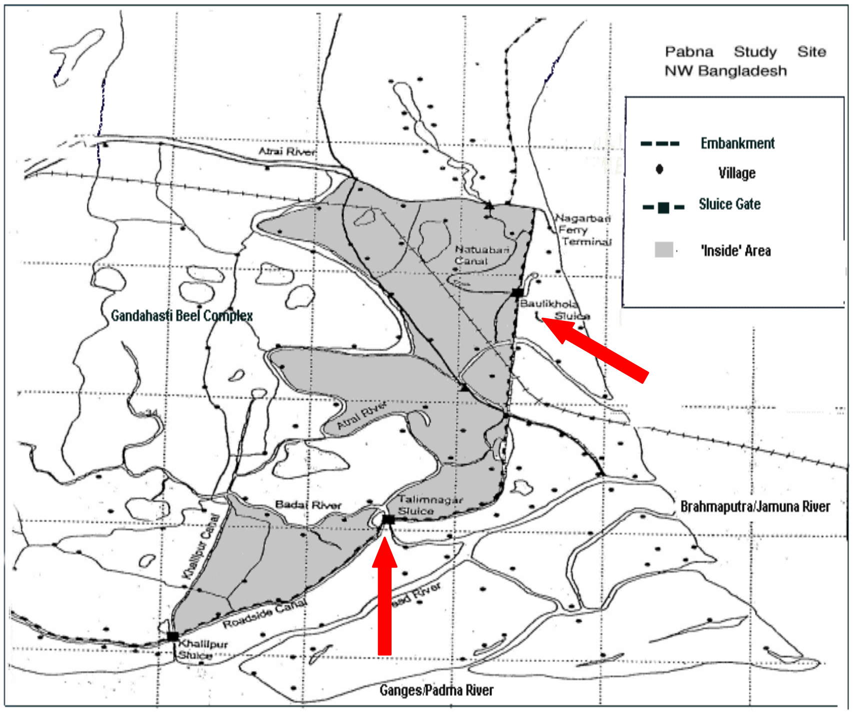

Figure 2 The south east boundary of the Pabna Irrigation and Rural Development Project (PIRDP) flood control scheme, showing the positions of the Talimnagar and Baulikhola sluice gates. Source: MRAG 1997.

2.3.2 The CPP

The CPP was completed in 1991 to provide controlled flooding to 13000 ha of land on the east bank of the Jamuna River. The compartment is divided into 16 sub-compartments or hydrological units, each of which can be managed independently according to the specific hydrological needs of their inhabitants. Water flowing into the compartment via the Lohajang river, a tributary of the Dhaleshwari River, is controlled by the Jugini sluice gate (Figure 3).

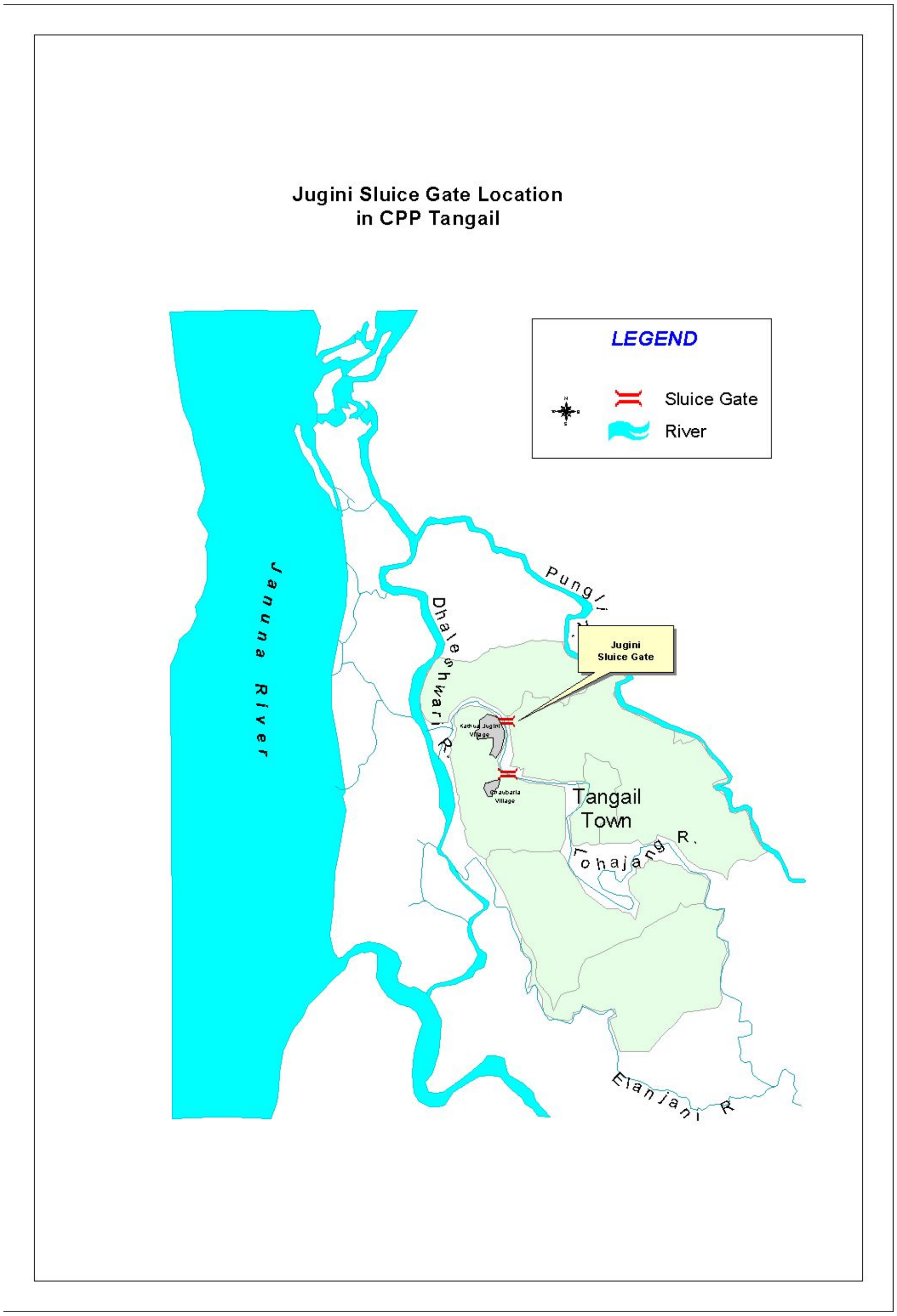

Figure 3 The position of the Jugini gate on the Lohajang River controlling inflowing water into the CPP, Tangail.

3 Data Collection

Data for the investigations described here were collected using two main approaches: (i) routine data collection programmes conducted over a two year period and (ii) a discrete study undertaken in Year 2 of the project to examine depletion effects along the main Badai River channel connecting the Talimnagar sluice gate with the main channel.

Routine data collection programmes

The primary field data for this fisheries component of this project were collected by local field staff under the supervision of MRAG staff. The following data were routinely sampled between June-March during the split year 2003/04 and then again between June and August 2004:

Catch and effort	Daily interviewing of active fishers
Hydrology	Monitoring of hydrological conditions at different frequencies
Length frequency	Bi-monthly sampling from non-selective gears
Biology	Monthly sampling to defined target *n* for defined fish sizes
Mark-release	Opportunistically depending upon fish availability
Mark-recapture	Daily reception of marked fish returned by fishermen.

Training in the data collection was provided by MRAG staff. A supporting field manual entitled: *Fisheries Assessment and Data Collection Methodologies* describing parameter outputs, survey objectives, planning considerations and routine sampling methodologies was provided.

3.1 The Fisheries Database

The data collected in the routine surveys was entered and stored in a specially created Microsoft Access database, installed at the headquarters of BCAS. The database enabled entry of data using rule-checking entry forms. The data is held in seven data tables supported by twelve ‘look-up’ tables. The database also contains a number of queries to download data in the required format for analysis. The database will be made available at www.fmsp.co.uk.

4 Hydrology and Sluice Gate Operations

4.1 Sluice Gate Physical Characteristics

Talimnagar

The Talimnagar Sluice on the Badai River is the largest of all the gates controlling the flow of water into and out of the PIRDP with six 6m-wide undershot gates, having a combined maximum aperture of 65m^2. The base of the gate is 5m above mean sea level (AMSL), below which the river becomes disconnected between the inside and outside sections of the channel.

Baulikhola

The much smaller Baulikhola gate on the Nataubari canal, in contrast, has only four 1.5m-wide gates and a maximum total aperture of 24m^2. Due to the smaller size of the Nataubari canal, the sill of the Baulikhola gate has an altitude of a relatively higher 6.3m. The Nataubari canal dries out completely around the Baulikhola sluice when water levels fall below approximately 6m, though pockets of water remain in the deeper canal sections both inside and outside the PIRDP.

Jugini

The Jugini gate on the Lohajang River also has three 3m wide gates, together with two smaller outer vents or “fish gates” that remain permanently open. The gate has a total maximum aperture of 10m^2. Further details of the gate’s development, design and operation are described by de Graaf *et al* (2001).

4.2 Sluice Gate Operations and Hydrological Conditions

4.2.1 Gate Operations

In 2003, the Talimnagar sluice gate was kept largely closed during the rising flood period, with sporadic, relatively small aperture openings occurring during July and August (Figure 4a). Sluice gates remained closed throughout June and September with the exception of one or two days, when the total gate aperture did not exceed more than 2m^2. During October the sluice gates were progressively opened until all the gates were fully open by the middle of October. The gates remained fully open until the end of November when observations ceased. During the flood of 2004, the gate was opened more frequently during the early flood period, but with apertures rarely reaching 2m^2. The gate was completely closed for most of the August up to the end of the monitoring period (Figure 5a).

In 2003, the Baulikhola gate was operated in a similar manner to Talimnagar during the rising flood phase with sluice gate openings being confined mainly to July and August. A more complex pattern of sluice gate management was employed during the drawdown period with apertures being changed almost continuously between October and December (Figure 4a) During 2004, the gates were opened less frequently in July compared to the first year of monitoring, but the converse was true during the first half of August after which the gates were completely closed for two weeks (Figure 5a). In 2003, the Jugini gate remained open throughout the monitoring period with total aperture reaching a maximum during August and then again in September (Figure 4a). Sluice gate aperture ranged from 7m^2 to approximately 10m^2. During 2004, a very similar pattern of operation emerged. The apparent closure during the first week of July is simply the result of missing data for this period (Figure 5a).

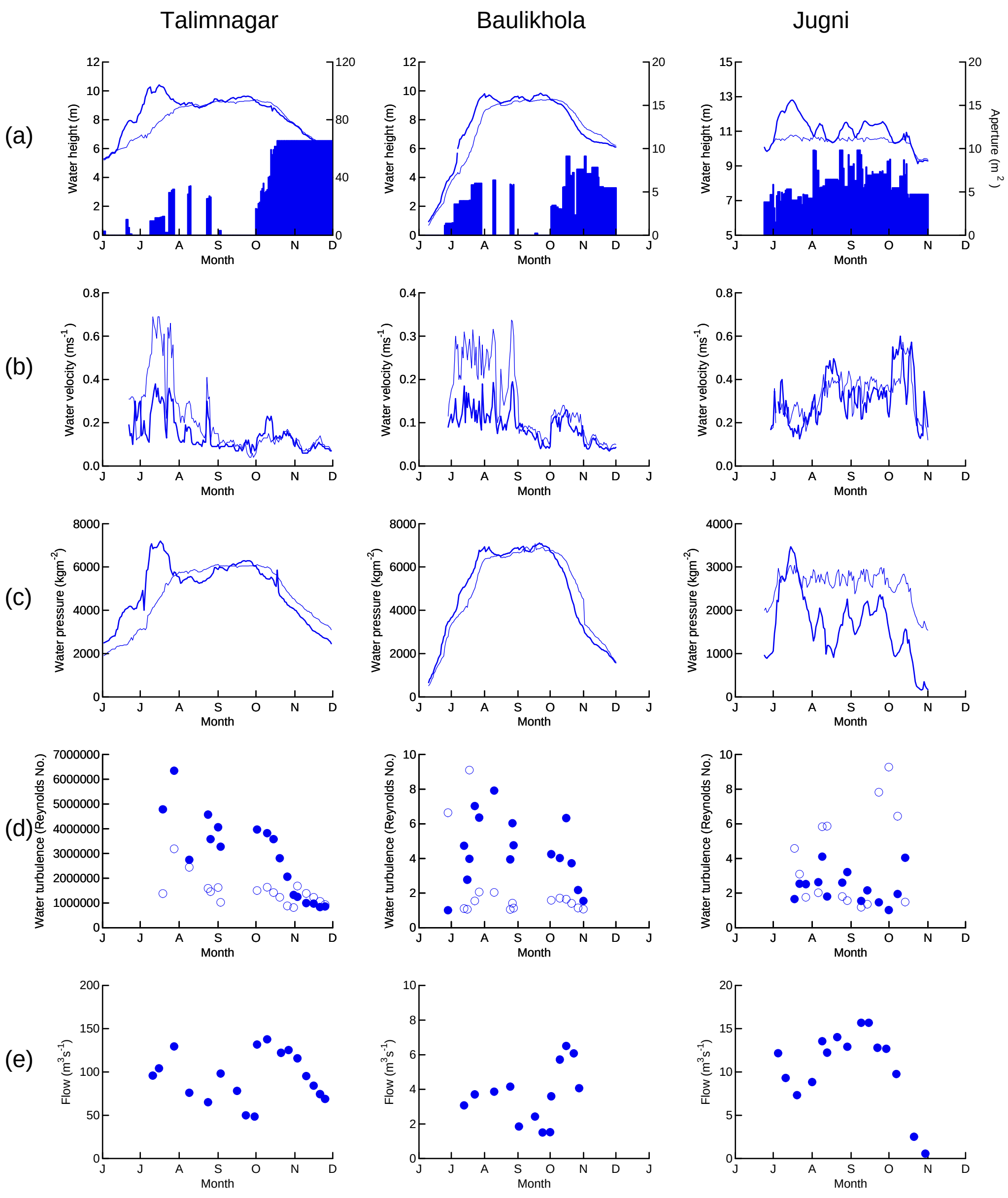

Figure 4 (a) Water levels (bars represent sluice gate apertures); (b) water velocity, (c) water pressure; (d) turbulence and (e) flow measured inside (thin line or filled symbol) and outside (thick line or open symbol) and at the three sluice gates June-November 2003.

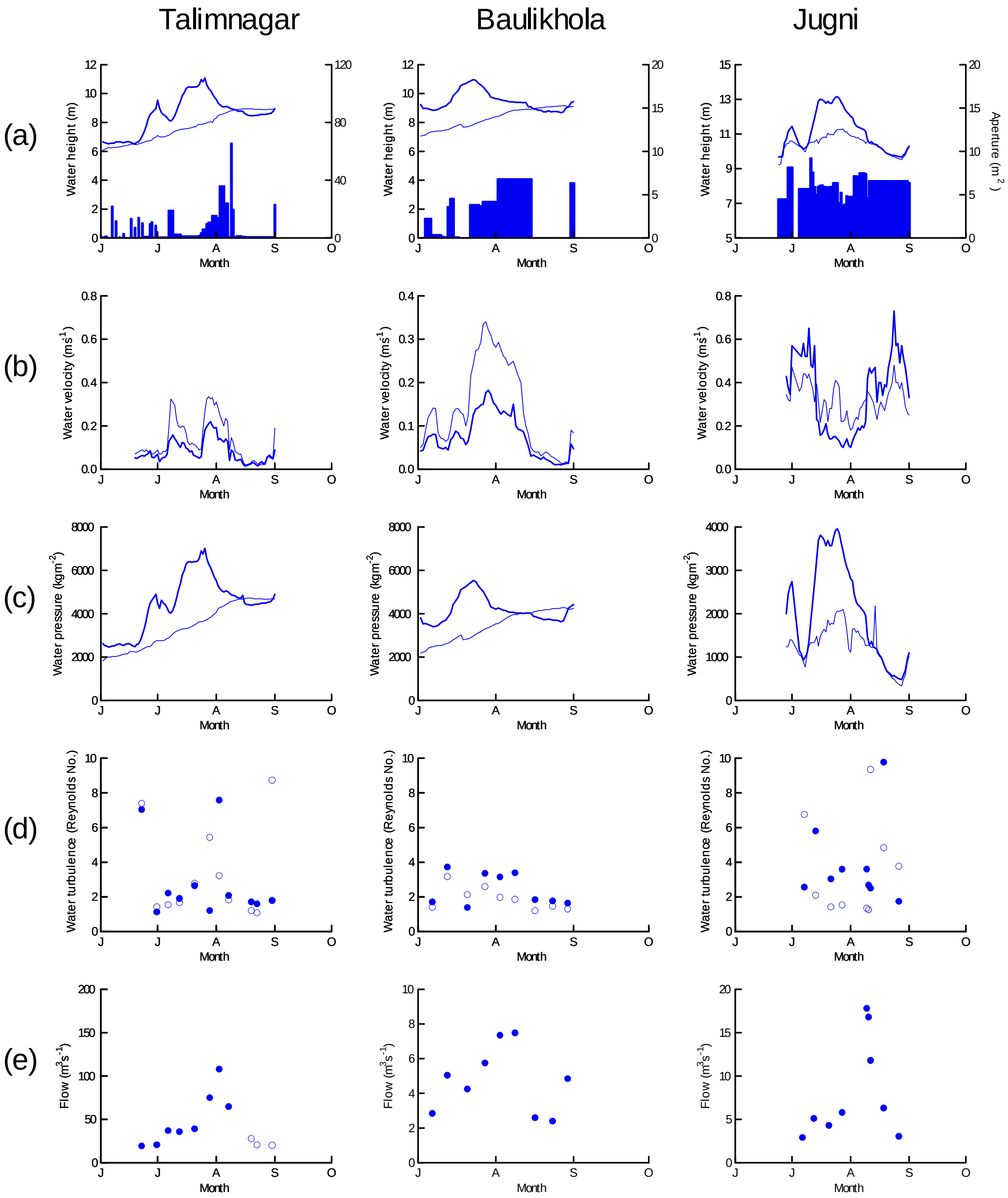

Figure 5 (a) Water levels (bars represent sluice gate apertures); (b) water velocity, (c) water pressure; (d) turbulence and (e) flow measured inside (thin line or filled symbol) and outside (thick line or open symbol) and at the three sluice gates June-Aug 2004.

4.2.2 Water Heights

At Talimnagar, the overall effect of the sluice gate is to delay and smooth the flood curve inside the scheme compared to that outside. The high flood levels between 10m-11m recorded outside the sluice gate, produced by pulses of the Jamuna/Padma rivers, are thus avoided inside, where water levels rose and fell more gradually and smoothly up to a maximum of approximately 9m. After August, water levels inside and outside the scheme were very similar (In 2003, the Jugini gate remained open throughout the monitoring period with total aperture reaching a maximum during August and then again in September (Figure 4a). Sluice gate aperture ranged from $7m^2$ to approximately $10m^2$. During 2004, a very similar pattern of operation emerged. The apparent closure during the first week of July is simply the result of missing data for this period (Figure 5a).

The Baulikhola sluice had a very similar effect on inside water levels, although the outside pulses were less pronounced. From August onwards, water levels inside the scheme were maintained at similar levels to those observed outside (Figure 4a and 5a)

Water levels outside the Jugini gate were more variable but over a narrower range. The sluice was operated in such a way as to maintain a relatively constant water level inside the scheme of approximately 10.5m, particularly during the first year of monitoring. After mid-October in 2003, and August in 2004, levels inside and outside the gate were similar (Figure 4a and 5a).

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4.2.3 Current Velocity

At both Talimnagar and Baulikhola sluice gates, water velocities were almost always higher inside compared to outside, with the highest velocities occurring during the rising water period. Water velocities were however, highly variable throughout the year, with maximum variation also occurring during the rising water period. Water velocities were at their minimum by the end of September in 2003 and by mid-late August in 2004, just prior to the start of the drawdown or *ebb flow* (Figure 4b and 5b).

Water velocities around the Jugini gate exhibited a more complex pattern. Water velocities were at times higher inside compared to outside and at vice versa during other times. In 2003, Water velocities increased in an almost cyclic nature from July to reach a maximum by mid-October before falling rapidly towards the end of October. In 2004, maximum velocities were recorded at the beginning of July and September, with lowest rates occurring during August (Figure 4b and 5b).

4.2.4 Pressure

Pressure is a function of water height and therefore unsurprisingly close correspondence was observed between temporal variations in these the two hydrological variables. Despite higher water levels outside, pressure was however, found to be lower outside the Jugini gate compared to inside (Figure 4c and 5c).

4.2.5 Turbulence

At both Talimnagar and Baulikhola gates, turbulence was generally higher or at least as high inside the gate compared to outside. Turbulence was also highest during the rising water period, declining to a minimum towards the end of the drawdown period. At both gates, the temporal variability closely matched that of water velocity. At Jugini, water turbulence inside the gate generally declined throughout the monitoring period. Outside the gate, the trend was less discernable, with little apparent correspondence with water velocity (Figure 4d and 5d).

4.2.6 Flow

Except for three measurements in August, at Talimnagar, flow was only monitored inside each sluice gate. In all three cases flow patterns were complex reflecting changes to a combination of both water velocity and volume (a function of water height). Generally speaking, at both Talimnagar and Baulikhola during 2003, flow was high at the start of the rising water period, declined towards the end of September and then rose to maximum levels at the start of the drawdown period (October) after which flow begins to fall again. Jugini exhibited a similar pattern, although the initial decline in flow and maximum flows occurred approximately one month earlier. In 2004, flow increased at all gates during July, before each and peak and falling during August (Figure 4e and 5e).

4.2.7 Flow Direction

During 2003, water flowed into the PIRDP through the Talimnagar and Baulikhola gates from June until the end (30th) of September, after which the flow reversed. During 2004, flow at Talimnagar reversed during mid August but remained flowing inwards at Baulikhola until the end of August. In both sampling years, water was observed only to flow into the CPP via the Jugini gate.

5 Magnitude and Timing of Migrations

The timing and magnitude of migrations was examined in terms of the catches of fish taken with interceptory gears positioned inside and outside the sluice gate. Only catches from liftnets (LN), jump traps (JT) and Bagnets (BN) were considered since whilst catches from seine nets (SN) and traps (PT) were significant, the orientation in which theses gears are fished relative to the sluice gate is often difficult to determine (see Figure 6 and Annex A).

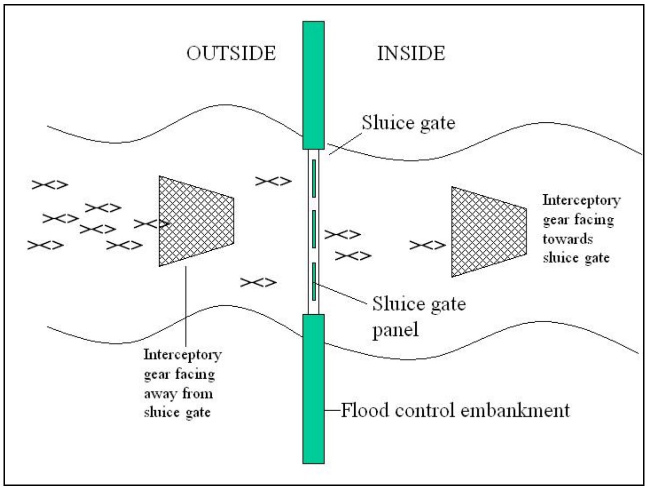

Figure 6 Schematic representation of fish migrations through a flood control sluice gate and relative gear orientations. Note that gear orientation relative to the sluice gate ie facing towards (FT) or facing away (FA) from the sluice gate will vary during the year according to the direction of water flow and fish migrations.

Based upon the catches of fish taken with gears inside and outside, their orientation relative to the sluice gates and the direction of water flow through the sluice gate, four categories of migrations can be identified after Hoggarth *et al* (1999):

Table 1 Summary of migration types through the sluice gates

Type of Migration	Water flow direction	Gear orientation relative to sluice gate (and position ie inside or outside the FCDI).
Passive Inward (passive immigration)	Inward (Flood)	FA (Outside) & FT (Inside)
Active Outward (active emigration)	Inward (Flood)	FT (Outside) & FA (Inside)
Passive Outward (passive emigration)	Outward (Ebb)	FT (Outside) & FA (Inside)
Active Inward (active immigration)	Outward (Ebb)	FA (Outside) & FT (Inside)

5.1 Relative magnitude of migrations

The relative magnitude of fish migrations were examined on the basis of catches recorded only for liftnets, bagnets and jump traps. Catches from other gears (not reported here) were significant but their variable orientation meant that it was difficult to interpret the direction of fish migrations based upon their catches.

5.1.1 Talimnagar Sluice Gate

During the first year of sampling, approximately 5t of fish were caught with liftnets, bagnets and jump traps attempting to migrate through Talimnagar sluice gate between June and November 2003 (Table 2). The bulk (~ 4t) of this catch was caught outside the sluice gate, made up of approximately 2t of fish migrating passively towards the gate with the rising flood waters and a further 2t actively migrating against the ebb as waters drained out of the scheme. The remainder (~1t) was caught inside the flood control scheme divided almost evenly between actively and passively migrating fish. Active inward migrations contributed marginally more (~3t) to the overall catch of inwardly migrating fish compared with passive inward migrations (~2t).

However, examination of length frequency distributions (Annex A) indicate that fish are significantly larger during the ebb compared to the early flood reflecting rapid growth during between these periods. This implies that the passive migration phase is of more significance in terms of potentially augmenting the number of recruits (the number of 0+ fish) to fisheries inside the flood control scheme compared to the active phase.

For example, based upon length weight relationships reported by Halls *et al* (1999) and estimates of modal length from length frequency data (Annex A), the mean weight of marbled gobies *Glossogbius giuris* during the early passive migration phase (July) is estimated to be approx 1g (corresponding to a 5cm fish) compared to 8g (for a 10 cm fish) during the active migration phase (October). One tonne of passively migrating fish caught during July would comprise nearly a million individuals, compared to 125,000 individuals during October. In other words, per unit biomass of fish, the numbers of fish migrating during the ebb may be 10 times that migrating during the ebb.

Table 2 Relative magnitude of migrations through Talimnagar sluice gate measured in terms of catches recorded for LN, BN and JT between June and November 2003.

			Recorded Catch (kg)		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	06 June - 30 Sept	Inward	1827	501	2328
Active Outward	06 June - 30 Sept	Inward	660	106	766
Passive Outward	01 Oct - 28 Nov	Outward	1700	99	1799
Active Inward	01 Oct - 28 Nov	Outward	2346	483	2829
Total Inward	06 June - 28 Nov	Inward & Outward	4173	984	5157
Total Outward	06 June - 28 Nov	Inward & Outward	2360	205	2565
					7722

During the second year, when sampling was restricted to a much shorter 3 month period (June-August), about 1 t of fish were caught attempting to migrate into the PIRDP through the gate, most (600kg) of which were caught inside the gate. Most (~800kg) were fish migrating passively with the flow of water into the scheme. Only approximately 400 kg of fish were caught attempting to migrate out of the scheme, the bulk caught outside (Table 3).

Table 3 Relative magnitude of migrations through Talimnagar sluice gate measured in terms of catches recorded for LN, BN and JT between June and August 2004.

			Recorded Catch (kg)		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	01 June - 11 Aug	Inward	269	512	781
Active Outward	01 June - 11 Aug	Inward	145	11	156
Passive Outward	12 Aug - 31 Aug	Outward	184	70	254
Active Inward	12 Aug - 31 Aug	Outward	64	113	177
Total Inward	01 June - 31 Aug	Inward & Outward	333	625	958
Total Outward	01 June - 31 Aug	Inward & Outward	329	81	410
					1368

5.1.2 Baulikhola Sluice Gate

Fishing activity at Baulikhola was geared to take advantage of fish attempting to migrate out of the flood control scheme rather than those attempting inward migrations. Hydrological conditions outside the gate during the rising flood period prevented the use of LN, BN and JT outside the gate. In the first year, just over 1t of inwardly migrating fish were caught with these three gears at this site compared with nearly 3t of fish caught migrating out of the gate towards the main river. Almost all the catch of inwardly migrating fish were caught during the passive migration phase by gears set inside the gate (Table 4).

Table 4 Relative magnitude of migrations through Baulikhola sluice gate measured in terms of catches recorded for LN, BN and JT between June and November 2003.

			Recorded Catch (kg)		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	23 July - 30 Sept	Inward	0	979	979
Active Outward	23 July - 30 Sept	Inward	18	1485	1503
Passive Outward	01 Oct – 09 Nov	Outward	232	1263	1495
Active Inward	01 Oct – 09 Nov	Outward	135	98	233
Total Inward	23 July – 09 Nov	Inward & Outward	135	1077	1212
Total Outward	23 July - 09 Nov	Inward & Outward	250	2748	2998
					4210

Sampling in the second year did cover the ebb flood period, as so no active inward or passive outward migrations were recorded. A similar quantity of fish was caught passively migrating into the scheme as actively migrating outwards during the three month period, almost all caught inside the PIRDP (Table 5).

Table 5 Relative magnitude of migrations through Baulikhola sluice gate measured in terms of catches recorded for LN, BN and JT between June and August 2004.

			Recorded Catch (kg)		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	26 June - 31 Aug	Inward	28	593	
Active Outward	26 June - 31 Aug	Inward	-	771	
Total Inward	26 June - 31 Aug	Inward	28	593	621
Total Outward	26 June - 31 Aug	Inward	-	771	771

5.1.3 Jugini Sluice Gate

Catch monitoring during the first year of sampling at this gate did not begin until mid July. This along with the small size of the river flowing through the gate accounts for the relatively small catches taken at this site. The river flows only inwards at this site and therefore no passive outward or active inward migrations were recorded. Similar to Baulikhola, passive inward migrations of fish caught inside the gate (~300kg) made up the bulk of the total catch (~400kg) at this site. Only 50kg of fish were caught outside the gate actively migrating against the inward flow (Table 6).

Table 6 Relative magnitude of migrations through Jugini sluice gate measured in terms of catches recorded for LN, BN and JT between June and November 2003.

			Recorded Catch (kg)c		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	15 July –16 Nov	Inward	46	295	341
Active Outward	15 July –16 Nov	Inward	55	0	55
Passive Outward		Outward	0	0	0
Active Inward		Outward	0	0	0
Total Inward	15 July –16 Nov	Inward & Outward	46	295	341
Total Outward	15 July –16 Nov	Inward & Outward	55	0	55
					396

In spite of the shorter monitoring period, the total catch in year 2 was marginally greater than year 1. Again all but a few kilograms of fish were caught passively migrating into the CPP, the bulk of which was caught inside the gate.

Table 7 Relative magnitude of migrations through Jugini sluice gate measured in terms of catches recorded for LN, BN and JT between June and August 2004.

			Recorded Catch (kg)c		
Type of Migration	**Timing**	**Flow Direction**	**Outside**	**Inside**	**Total**
Passive Inward	01 June - 31 Aug	Inward	50	485	535
Active Outward	01 June - 31 Aug	Inward	1	3	4
Total Inward	01 June - 31 Aug	Inward & Outward	50	485	535
Total Outward	01 June - 31 Aug	Inward & Outward	1	3	4
					539

Given the focus of this study, the remainder of this section focuses just on the *inward migrations* of fish recorded outside and inside the three sluice gates.

5.2 Species Composition of Inward Migrations

The species compositions of the catches of fish attempting to migrate ***into*** the flood control schemes via the three gates both actively and passively in year 1 are summarised in Figure 7 below.

At Talimnagar, catches both inside and outside the gate during the passive inward migration phase contained a similar set of species during year 1, but their relative contribution to the total catch within each location differed markedly (Figure 7). For example, catches recorded outside the gate were dominated by rheophilic *whitefish* species including *Cirrhinus reba,* shrimp species*, Cirrhinus mrigala, Catla catla, Hilsa ilisha,* and *Labeo rohita.* Inside the gate, catches of inwardly migrating fish comprised mainly small species including shrimp, *Puntius sophore, Glossogobius giuiris*, *Chanda nama, and Channa punctatus* – a species often regarded as a floodplain-resident *blackfish.* Several species caught outside the gate albeit in relatively small quantities were caught in extremely small numbers (effectively absent) inside the gate including the rheophilic *whitefish*: *Mystus Cavasius, Mystus aor* and *C. catla.* It is difficult to say whether these differences reflect differences in passage success through the gate or simply differences in the relative susceptibility of species to capture (catchability) in the two locations.

Catches recorded outside during the ebb flood exploiting active migrations towards the gate (active immigrations) largely comprised a mixture of black and whitefish: *Puntius sophore*, *Wallago attu, Puntius ticto,* shrimp*, L. rohita, Chanda nama* and *C. punctatus.* Inside the gate, the catch composition of actively migrating fish was dominated by *W. attu, C. reba, P. sophore*, shrimp, *P. ticto, L. rohita* and *C. nama.* Notably absent species inside the gate but present in catches outside the gate include *M. cavasius, Mastacembelus armatus, Macrognathus aculeastus* and *G. girius* – all rheophilic *whitefish* species.

During the rising flood period during year 2, no species caught outside passively migrating towards the Talimnagar gate were absent from catches taken inside the gate. Indeed catches taken inside were often larger than those taken outside. Differences in fishing effort may be partly responsible for this, but it may also suggest that all species attempting to passively migrate into the PIRDP during this time were successful (Figure 8). This apparent improved passage success compared to year 1 may reflect the fact that the gates were open more frequently during this period (Figure 4a and Figure 5a).

The small quantity of fish actively immigrating into the PIRDP during the second half of August when the flow had reversed also contained a similar set of species both inside and outside the gate. However, the gate was closed throughout this period (Figure 5a) suggesting that the species caught inside the gate may have passively immigrated into the scheme earlier in the month when the gates were open and water was still flowing into the scheme.

Hydrological conditions outside the Baulikhola gate meant that LN, BN or JT gears could not be operated at this location during the rising flood period. Passive migrations of fish caught inside the gate (passive immigrations) in year 1 were dominated by those of *C. reba, L. bata, Botia Dario*, shrimp, *C. catla, C. mrigala, and L. rohita* (Figure 7). Actively migrating fish caught outside the gate albeit in very small quantities (active immigrations) comprised mainly *L. rohita, C. reba, C .nama and P. sophore.* The catch composition of actively migrating fish caught inside the gate also differed, comprising mainly *P. sophore*, *C. reba,* and *C .nama.*

During year 2, catches were dominated by *G. giuris*, shrimp, *P. sophore*, *A. coila*, *C. nama* and *C. reba*. The greater abundance of rheophilic whitefish in the catch during the first year of sampling may reflect the greater frequency at which the gate was opened during the first compared to the second year of sampling (Section 4.2.1) and/or the longer sampling period.

No active migrations were recorded since the sampling period in year 2 coincided only with the rising flood period.

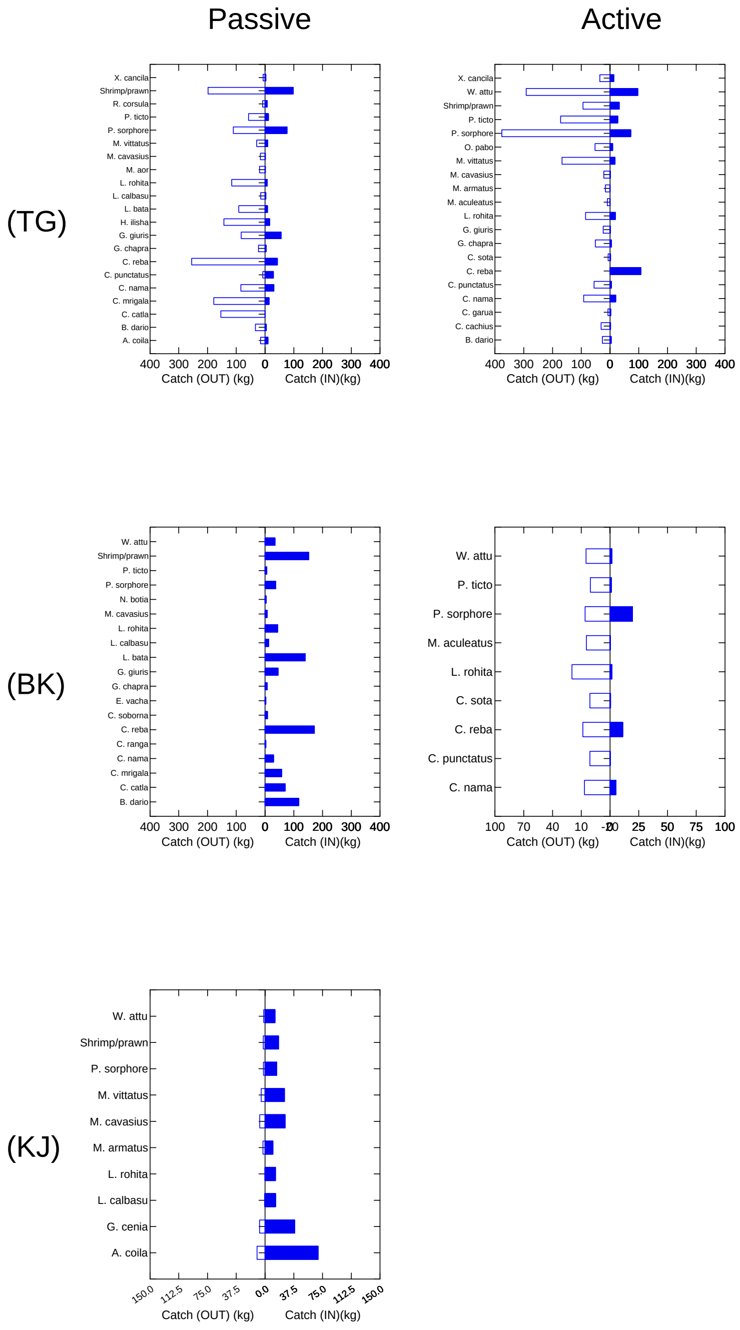

Figure 7 Species composition of *inward* active and passive migrations caught outside (open bars) and inside (filled bars) the three sluice gates with interceptory gears during the first year of sampling (June-November 2003). Data for Jugini gate (KJ) also includes catches from

Bagnets. Species contributing less than 10kg to the total catch of inwardly migrating fish are not shown.

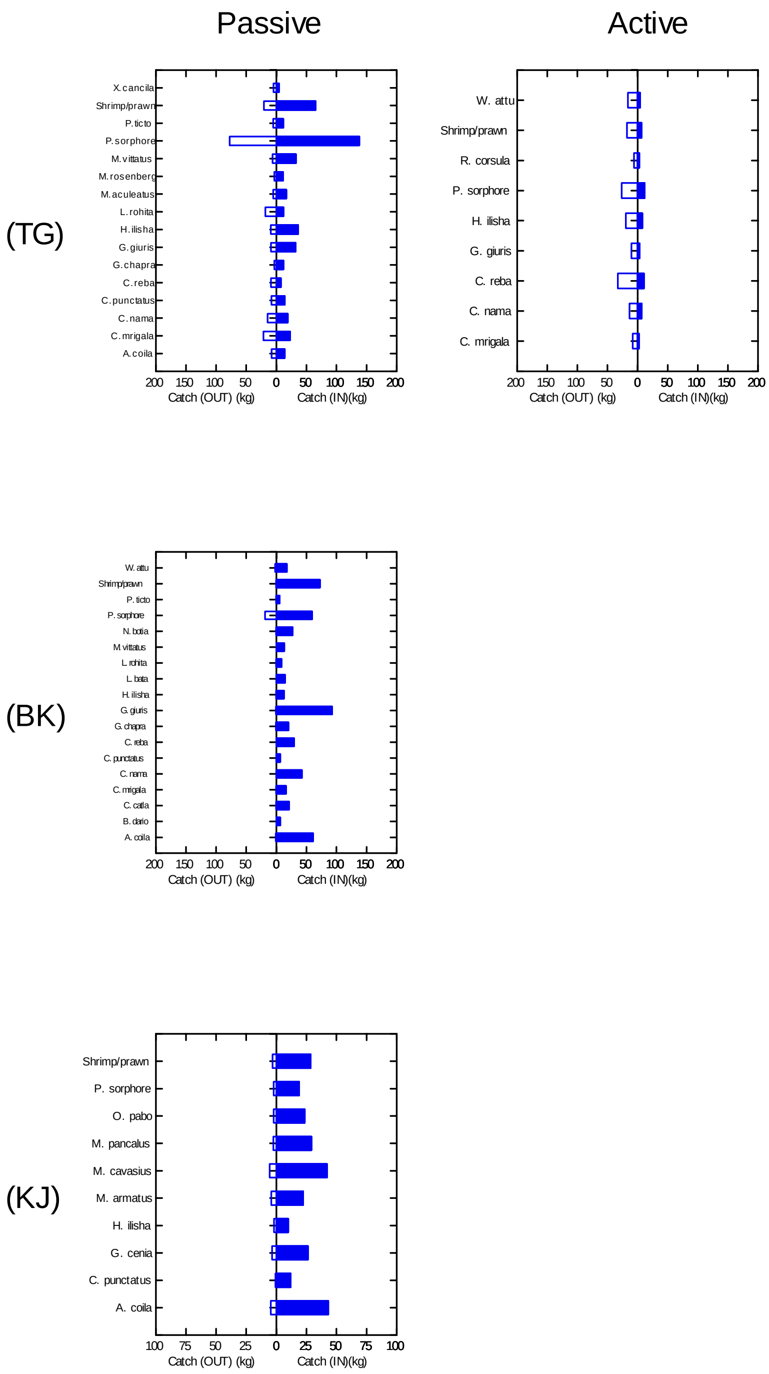

Figure 8 Species composition of *inward* active and passive migrations caught outside (open bars) and inside (filled bars) the three sluice gates with interceptory gears during the second year of sampling (June-August 2004). Species contributing less than 10kg to the total catch of inwardly migrating fish are not shown.

At Jugini, passive inward migrations were also dominated by whitefish in both sampling years although the species mix differed markedly from those caught around the Talimnagar and Baulikhola gates reflecting the regional differences in the species assemblages (Halls *et al* 1998). Similarly, there was little fishing activity outside the gate during the rising flood period in both years (Figure 7 and Figure 8).

A similar mix of species was caught outside the gate s during both sampling years comprising mainly *Ailia coila, G. cenia, M. pancalus, M. cavasius*, and *M. vittatus,* shrimp and *O. padma*. The same species tended to also dominate the catches taken inside the gate implying high inward passage success during this period (Figure 7 and Figure 8).

5.3 Timing of Inward Migrations

The timing of migrations through the sluice gate was examined on the basis of plots of daily catches recorded from the three main interceptory gears: liftnets, bagnets and jump traps. This approach does not take account of changes to fishing effort or gear catchability and therefore provides only an approximate indication of the relative strength of fish migrations with time.

5.3.1 Talimnagar

Passive inward migrations (Year 1: July-September, Year 2: June-mid August)

During year 1, fish passively migrating towards the gate were not recorded in catches outside the gate until the middle of July (Figure 9b). This is likely to reflect the absence of any fishing activity in this location with the three gear types as opposed to the absence of fish migrations during this period. During this month, catches comprised mainly of *P. sophore*, shrimp*, L. rohita, C. catla, C. nama, and G. giuris* (Figure 11). Examination of the available length frequency data for this period and location suggest that fish caught during this period are mainly juvenile young of the year with a fork-length of between 3-7cm (Figure 33; Figure 35; Figure 36).

These passive fish migrations towards this gate reflected in the catches taken outside the scheme showed an overall increase during August and September. The observed peaks in catches during the first half of September were largely attributable to migrations of carp species including *C. mrigala, C. reba, L. bata* and *L. rohita,* and shrimp (Figure 11). Most of the fish caught during this period were larger with a fork length of between 6-12cm (Figure 35; Figure 37).

During year 2, passively immigrating fish were caught outside the gate from June onwards with clear peaks in late June and July coinciding with rapidly changing water height and the frequency and aperture of gate openings (Figure 10b). The peaked catches in June were largely attributable to inwardly migrating *P. sophore* and shrimp, followed by *C. mrigala* and *L. rohita* (Figure 12).

Passive inward migrations of fish caught ***inside*** the gate were recorded as early as June in year 1, thereafter remaining highly variable during the remaining flood period (Figure 9c). The peak observed in late June was largely attributable to migrations of small, young-of-the-year *G. giuris, Puntius* and shrimp species (Figure 33; Figure 36). The bi-modality of the length frequency distributions sampled from gears inside and facing towards the gate does however suggests that adult *P. sophore* and *G. giuris* are also migrate passively through the gate as early as June.

During year 2, the daily catches of passively immigrating fish caught *inside* the gate followed the same pattern as those caught outside (Figure 10c). The pronounced peak in late July was largely attributable to large catches of *P. sophore* (Figure 14).

Active inward migrations (Year 1: October-November, Year 2: mid-end of August)
During year 1, significant active migrations towards the gate began in October when the sluice gates were reopened and the flood-waters began to ebb (Figure 9b). Daily catches of inwardly migrating whitefish species caught *outside* the gate: *C. catla, C. nama, C. reba, L. rohita and P. sophore* all peaked during this month (Figure 11). Examination of the length-frequency distributions (Figure 33; Figure 37) combined with estimates of length at maturity (Section 6.2) suggest that these migrations comprised individuals that were sexually mature.

Active inward migrations of fish caught *inside* the gate from October onwards followed a similar pattern of daily variability as those recorded by gears set outside the gate (Figure 9b &c). These active inward migrations were mostly attributable to *C. reba, W. attu, P. sophore* and shrimp species. Examination of the length frequency data show that for some of these species *vis-à-vis L. rohita* and *C. reba*, a wide size range of fish migrate at this time.

Examination of the length-frequency data for this gate also reveals that with the exception of *L. rohita* sampled during November where fish caught inside are larger, there is little evidence of any difference in the modal size of inwardly migrating fish outside and inside the gate suggesting that passage success is independent of fish size.

During year 2, the pattern of daily catches of actively immigrating fish caught inside and outside the gate outside was very similar (Figure 10b & c) mostly comprising *P. sophore* (Figure 12 and Figure 14).

5.3.2 Baulikhola Sluice Gate

Passive Inward (Year 1: August and September, Year 2: July and August)
In year 1, due to the prevailing hydrological conditions, no gears could be set ***outside*** the Baulikhola gate during the rising flood period to capture fish attempting to passively migrate through the gate (Figure 9c).

Passive inward migrations of fish caught ***inside*** the gate in year 1 were not recorded until the end of July/beginning of August thereafter remaining highly variable during the remaining flood period (Figure 9c). The peak catches observed during the first half of September were largely attributable to migrations of mostly Indian major carps: *C. catla, L. bata, C. reba, L. rohita, B. dario, C. mrigala* and shrimp. Examination of the available length-frequency data (Figure 38; Figure 39; Figure 40; Figure 41) indicates that a wide size range of fish migrate at this time probably comprising both young of the year and fish of age 1+ or greater especially in the cases of *L. rohita* and *C. reba* (see also Section 6.2).

Due to the patchiness of the data set, no comparisons of length frequency data sampled from gears located outside and facing away from the gate, and gears located inside and facing towards the gate could be made to test the hypothesis that passage success is size dependent.

During year 2 almost all fish believed to be passively immigrating were caught inside the gate during August (Figure 10b & c) comprising a number of different species (Figure 18)

Active Inward (Year 1: Oct-Nov; Year 2: no observations)
During year 1, liftnets were first deployed outside the gate in October to catch fish attempting to actively migrate into the PIRDP against the ebb flood after the gates had been re-opened (Figure 9b). Catches of actively migrating fish reached a peak early in October largely comprising *L. rohita, N. notopterus* and *C. catla* (Figure 15).

5.3.3 Jugini

Passive inward Year 1 and 2.
The majority of inwardly migrating fish were caught inside compared to outside the Jugini sluice gate during both sampling years, but with little difference in daily trends (Figure 9 and Figure 10). In the first year of sampling, migrations were recorded from mid July followed by five distinct migration pulses. These five pulses were evident in the catches (migrations) of several species landed at the gate including *Gagata cenia, W. attu,* and shrimp (Figure 21). The sparse and patchy length frequency data for this site (Figure 43 Figure 44 Figure 45 Figure 46) provide no evidence to support the hypothesis that passage success is size dependent. Inwardly migrating juvenile fish dominated the catches during the rising flood although adult fish were also present.

During the second year catches peaked in early and late July and then oscillated during the remaining sampling period. These catches comprised a number of different species (Figure 20 and Figure 22).

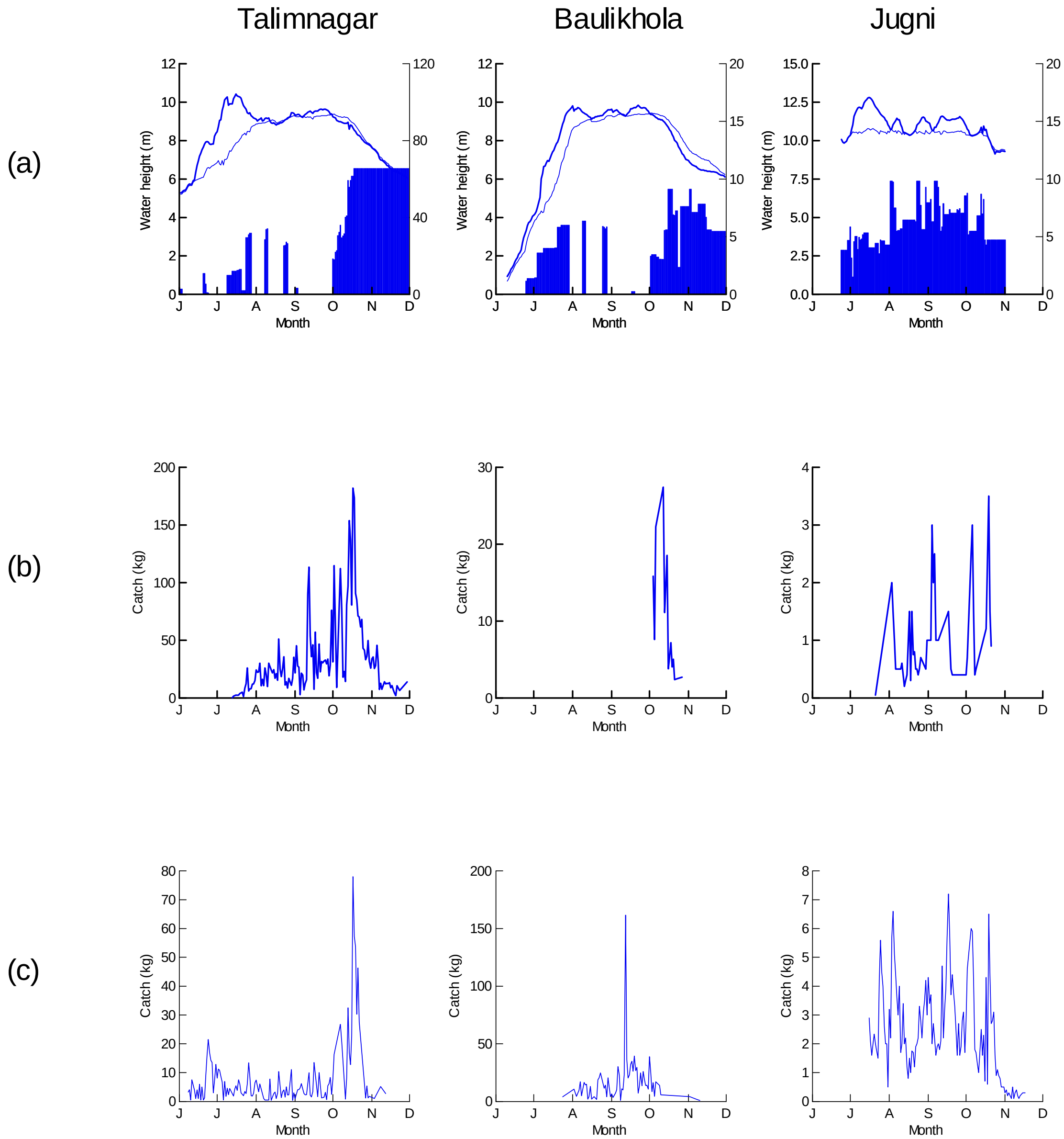

Figure 9 (a) Water heights inside (thin line) and outside thick line) in relation to sluice gate aperture (solid bars); and (b) daily catch (kg) of inwardly migrating fish taken outside and (c) inside the three sluice gates during year 1 (June 2003-Nov 2003). Note variable axis scaling.

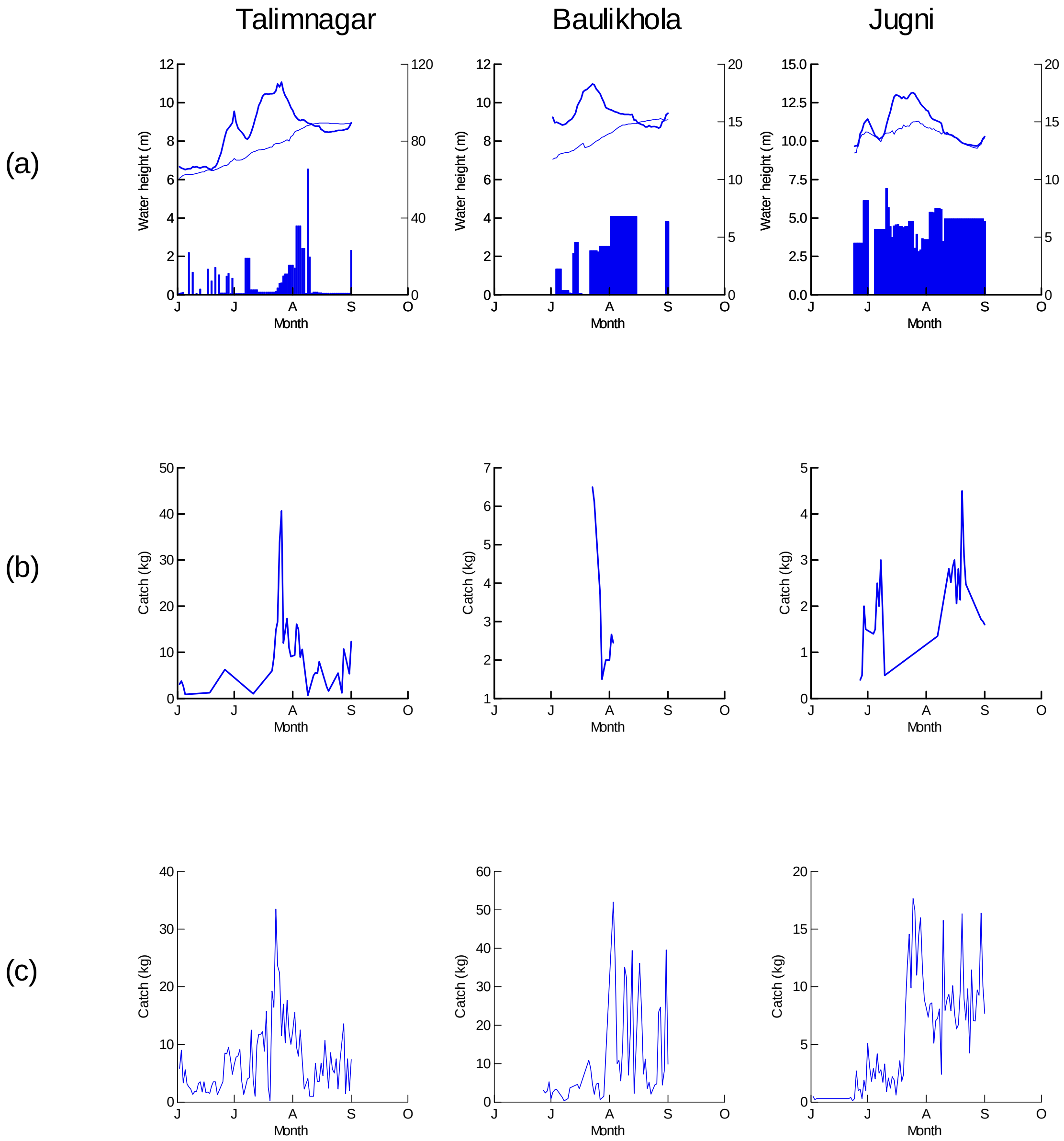

Figure 10 (a) Water heights inside (thin line) and outside thick line) in relation to sluice gate aperture (solid bars); and (b) daily catch (kg) of inwardly migrating fish taken outside and (c) inside the three sluice gates during year 2 (June -August 2004). Note variable axis scaling.

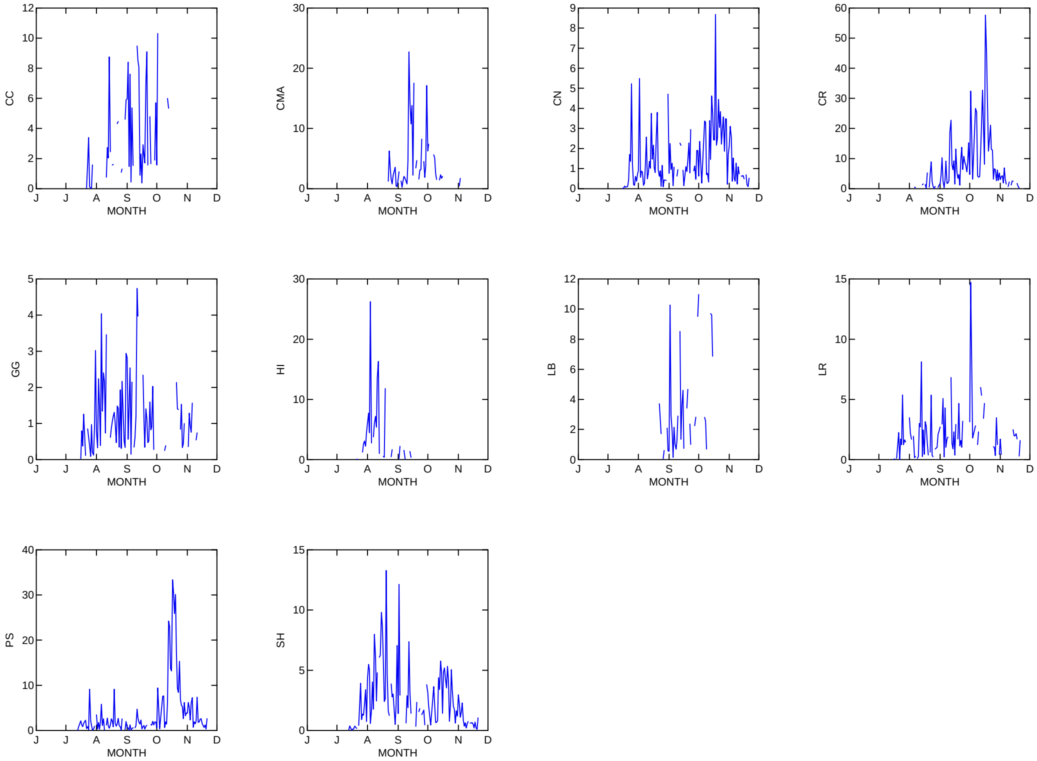

Figure 11 Daily catch (kg) of inwardly migrating species taken outside the Talimnagar sluice gate during year 1 (June – Nov 2003). Note variable axis scaling. Only species contributing to more than 100kg to the total catch weight are shown.

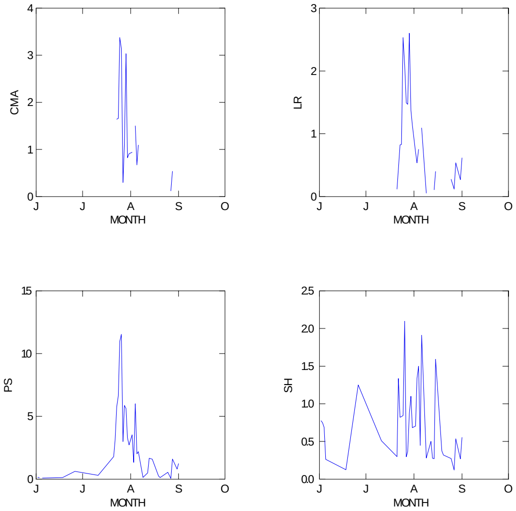

Figure 12 Daily catch (kg) of inwardly migrating species taken *outside* the Talimnagar sluice gate during year 2 (June – Aug 2004). Note variable axis scaling. Only species contributing to more than 25kg to the total catch weight are shown.

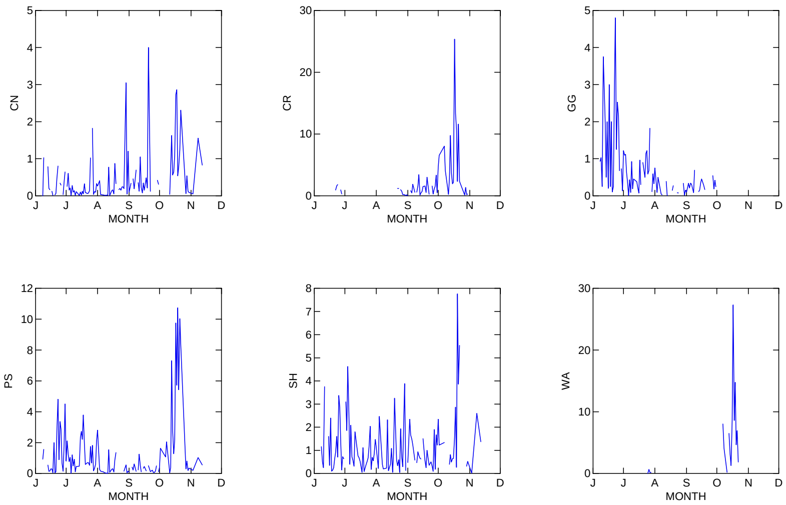

Figure 13 Daily catch (kg) of inwardly migrating species taken *inside* the Talimnagar sluice gate during year 1 (June - November 2003) Note variable axis scaling. Only species contributing to more than 50kg to the total catch weight are shown.

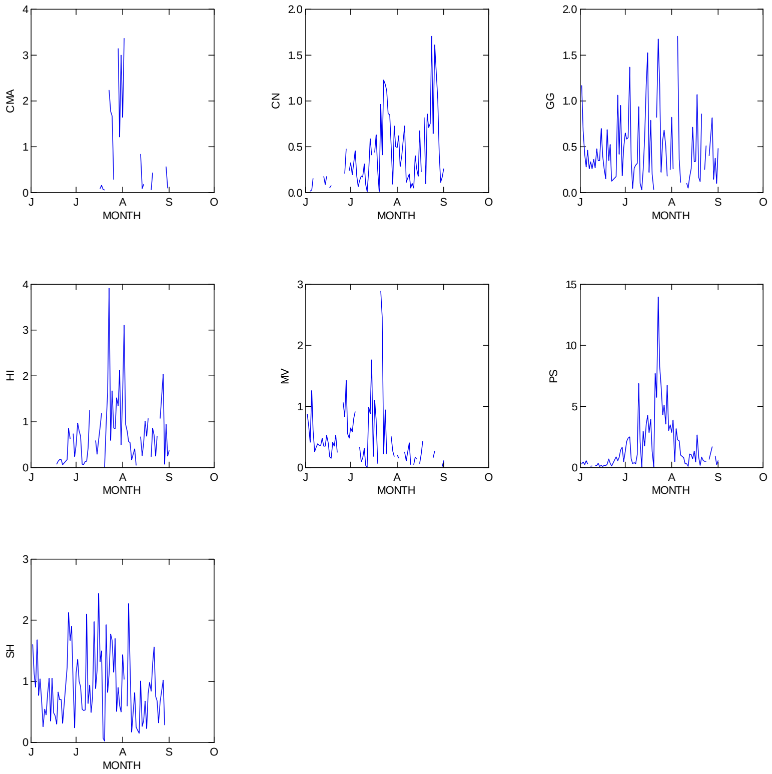

Figure 14 Daily catch (kg) of inwardly migrating species taken *inside* the Talimnagar sluice gate during year 2 (June-August 2004). Note variable axis scaling. Only species contributing to more than 25kg to the total catch weight are shown.

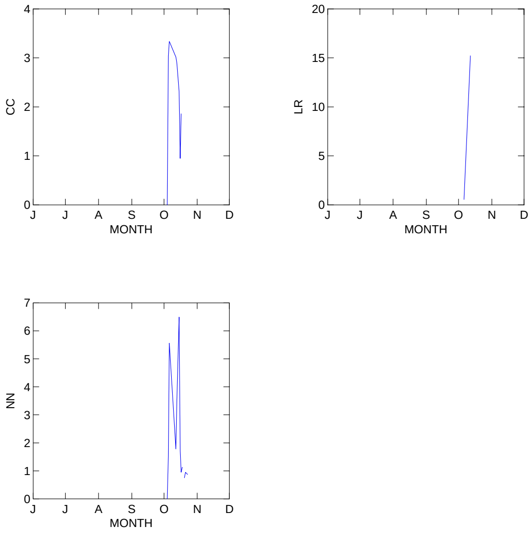

Figure 15 Daily catch (kg) of inwardly migrating species taken outside the Baulikhola sluice gate during year 1 (June-Nov 2003). Note variable axis scaling. Only species contributing to more than 15kg to the total catch weight are shown.

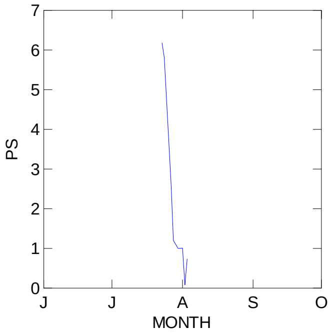

Figure 16 Daily catch (kg) of inwardly migrating species taken outside the Baulikhola sluice gate during year 2 (June-Aug 2004). Note variable axis scaling. Only species contributing to more than 25kg to the total catch weight are shown.

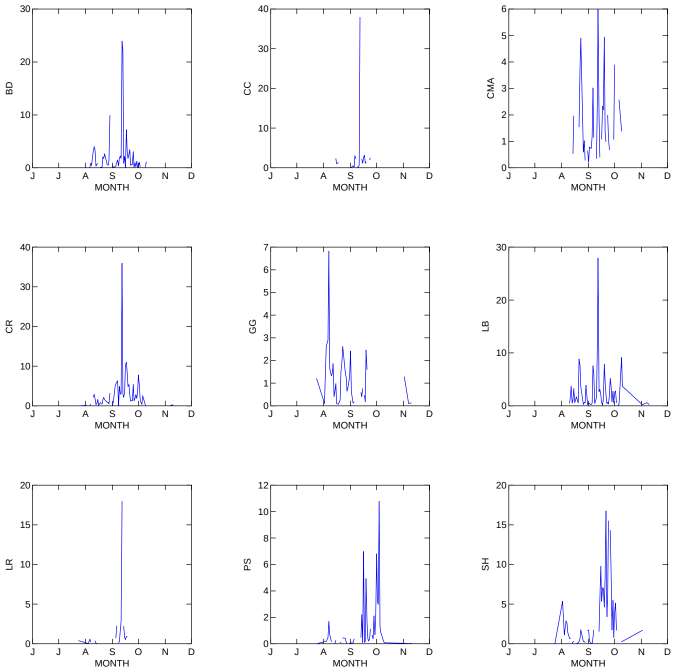

Figure 17 Daily catch (kg) of inwardly migrating species taken inside the Baulikhola sluice gate during year 1 (June-Nov 2003). Note variable axis scaling. Only species contributing to more than 50kg to the total catch weight are shown.

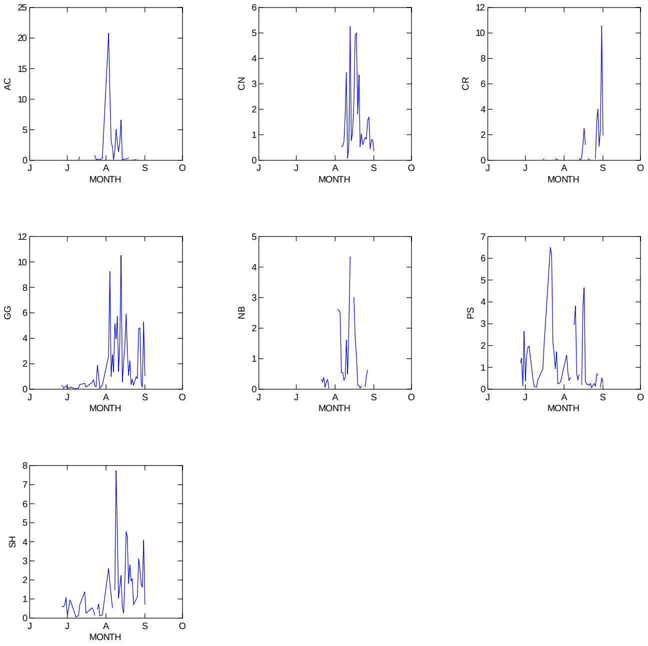

Figure 18 Daily catch (kg) of inwardly migrating species taken inside the Baulikhola sluice gate during year 2 (June-Aug 2004). Note variable axis scaling. Only species contributing to more than 25kg to the total catch weight are shown.

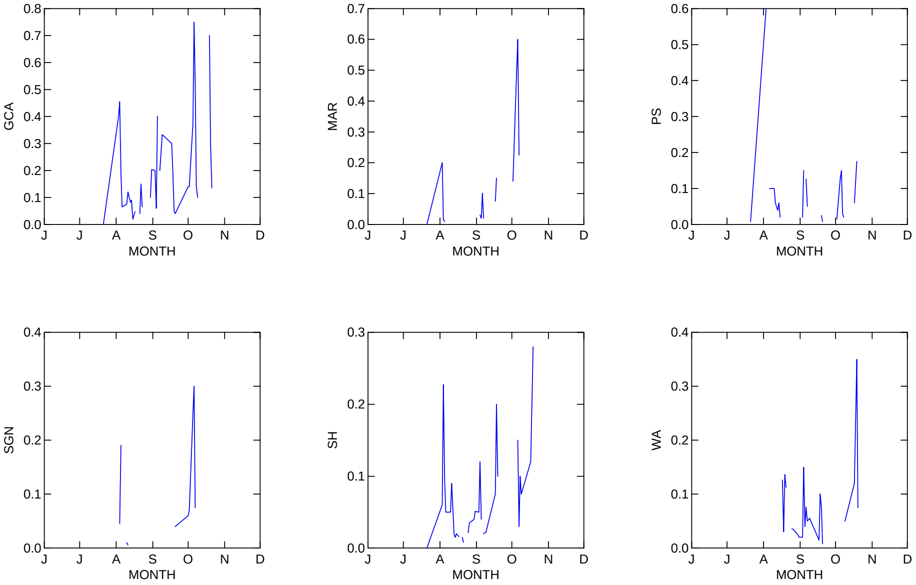

Figure 19 Daily catch (kg) of inwardly migrating species taken outside the Jugini sluice gate during year 1 (June-Nov 2003). Only species contributing to more than 1kg to the total catch weight are shown Note variable axis scaling.

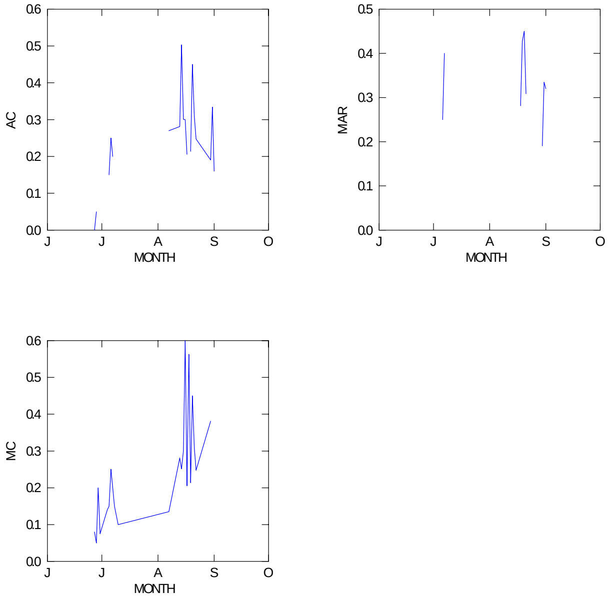

Figure 20 Daily catch (kg) of inwardly migrating species taken outside the Jugini sluice gate during year 2 (June-Aug 2004). Only species contributing to more than 5kg to the total catch weight are shown Note variable axis scaling.

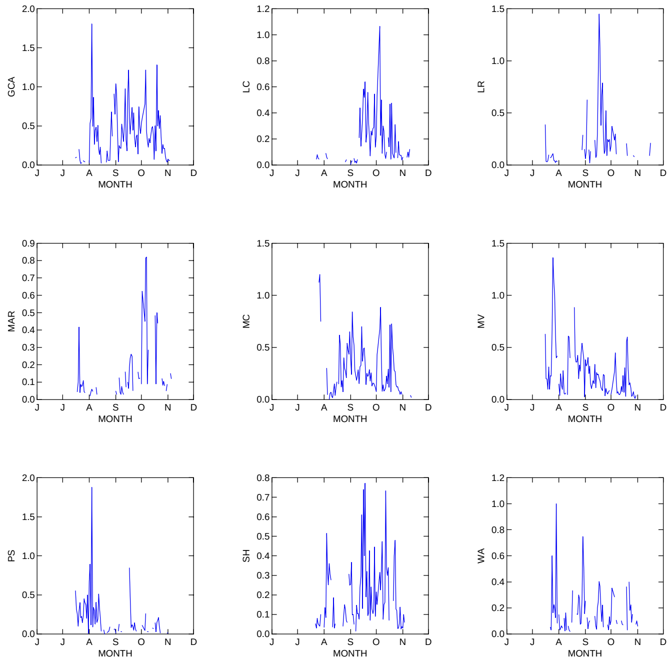

Figure 21 Daily catch (kg) of inwardly migrating species taken inside the Jugini sluice gate during year 1 (June-November 2003). Only species contributing to more than 10kg to the total catch weight are shown Note variable axis scaling.

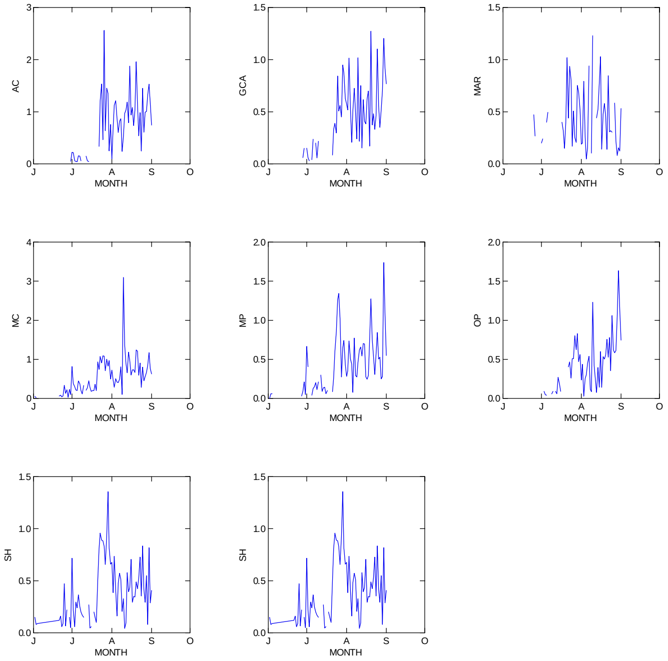

Figure 22 Daily catch (kg) of inwardly migrating species taken inside the Jugini sluice gate during year 2 (June-Aug 2004). Only species contributing to more than 25kg to the total catch weight are shown Note variable axis scaling.

6 Reproductive Strategies of Migrating Fish

The *reproductive state* monitoring programme described in Section 6 of the *Fisheries Assessment and Data collection Manual* was designed to provide data to help understand the reproductive behaviour of migrating fish. This information, when combined with information on the population size structure from length frequency data (See Annex A) can be used to help identify appropriate management measures and operational procedures for sluice gates, particularly in relation to maximising the number of potential recruits to modified floodplains inside FCDIs and spawning stock biomass considerations.

Fish for reproductive examination were sub-sampled from those sampled for the length frequency (LF) monitoring programme (See Section 6 of the *Fisheries Assessment and Data collection Manual*) to provide six evenly-spaced monthly samples comprising 30 individuals of each species stratified according to size (small, medium and large) and sampling location (inside and outside the sluice gate). These data were used to determine the seasonality of reproduction (spawning) and the length at which 50% of fish become sexually mature (Lm_{50}). Further details of the monitoring programme are provided in Section 6 of the *Fisheries Assessment and Data collection Manual*.

6.1 Timing of spawning (GSI)

The spawning period of the species selected for sampling was determined by examining temporal variations in their gonadosomatic index (GSI), defined as:

$$GSI = \frac{gonadweight}{Totalweight}.100 \qquad \textbf{(Equation 1)}$$

The GSI typically peaks just prior to spawning after which the index declines as gametes are released from the gonad. Here, temporal variations in GSI were examined only for female fish.

Because, in most cases, sample size targets were not met, it was necessary to combine data across both sampling years and locations (inside and outside the gate). To maximise the number of samples in each month, data collected from the around the Talimnagar and Baulikhola sluice gates were also combined. This was deemed acceptable practice given the close proximity of the gates to one another.

6.1.1 Talimnagar and Baulikhola

Even after combining data across sampling years, locations and gates and gates, sample sizes remained small. The GSI in two or more months could be estimated at the PIRDP only for four species and confidence intervals around the mean estimate were typically wide. Examination of the monthly GSI estimates indicate that three of the four species examined; *C. reba, M. vittatus* and *P. sophore*, are likely to spawn before or during June or July (Figure 23). *Glossogobius girius* appears may spawn in July or August although evidence presented by Halls *et al* (1999) indicates that this species may have a protracted spawning period.

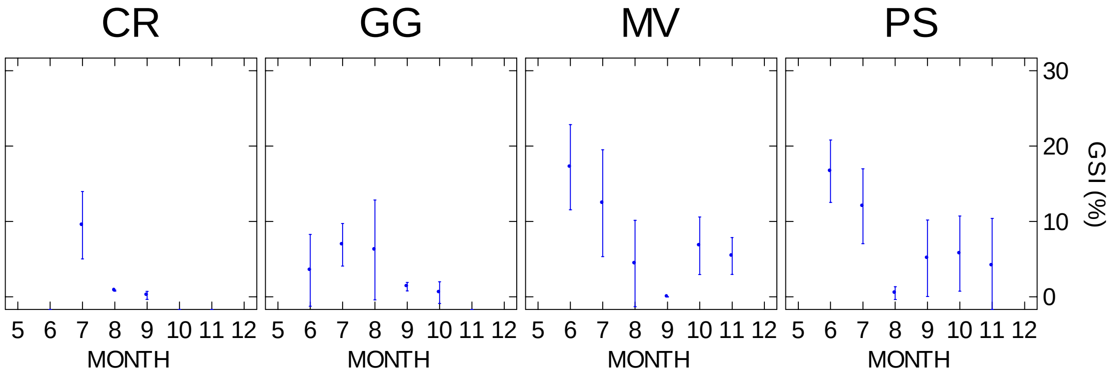

Figure 23 Mean GSI with 95% confidence intervals plotted as a function of month of capture. CR- *Cirrhinus reba*; GG- *Glossogobius giuris*; MV-*Mystus vittatus*; PS-*Puntius sophore*. Monthly estimates include data for both 2003 and 2004.

6.1.2 Jugini

The sparse data available for the two year sampling period at the Jugini gate do not contradict the estimated spawning periods made for the PIRDP and compare well with those reported by Halls *et al* (1999) although monthly GSI estimates appear consistently lower (Figure 24).

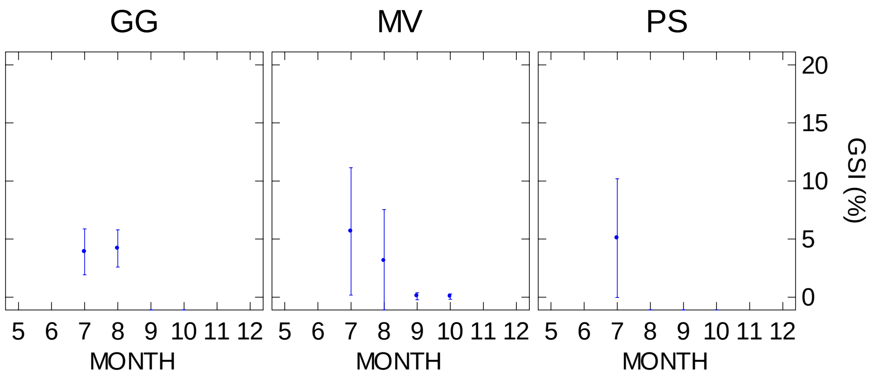

Figure 24 Mean GSI with 95% confidence intervals plotted as a function of month of capture. GG- *Glossogobius giuris*; MV-*Mystus vittatus*; PS-*Puntius sophore*. Monthly estimates include data for both 2003 and 2004.

6.2 Sexual Maturation (lm50)

Length at maturity (lm_{50}) for sampled species was estimated as the length at which half the sampled individuals were observed to be sexually mature. It was assumed that the size at maturation follows a normal distribution and therefore a plot of the percentage (or fraction) mature at length, M(L) will follow a cumulative normal distribution (King 1995). The logistic function (Equation 2), which approximates the cumulative normal distribution function, was fitted to each dataset using non-linear least squares (NONLIN) programme of SYSTAT 10 to provide parameter estimates.

$$M(L) = \frac{1}{1+\exp(\alpha(lm_{50} - L)} \qquad \textbf{(Equation 2)}$$

where α is a constant and L is the fork length of the fish.

Three stages of maturity were recognised; mature, ripe and spent classified according to the methodology described in 6.4.2 of the *Fisheries Assessment and Data collection Manual*. Data were pooled across both sampling years to maximise sample sizes. For the same reason, data for Talimnagar and Baulikhola sluice gates were also pooled. Pooling data in this way assumes that all mature individuals are in reproductive condition at approximately the same time.

Results

Due to patchy data and small sample sizes, estimates of lm(50) with 95% confidence intervals could be made only for *M. vittatus*, *C. reba*, *P. sophore* and *G. giuris* (Table 8). Corresponding data and model fits are illustrated in Figure 25 below. Estimates for *P. sophore* and *G. giuris* are marginally lower than those reported by Halls *et al.* (1999): 6.1cm [95% CI 5.5-6.5cm] and 10.4cm [95% CI 8.5-12.3cm].

Table 8 Non-linear estimates of lm50 with 95% confidence intervals for selected species sampled at PIRDP and CPP for data combined across 2003 and 2004.

Gate(s)	Species	α	lm_{50} (cm)	Lm_{50} 95% CI (cm)
Talimnagar/Baulikhola	*P. sophore*	-	-	-
(PIRDP)	*G. giuris*	-	-	-
	M. vittatus	2.40	5.1	4.9 – 5.2
	C. reba	22.0	9.0	8.9 – 9.1
Jugini (CPP)	*P. sophore*	34.4	4.5	-
	G. giuris	17.7	7.9	7.9 – 7.9
	M. vittatus	21.1	5.0	-

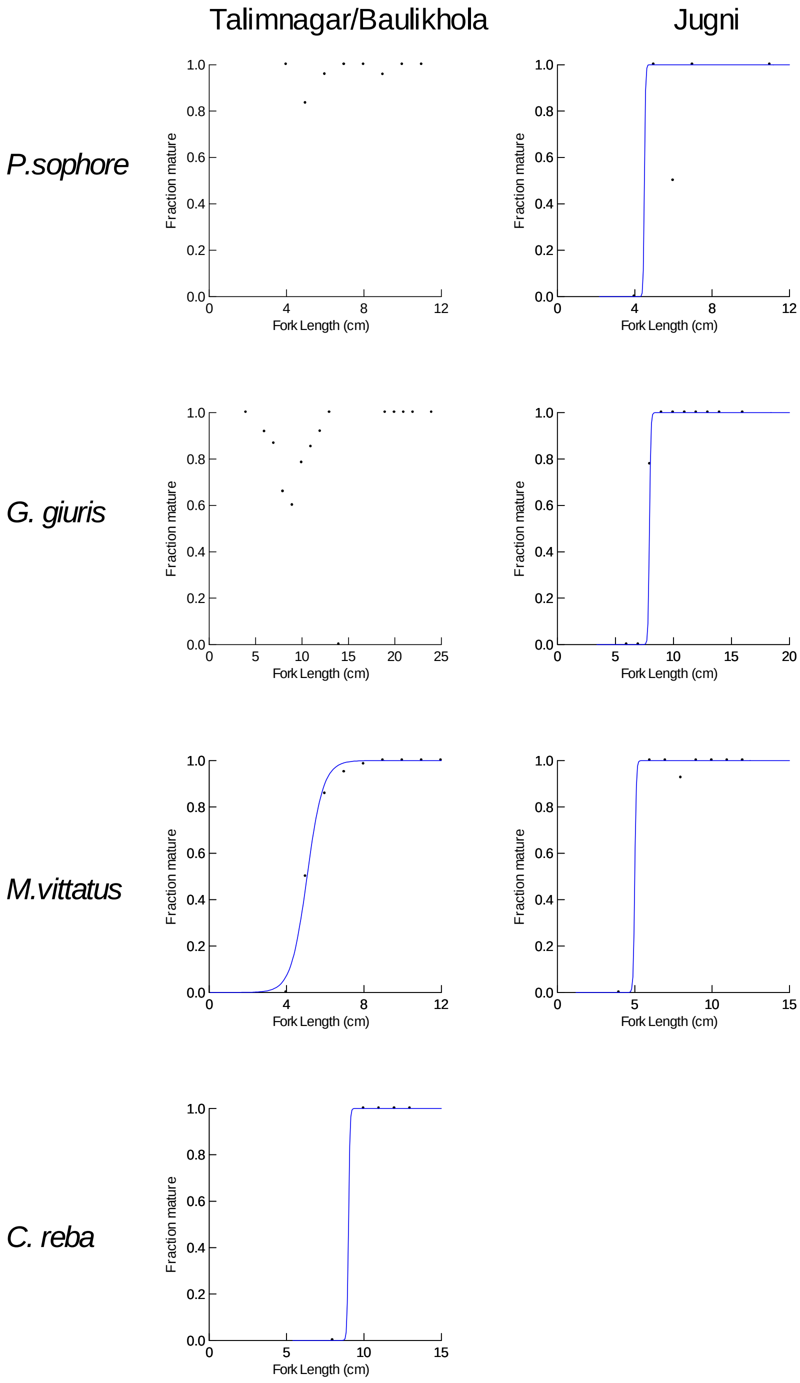

Figure 25 Fraction of the sampled population sexually mature by fork length with fitted logistic function for pooled dataset (2003-2004) for Baulikhola and Talimnagar (combined) and Jugini sluice gates.

7 Factors Affecting Inward Migrations – Catch and Effort Based Assessment

This study is principally interested in identifying means to improve the **inward** passage or *recruitment* of fish through sluice gates to modified floodplains. To do so, it is first necessary to develop an understanding of the factors affecting the magnitude of *inward migrations.*

We begin this process here using data generated from the catch and effort monitoring programme. We then repeat this process in the following Section 1 using data generated from the mark and recapture programme.

7.1 Methodology

When employing catch and effort data, the magnitude of *inward migrations* can be assessed in terms of the quantity of fish caught outside the flood control scheme by interceptory gear facing away from the sluice gate *(potential inward migrations)*, and *apparently successful migrations* - measured in terms of the quantity of fish caught inside the flood control just behind the sluice gate by gears facing towards the gate (see Figure 6).

To account for changes in fishing effort and differences in catchability among different gear types, the relative magnitude of migrations of different species was examined on the basis of estimates of catch-per-unit-effort (CPUE) – a proxy of fish abundance, recorded for liftnets (the single most important gear) only. Differences in catching power among liftnets of different size were accounted for by expressing effort in terms of net area hours (m^2 hours).

The CPUE estimates were generally very small numbers and were therefore expressed in terms of kg per 100hrs fishing with a $10m^2$ net by raising the CPUE estimates by 1000.

In spite of these attempts to standardise effort, it should be borne in mind that the CPUE estimates will only be proportional to fish abundance or biomass, *B* if the gear catchability, *q* remains constant (Equation 3).

$$CPUE = Bq \qquad \textbf{(Equation 3)}$$

Unfortunately, factors such as current velocity can affect *q*, and biomass may also change with time reflecting changes in the mean weight (growth) of individual fish ($\overline{W}$) in the population of *N* individuals (Equation 4).

$$B = N\overline{W} \qquad \textbf{(Equation 4)}$$

This analysis therefore assumes that changes in *q* and $\overline{W}$ through time are small compared to changes in the numbers of fish *N* caught migrating towards or through the sluice gate. A degree of caution should therefore be exercised in interpreting the results of this analysis.

For each sluice gate, and location (inside and outside the gate) and migration phase (passive and active), correlations between estimates of daily CPUE aggregated across all species and daily estimates of sluice gate and hydrological explanatory variables (Table 9) were examined:

Table 9 Hydrological explanatory variables

Variable[1]	Variable Name
Sluice gate aperture (m^2)	Aperture
Head[2] of water (m)	Head
Current velocity inside the gate (ms^{-1})	Velocity in
Current velocity outside the gate (ms-1)	Velocity out
Turbulence inside the gate (Reynolds No.)	Turb in
Turbulence inside the gate (Reynolds No.)	Turb out
Flow inside the gate (m^3s^{-1})	Q in
Secchi depth inside the gate (m)	Secchi in
Secchi depth inside the gate (m)	Secchi out

[1] Water pressure was not examined as this was found to be highly correlated with water height.

[2] Head of water = Water height measured outside the gate – water height inside the gate.

Further to the problems associated with changes to mean individual weight and gear catchability described above, the numbers of fish migrating towards the gate may also be dependent on a host of other interacting factors not considered here including upstream spawning success and fishing activities, lunar cycles, water chemistry...etc. All these factors may affect the *natural* variations in fish abundance and may be completely unrelated to hydrological conditions around sluice gates and their mode of operation.

The mark-recapture study described in Section 1, attempts to overcome this problem of effectively *independent* variations in the biomass of fish in the vicinity of the gates by marking and releasing an equal quantity of fish both inside and outside the gate, then determining *passage success* in relation to the explanatory variables listed in Table 9 above on the basis of the relative numbers of fish recaptured.

7.2 Results

Overall, few significant correlations were detected between sluice gate aperture or any of the hydrological variables monitored and the biomass of fish migrating towards or through sluice gates, as indicated by daily catch rates (CPUE) of liftnets positioned inside and outside of the gates during the flood and ebb flows. This is likely to reflect significant changes in fish biomass that are independent of the variables monitored, as well as changes to the liftnet catchability during each month. It is therefore very difficult to make any robust recommendations for sluice gate operations on the basis of these results.

Passive inward migrations of fish caught *outside* the gate

The most consistent correlations were found for sluice gate aperture, the head of water and secchi depth (Table 1.1). In most cases, some of which were significant ($P < 0.05$), the biomass of migrating fish caught outside the gate was negatively correlated with sluice gate aperture and positively with the head of water. This may reflect an *accumulation* of fish biomass outside the gate as their entry into the FCDI is restricted by sluice gate aperture. The head of water will increase with diminishing sluice gate aperture. The consistent and sometimes significant negative correlation between CPUE and Secchi depth is likely to reflect the ability of fish to avoid the net when water transparency is greater.

Whilst these data and interpretation offers some insight into how it might be possible to accumulate fish biomass outside sluice gates, they provide no indication as to how sluice gates may be operated to increase the biomass of fish passively migrating towards the sluice gate.

Passive inward migrations of fish caught *inside* the gate.

Gate aperture was anticipated to be an important factor determining the biomass of passively immigrating fish caught inside sluice gates. Whilst positive correlations were found between CPUE and aperture at Jugini for all months examined, negative correlations were consistent at Baulikhola (Table 1.2). None of these correlations were however, significant at the 5% level. The only significant positive correlation between these two variables was detected at Talimnagar gate for July. In the majority of cases, the CPUE was positively correlated with the velocity of inflowing water measured outside the gate, but only one of these was statistically significant. Negative correlations between CPUE and Secchi depth were also common but only case was significant at the 5% level. Negative but non significant ($P > 0.05$) correlations between CPUE and water turbulence measured inside were common.

These results are largely inconclusive and therefore offer little in the way of recommendations for sluice gate operation to maximize the biomass of fish entering the FCDIs via sluice gates. However, a large gate aperture to generate high water velocity inside the FCDI scheme, whilst minimizing water turbulence might be the best strategy.

Active inward migrations of fish caught *outside* and *inside* the gates

No significant correlations were detected between the biomass (CPUE) of actively migrating fish caught outside the Baulikhola gate and the variables monitored (Table 1.3). At Talimnagar, significant ($P<0.05$) negative correlations exist between CPUE and both water velocity and the head of water suggesting that high flows impact on the ability of fish to migrate towards the gate. Some weak evidence also exists for catches taken inside the gates to support this (Table 1.4).

Table 10 Correlations between liftnet CPUE and hydrological variables; (+) positive correlation between CPUE and variable; (-) negative correlation between CPUE and variable; bold/red font indicates significant (P<0.05) correlation.

10.1. *Passive inward* migrations of fish caught *outside* the gate (no data for Jugini)

Sluice Gate	Month/Yr	Aperture	Head	Velocity in	Velocity out	Secchi in	Secchi out	Turb.in	Turb. out	Q in
Talimnagar	Jun 2	(-)	**(+)**	**(-)**	**(-)**	(-)	(-)	(-)	(-)	(-)
	Jul 1	(-)	(+)	(+)	(+)			(+)	(+)	(+)
	Jul 2	**(-)**	(+)	**(-)**	**(-)**	(-)	**(-)**	(-)	(-)	(-)
	Aug 1	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)
	Aug 2	(+)	(-)	(-)	(-)	(+)	(+)			
	Sep 1	(-)	(+)	(+)	(-)	(+)	(-)			(-)
Baulikhola	Jun 2	(-)	**(+)**	(-)	(-)	**(-)**	**(-)**	(+)	(+)	(-)
	Jul 2	**(-)**	**(+)**	(-)	(-)	(-)	(-)			
	Total (+)	1 **(0)**	7 **(3)**	3 **(0)**	2 **(0)**	2 **(0)**	1 **(0)**	1 **(0)**	3 **(0)**	2 **(0)**
	Total (-)	7 **(2)**	1 (0)	5 **(2)**	5 **(2)**	5 **(1)**	6 **(2)**	4 **(0)**	2 **(0)**	4 **(0)**

10.2 *Passive inward* migrations of fish caught *inside* the gate.

Sluice Gate	Month/Yr	Aperture	Head	Velocity in	Velocity out	Secchi in	Secchi out	Turb. in	Turb. out	Q in
Talimnagar	Jun 1	(-)	(-)	(-)	(+)					
	Jun 2	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)
	Jul 1	**(+)**	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
	Jul 2	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)
	Aug 1	(+)	(-)	(-)	(+)	(-)	(-)			
	Aug 2	(+)	(-)	(-)	(-)	(+)	(+)			
	Sep 1	(-)	(+)	(-)	(-)	(+)	(+)			(-)
	Sub-total (+)	3 **(1)**	2 **(0)**	1 **(0)**	3 **(0)**	2 **(0)**	4 **(0)**	1 **(0)**	1 **(0)**	1 **(0)**
	Sub-total (-)	4 **(0)**	5 **(0)**	6 **(0)**	4 **(0)**	4 **(0)**	4 **(0)**	2 **(0)**	2 **(0)**	3 **(0)**
Baulikhola	Jun 2	(-)	**(+)**	(+)	(+)	(-)	(-)	(-)	(+)	(+)
	Jul 2	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(+)	(+)
	Aug 1	(-)	**(+)**	(-)	(-)	(+)	(+)	(-)	(-)	
	Aug 2	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)
	Sep 1	(-)	**(-)**	(+)	(+)	(+)	(+)			(-)
	Sub-total (+)	0 **(0)**	4 **(2)**	3 **(0)**	3 **(0)**	2 **(0)**	2 **(0)**	1 **(0)**	3 **(0)**	3 **(0)**
	Sub-total (-)	5 **(0)**	1 **(1)**	2 **(0)**	2 **(0)**	3 **(0)**	3 **(0)**	3 **(0)**	1 **(0)**	1 **(0)**
Jugini	Jun 2	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)
	Jul 1	(+)	(+)	**(-)**	(+)					
	Jul 2	(+)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	**(-)**
	Aug 1	(+)	(-)	**(+)**	**(+)**	**(-)**		(-)	(-)	(-)
	Aug 2	(+)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(-)
	Sep 1	(+)	(-)	**(-)**	(+)	(-)	(-)	(-)	(+)	
	Sub-total (+)	6 **(0)**	2 **(0)**	4 **(1)**	6 **(1)**	0 **(0)**	1 **(0)**	0 **(0)**	1 **(0)**	0 **(0)**
	Sub-total (-)	0 **(0)**	4 **(0)**	2 **(2)**	0 **(0)**	5 **(1)**	3 **(0)**	5 **(0)**	4 **(0)**	4 **(1)**
	Total (+)	9 **(1)**	8 **(2)**	8 **(1)**	12 **(1)**	4 **(0)**	5 **(0)**	2 **(0)**	5 **(0)**	4 **(0)**
	Total (-)	9 **(0)**	10 **(1)**	10 **(2)**	6 **(0)**	12 **(1)**	10 **(0)**	10 **(0)**	7 **(0)**	8 **(0)**

10.3 *Active inward* migrations of fish caught *outside* the gate

Sluice Gate	Month/Yr	Aperture	Head	Velocity in	Velocity out	Secchi in	Secchi out	Turb.in	Turb. out	Q in
Talimnagar	Oct 1	(+)	(-)	**(-)**	(-)	(-)	(-)	(+)	(+)	(-)
	Nov 1		**(-)**	(-)	(-)	**(-)**	**(-)**	(-)	(-)	(-)
	Sub-total (+)	1 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**	1 **(0)**	1 **(0)**	0 **(0)**
	Sub-total (-)	0 **(0)**	2 **(1)**	2 **(1)**	2 **(0)**	2 **(1)**	2 **(1)**	1 **(0)**	1 **(0)**	2 **(0)**
Baulikhola	Oct 1	(-)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)
	Total (+)	1 **(0)**	1 **(0)**	1 **(0)**	1 **(0)**	1 **(0)**	0 **(0)**	1 **(0)**	1 **(0)**	0 **(0)**
	Total (-)	1 **(0)**	2 **(1)**	2 **(1)**	2 **(0)**	2 **(1)**	3 **(1)**	2 **(0)**	2 **(0)**	3 **(0)**

10.4 *Active inward* migrations of fish caught *inside* the gate

Sluice Gate	Month/Yr	Aperture	Head	Velocity in	Velocity out	Secchi in	Secchi out	Turb in	Turb. out	Q in
Talimnagar	Oct 1	(-)	(+)	**(-)**	(+)	(-)	(+)	(-)	(-)	(-)
	Nov 1		(-)	(-)	(-)	(-)	(-)	(-)		
	Sub-total (+)	0 **(0)**	1 **(0)**	0 **(0)**	1 **(0)**	0 **(0)**	1 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**
	Sub-total (-)	1 **(0)**	1 **(0)**	2 **(1)**	1 **(0)**	2 **(0)**	1 **(0)**	2 **(0)**	1 **(0)**	1 **(0)**
Baulikhola	Sep 1	(-)	(+)	(+)	(+)	(-)	(-)			
	Oct 1	(+)	(-)	(+)	(+)	(+)	(+)			
	Nov 1	(+)	(+)	(-)	(-)	(+)	(+)			
	Sub-total (+)	2 **(0)**	2 **(0)**	2 **(0)**	2 **(0)**	2 **(0)**	2 **(0)**			
	Sub-total (-)	1 **(0)**	0 **(0)**	1 **(0)**	1 **(0)**	1 **(0)**	1 **(0)**			
	Total (+)	2 **(0)**	3 **(0)**	2 **(0)**	3 **(0)**	2 **(0)**	3 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**
	Total (-)	2 **(0)**	1 **(0)**	3 **(1)**	2 **(0)**	3 **(0)**	2 **(0)**	2 **(0)**	1 **(0)**	1 **(0)**

8 Factors Affecting Passage Success: A mark-recapture based assessment

As described in Section 7 above, significant problems arise in attempting to explore the affects of hydrological conditions and sluice gate operation on *potential* or *assumed* immigrations of fish using biomass indices such as CPUE, principally because biomass is likely to vary independently of the hydrological conditions within the vicinity of the sluice gates. In this section, we explore the affects of hydrological conditions and sluice gate operation on immigrations of fish or *passage success* on the basis of a mark and recapture approach.

8.1 Methodology

Two equal-size batches of live fish of mixed species and of different sizes (lengths) were marked with a subcutaneous injection of Alcian Blue dye (paint) in the caudal peduncle region of the tail using a 'PanJet' needless injector system. Left-side and right-side marks were used to distinguish fish from the two batches. One batch was then released just in front of (outside) the sluice gate, the other released just behind (inside) the gate. Fish receiving marks to their *right* side were released *outside* the sluice gate. Fish receiving marks to their *left* side were released *inside* the gate.

Following the methodology described in Section 3 of the *Fisheries Assessment and Data collection Manual* the two batches of released fish contained approximately similar numbers of fish of the same species and sizes (ie similar species and size compositions).

Marked and released fish were recaptured by fishermen within the vicinity of the sluice gates. A small monetary reward of TK10 was given to the fishermen for each marked fish they returned. To qualify for the reward, the fishermen had to report how, where and when the fish was caught. In addition to the cash reward, the value of the fish was be refunded to the fishermen by the project. Full details of the mark-recapture programme methodology are provided in the *Fisheries Assessment and Data collection Manual*.

At each sluice gate, batches of up to 6 species of fish were marked and released every 3-4 weeks. This period between releases was regarded as adequate to monitor the passage success of each batch, after preliminary investigations revealed that the majority of the marked fish within each batch were recaptured within the first week, and that 90% were recaptured within 3 weeks of release.

The *passage success* (PS) of the released multi-species batches of fish through each sluice gate was estimated using the following expression:

$$PS\% = \left(\frac{N_{release=IN,\ w}}{N_{release=OUT,\ w})} \right) . \left(\frac{\sum_{w}^{w=w+1} N_{recapture=IN,release=OUT,w}}{\sum_{w}^{w=w+1} N_{recapture=IN,release=IN,w}} \right) .100 \qquad \textbf{(Equation 5)}$$

where $N_{released\ =IN,\ w}$ and $N_{released\ =OUT,\ w}$ are the number of marked fish released inside and outside the sluice gate during week *w*, respectively, and $N_{recaptured\ =IN,\ release=OUT}$ is the number of fish recaptured inside the sluice gate during week *w* bearing an 'outside' release mark, and $N_{recaptured\ =IN,\ release=IN}$ is the number of fish recaptured inside the sluice gate during week *w* bearing an 'inside' release mark.

Estimates of passage success at each gate were plotted as functions of the hydrological explanatory variables described in Sections 1 and 7 above. Linear regressions were also fitted to determine both the significance of any linear relationships detected, and the total variance in passage success explained by each hydrological explanatory variable.

8.2 Results

During the two year period, seven batches of fish were released at the Talimnagar gate. Passage success into the PIRDP through the gate varied from 0% during the ebb flow (see below) to between 35 and 70% during the flooding period. Only three batches of fish were released at the Baulikhola gate, where passage success varied from less than 10% to 100%. At Jugini, where the gates remained permanently open, and water flowed only inwards into the CPP, passage success was consistently above 40% for all nine batch releases (Figure 26; Figure 27; Figure 28).

Whilst passage success was positively but not significantly correlated with sluice gate aperture at both Talimnagar ($p=0.29$) and Baulikhola ($p=0.32$), passage success at these two gates was found to be significantly dependent ($p<0.05$) upon only the volumetric *flow rate* of water entering the scheme (m^3s^{-1}) as measured inside the scheme. Passage success was found to increase linearly with increasing flow (Figure 26; Figure 27; Table 11).

Marked fish were released only once during the ebb flood at Talimnagar during November 2003. However, the results indicate that whilst a number of fish that were released inside the scheme were re-caught, none of those released outside the scheme were re-caught within the first 7 days and less than 5% were recaptured within three weeks of their release. Similar percentage passage success at this time was reported by MRAG (1997) for the silurid catfish *Wallago attu*. This would suggest that passage success is negligible during the ebb flood even when the gates are often fully open but when flows outwards from the scheme can exceed $100m^3s^{-1}$. It is likely that fish are unable to swim against the strong outward flows during this period.

At Jugini, sluice gate aperture was not significant ($p>0.05$) in determining passage success (Figure 28), but then gate aperture consistently exceeded $7m^2$ without considerable variability (Section 4.2.1). It may be that beyond some threshold, sluice gate aperture becomes unimportant, and that other factors such related to gate aperture such as flow and turbulence become more important. Greater contrast in the data set for this gate may have helped reveal those to be important.

Passage success at Jugini was found to be significantly dependent ($p<0.05$) upon only the *turbulence* of water measured outside the scheme (Figure 28). Passage success increased as turbulence decreased. A similar but not significant trend ($p>0.05$) was also found at Talimnagar gate (Table 11; Figure 26). Turbulence outside of the gate may act as an obstacle to the induction and smooth passage of fish through the gates.

Whilst catches of fish actively migrating towards the gates during the ebb flood are significant (Section 5.1), passage success during this ebb flood phase appears very low. This suggests that recruitment of fish to modified floodplains can only be achieved by improving sluice gate practices during the rising water period. These should focus upon maximising the volumetric inflow of water through the gates whilst minimising turbulence outside the gate.

Table 11 Summary of the regression models for Talimnagar gate illustrated in Figure 26. For all models listed, the dependent variable is passage success (%).

Explanatory Variable	n	α	β	R^2	P
Gate aperture	6	40.28	1.41	0.27	0.29
Outside water height	7	-38.65	10.02	0.18	0.33
Inside water height	7	-99.77	18.68	0.32	0.18
Head of water	7	48.97	0.92	0.00	0.94
Outside water velocity	7	31.99	175.56	0.40	0.13
Inside water velocity	7	31.96	95.96	0.40	0.13
Velocity difference	7	32.88	-200.23	0.38	0.14
Inside Secchi depth	7	47.91	4.60	0.00	0.90
Outside Secchi depth	7	50.99	-3.33	0.00	0.93
Inside water pressure	7	2.41	0.01	0.17	0.36
Outside water pressure	7	5.47	0.0089	0.17	0.36
Pressure difference	7	47.85	0.0023	0.01	0.84
Inside turbulence	**6**	**7.05**	**0.000013**	**0.65**	**0.05**
Outside turbulence	6	58.12	-0.00001	0.06	0.63
Inside flow rate	**6**	**32.37**	**0.31**	**0.82**	**0.01**

Table 12 Summary of the regression models for Baulikhola gate illustrated in Figure 27. For all models listed, the dependent variable is passage success (%).

Explanatory Variable	n	α	β	R^2	P
Gate aperture	3	4.67	13.47	0.76	0.32
Outside water height	3	232.50	-18.62	0.08	0.82
Inside water height	3	101.40	-6.07	0.01	0.94
Head of water	3	52.37	-2.80	0.01	0.94
Inside water velocity	3	209.36	-899.31	0.28	0.64
Outside water velocity	3	172.45	-1244.30	0.38	0.58
Velocity difference	3	131.20	1039.34	0.01	0.92
Inside Secchi depth	3	-43.69	276.70	0.53	0.48
Outside Secchi depth	3	4.42	160.80	0.21	0.70
Inside water pressure	3	112.52	-0.014	0.33	0.61
Outside water pressure	3	225.23	-0.0328	0.94	0.15
Pressure difference	3	55.31	-0.0075	0.04	0.87
Inside turbulence	3	78.41	-0.000009	0.14	0.76
Outside turbulence	3	-55.80	0.000061	0.28	0.64
Inside flow rate	**3**	**-27.05**	**16.90**	**0.99**	**0.04**

Table 13 Summary of the regression models for Jugini gate illustrated in Figure 28. For all models listed, the dependent variable is passage success (%).

Explanatory Variable	n	α	β	R^2	P
Gate aperture	9	210.97	-20.28	0.29	0.13
Outside water height	9	39.43	2.78	0.01	0.79
Inside water height	9	3.25	6.40	0.01	0.83
Head of water	9	67.63	4.28	0.01	0.78
Inside water velocity	9	191.41	-342.39	0.37	0.08
Outside water velocity	9	74.06	-10.56	0.00	0.91
Velocity difference	9	71.46	43.79	0.04	0.60
Inside Secchi depth	9	94.20	-172.38	0.14	0.33
Outside Secchi depth	3	109.15	-247.04	0.11	0.78
Inside water pressure	9	101.43	-0.014	0.22	0.20
Outside water pressure	9	60.18	0.005	0.04	0.59
Pressure difference	9	75.37	0.01	0.31	0.12
Inside turbulence	5	104.36	-0.000009	0.09	0.62
Outside turbulence	**5**	**140.51**	**-0.000044**	**0.79**	**0.04**
Inside flow rate	6	103.97	-2.43	0.16	0.43

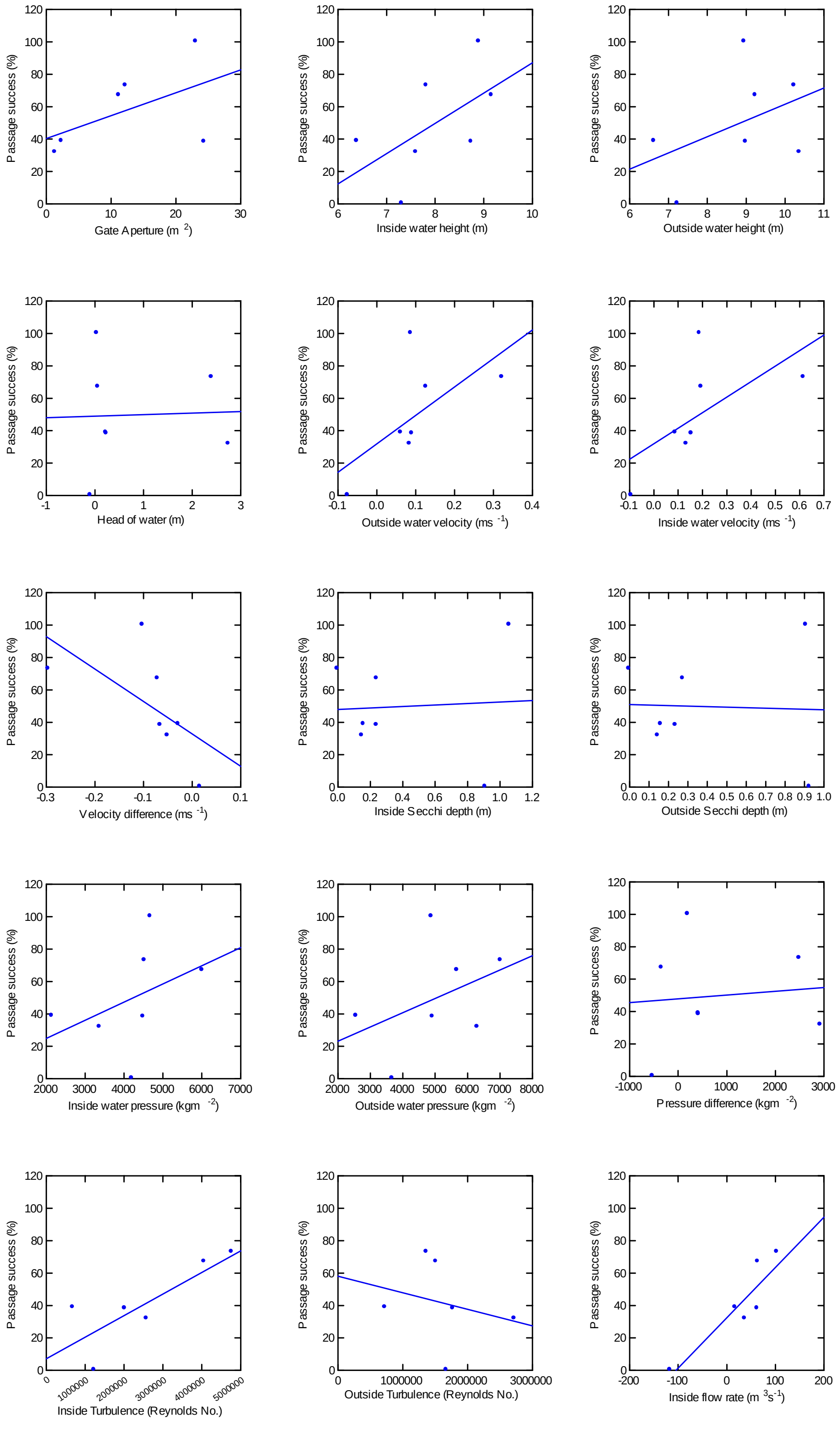

Figure 26 Passage success through Talimnagar Sluice gate plotted as a function of hydrological variables.

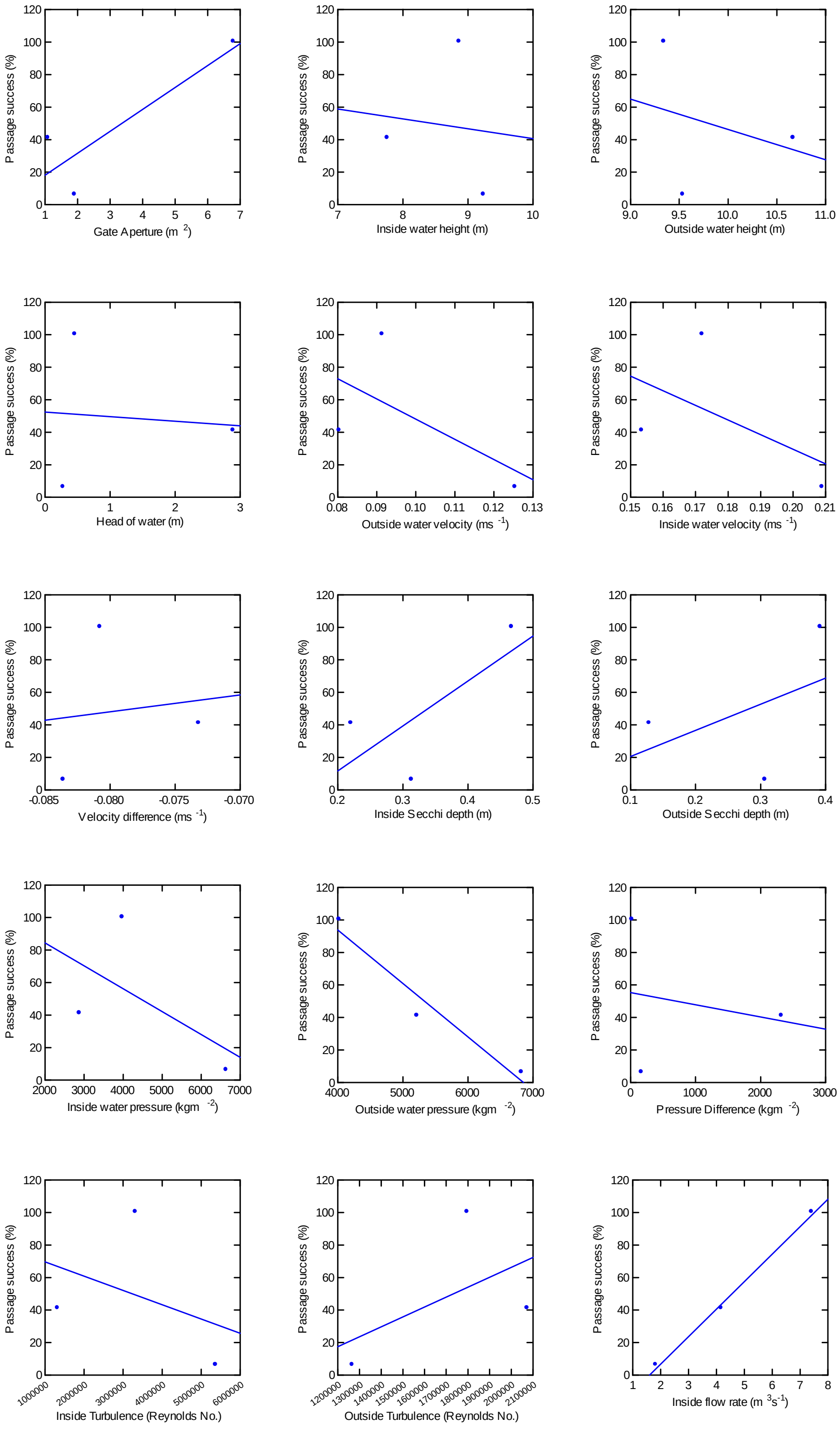

Figure 27 Passage success through Baulikhola Sluice gate plotted as a function of hydrological variables.

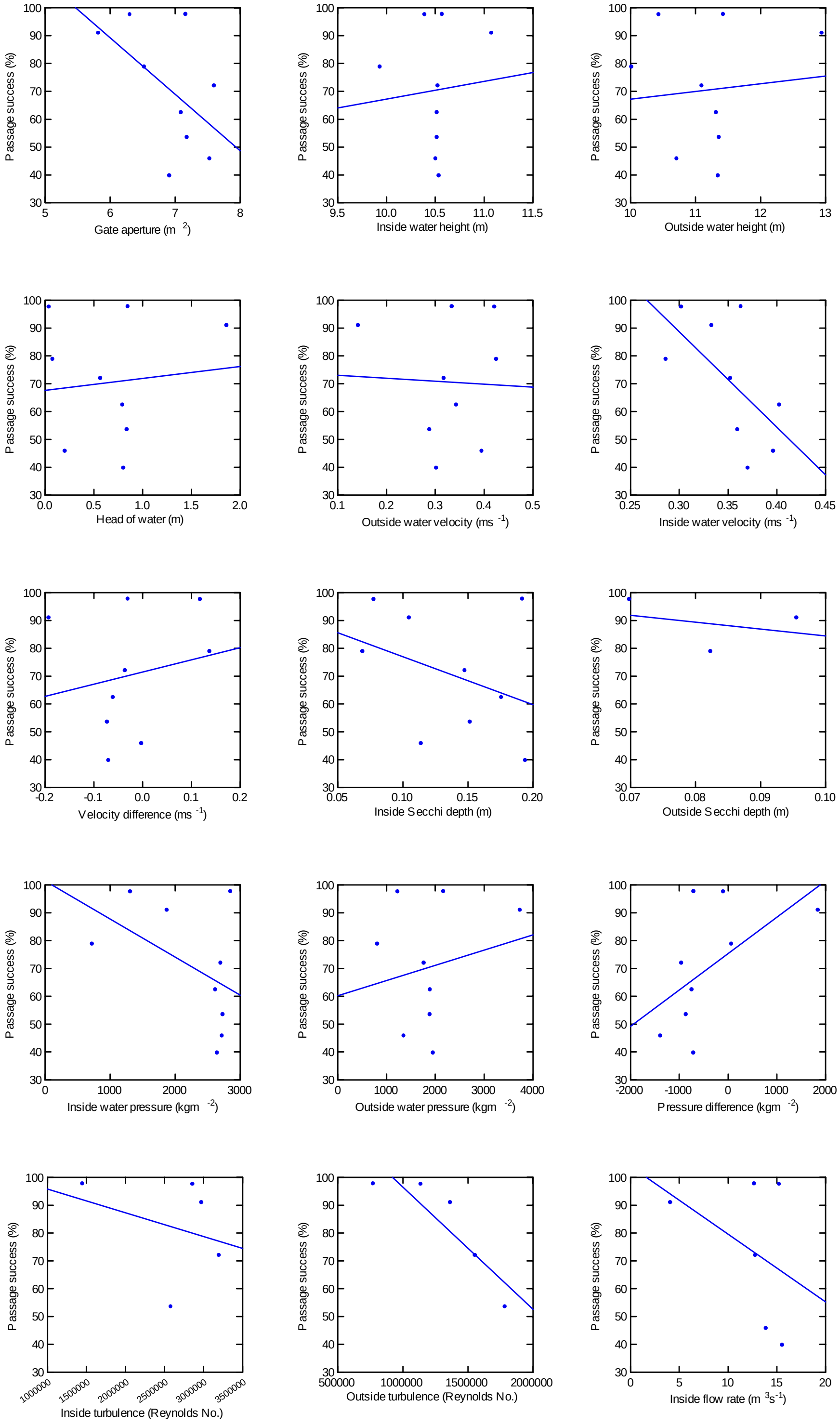

Figure 28 Passage success through Jugini Sluice gate plotted as a function of hydrological variables.

8.3 Why are fish unable to successfully migrate into the PIRDP during the ebb flow?

During the ebb flow, fish would only able to swim through sluice gates if they can swim faster than speed (velocity) of outflowing water. Maximum sustainable swimming speeds can be estimated using the following empirical relationship (see Lucas and Baras 2001):

$$U_{ms} = \frac{L(n\,(1.1(W)^{-0.14})}{100} \qquad \textbf{Equation 6}$$

Where U_{ms} is the maximum sustainable swimming speed, L and W is the mean length and weight of the fish, respectively and n is a constant. A value for n of 3 was used here after Lucas and Baras (2001).

Table 14 Estimates of maximum sustainable swimming speeds for six important species caught at the Talimnagar gate

Species	length (cm)	weight (g)	Ums (ms-1)
Glossogobius giuris	10	8.7	0.24
Puntius sophore	6	3.9	0.17
Wallago attu	25	90	0.44
Cirrhinus reba	11	16.7	0.24
Labeo rohita	14.7	67	0.27
Mystas vittatus	6.4	4.75	0.17
		Mean	**0.25**

Comparisons of estimates of maximum sustainable swimming speeds (Table 14) in relation to current velocity estimates at Talimnagar for 2003 (

Figure 29) suggest that for small species such as *P. Sophore* and *M. vittatus*, ebb flow velocities exceed their maximum sustainable swimming speeds for much of the ebb phase of the flood. Even average maximum speeds often only match those of outflowing current velocities during the early ebb phase. Only fast swimming large species such as *W. attu* could maintain positive ground speed during the ebb flow period.

Sluice gate managers should therefore attempt to ensure that sluice gate apertures during the ebb flow do not create current velocities exceeding the slowest maximum sustainable swimming speeds of those fish attempting to migrate. (Equation 7). Liftnet sampling of fish during or just before the ebb flow will provide estimates of *L* and *W*.

$$Max\ Outflow\ Velocity < U_{ms} \qquad \textbf{Equation 7}$$

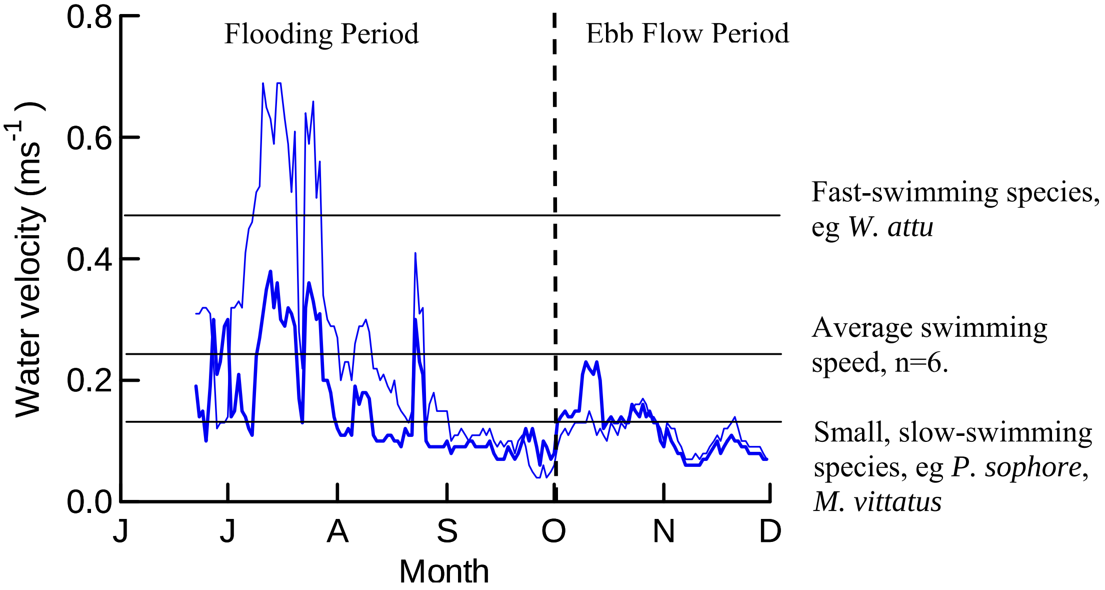

Figure 29 Estimates of maximum sustainable swimming speeds of fish at Talimnagar in relation to observed current speeds.

8.4 Attraction velocities

Whilst inward migrations into flood control schemes during the ebb flow period will be constrained by the maximum swimming speed of the immigrating fish, we also know that fish are also attracted to the gates by the out-flowing water (*rheotaxis*).

Managers should therefore aim to open sluice gates to create ebb flows that *maximise attraction* (optimal attraction velocity) but that do not exceed the maximum swimming capacities of fish.

8.4.1 Estimated Optimal Attraction Velocity at Talimnagar

Optimal attraction velocities were estimated for the Talimnagar gate by plotting the catch per unit of effort (CPUE) [an index of the biomass] of immigrating fish caught outside the gate as a function of the out-flowing current velocity. A typical optimal attraction velocity response (see Pavlov 1989) was found (Figure 30). Fish become increasingly attracted to the gate as current speeds increase. Maximum attraction occurs at current speeds of approximately $0.1 ms^{-1}$, after which attraction declines. Also note that no fish are caught beyond current speeds of $0.25 ms^{-1}$ – the average maximum swimming speed of key species (Section 8.3).

Liftnets could also be easily sampled for CPUE data to estimate optimal attraction velocities in this way.

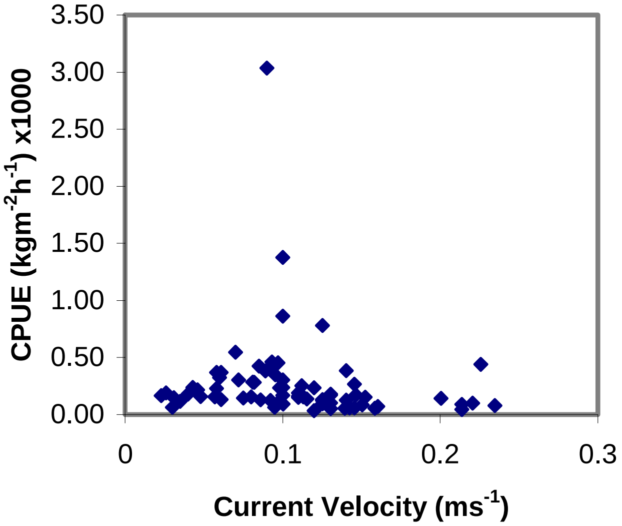

Figure 30 Catch rates of immigrating fish caught outside the Talimnagar gate during the ebb flood of 2003 plotted as a function of the out-flowing current velocity.

9 Depletion Of Immigrating Fish In Connecting Channels

9.1 Background

Sluice gates controlling the flows of water into and out of FCDI schemes are rarely positioned immediately adjacent to main rivers. Instead, channels or secondary rivers usually connect FCDI schemes to the main rivers. Fishers often set barrier or liftnet gears along the entire lengths of such channels to intercept fish as they migrate along them either towards the gates or back to the main river channel.

The recruitment of fish from the main channel to modified floodplains will therefore not only be affected by the operation of sluice gates, but also by fishing activities along connecting channels. Indeed, it may be that removals of fish along these channels have a greater impact on recruitment than the mode of sluice gate operation (except of course when gates are completely closed) or the prevailing hydrological conditions around the gate.

9.2 Methodology

To help assess the relative importance of these factors, fishing effort and removals of passively immigrating fish by liftnets positioned at fixed locations along the 5km length of Badai River connecting the Talimnagar gate to the main Padma and Jamuna Rivers (Figure 31) were monitored during July and August 2004. Mean monthly catch rates (CPUE) of each liftnet - an index of the biomass of immigrating fish, were plotted as a function of the position (distance) of each liftnet relative to the main channel. If removals are significant, then a reduction or *depletion* in biomass (CPUE) with distance from the main channel would be expected. Full details of the methodology are given in the *Fisheries Assessment and Data collection Manual.*

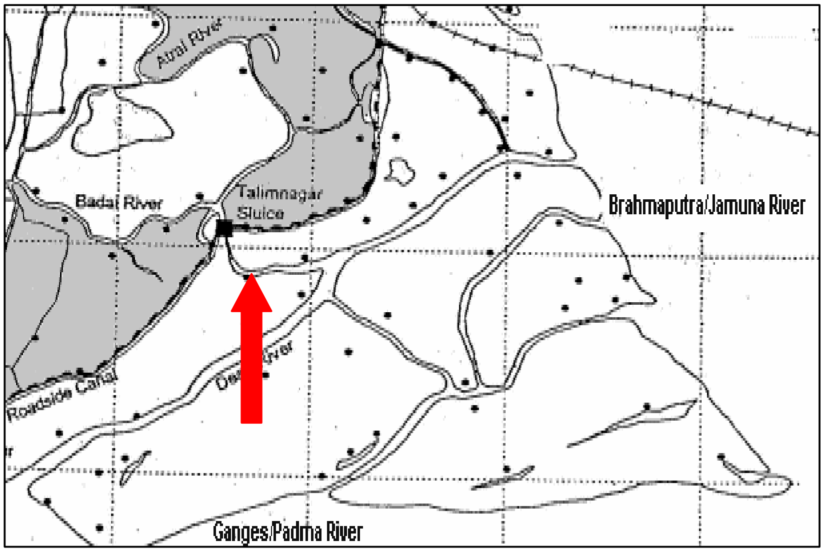

Figure 31 The Badai river channel connecting the Talimnagar gate to the main rivers monitored for the depletion study.

9.3 Results

Liftnet catch rates were monitored at 12 fixed locations during July and 13 in August. Significant (P<0.05) declines in catch rates (biomass) of passively immigrating fish were detected in both months from the mouth of the Badai river towards the sluice gate (Table 15; Figure 32).

The slopes and intercepts of the two depletion models were found not to be significantly different at P=0.05 (Table 15). For July, the model predicts that over the 4.5 km distance over which the observations were made, the biomass of migratory fish, as indicated by CPUE, declined 42% [95% CI: 17%, 76%] from the mouth of the Badai river to the location of the last net. In August, this decline is estimated to be approximately 54% [95% CI: 21%, 104%].

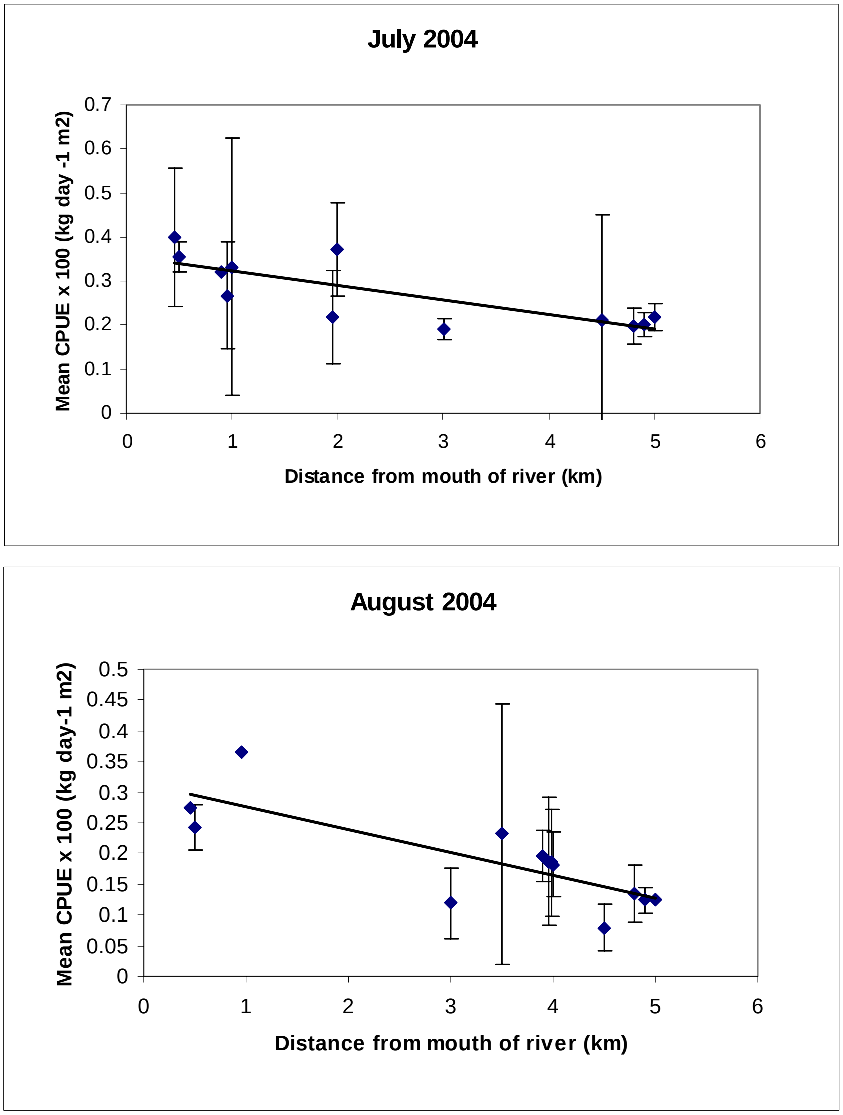

Figure 32 Mean CPUE for fixed liftnets in (a) July and (b) August, plotted as a function of the distance of the net from the mouth of the Badai river.

Table 15 Deletion model parameter estimates for (a) July and (b) August.

(a) July

Regression Statistics	
Multiple R	0.796081105
R Square	0.633745126
Adjusted R Square	0.597119639
Standard Error	0.049283377
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.042027363	0.042027363	17.30339095	0.001949557
Residual	10	0.024288513	0.002428851		
Total	11	0.066315876			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.357303034	0.024610539	14.51829377	4.78251E-08	0.302467336	0.412138732	0.302467336	0.412138732
X Variable 1	-0.033469585	0.008046087	-4.159734481	0.001949557	-0.051397384	-0.015541786	-0.051397384	-0.015541786

(b) August

Regression Statistics	
Multiple R	0.793156485
R Square	0.62909721
Adjusted R Square	0.595378775
Standard Error	0.049201664
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.045165822	0.045165822	18.65736659	0.001215853
Residual	11	0.026628841	0.002420804		
Total	12	0.071794663			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.312973259	0.03191242	9.807255703	8.97702E-07	0.242734497	0.38321202	0.242734497	0.38321202
X Variable 1	-0.037289721	0.008633044	-4.319417391	0.001215853	-0.056290923	-0.018288519	-0.056290923	-0.018288519

These declines in the biomass of passively immigrating fish are significant. Measures to control fishing along the rivers and channels connecting sluice gates to the main rivers are therefore fundamental for improving recruitment to modified floodplains, and in some case may be as or more important as appropriate sluice gate operating procedures, particularly when gates are rarely closed such as at Jugini (4.2.1).

10 Conclusions and Recommendations

This study supports earlier conclusions reported by MRAG (1997); Halls *et al* (1998) and Hoggarth *et al* (1999) that fish can successfully migrate through sluice gates. Sluice gates should therefore be recognised as important structures for improving the recruitment of fish to modified floodplains within FCDIs.

Fish attempt to migrate into FCDIs throughout the year. Most immigrating species are rheophilic whitefish including prized Indian major carp species. During the early flood (June-July) immigrating fish largely comprise small juvenile fish but are also accompanied by sexually mature individuals that have either recently spawned or will spawn imminently. So **when** and **how** should sluice gates be operated during the hydrological cycle?

When?

Whilst catches of fish tend to increase from June to reach a maximum during the ebb flow (Oct - Dec) (see Section 5.3), the length frequency data (Annex A) shows that the average fish size is much greater at this time. Thus the numbers of fish (ie potential recruits) per unit biomass is much greater during the *early flood phase*. For example, using length-weight relationships reported by Halls *et al* (1999), 1 tonne of passively immigrating *glossogobius giuris* in July would comprise about 1million individuals. However, in October 1 tonne would comprise only about 125,000 individuals. In other words, per unit biomass, the numbers of fish migrating during the early flood may be 10 times greater than during the ebb. So while, in terms of weight, catches of fish during the early flood appear small, they are very significant in terms of the numbers of potential recruits that could enter flood control schemes.

The reproductive studies showed that fish spawn in May-July before ebb (Section 6.1). Sluice gates should be operated to ensure fish can enter schemes during the rising flood period *before* they spawn to maximise recruitment.

Few (if any) fish appear able to penetrate the sluice gates during ebb flow period (Section 8.2) apparently because current speeds exceed their max swimming speeds in most cases (Section 8.3). During the flood period however, fish can passively migrate with in-flowing current and pass apparently unhindered through the gates (ie up to 100% passage success) in some cases.

The main conclusion we can draw from this evidence is therefore that **sluice gate management practices during the rising flood are likely to have the greatest positive impact.**

How?

Sluice gate managers should aim to:

7. **Maximise the flow of water (volume of water per unit time) into the flood control scheme during the rising flood period.** In effect, managers should attempt to maximise the transport of water (and therefore fish) through the gates (Section 8.2).

8. **Maximise frequency of gate openings.** Anecdotal evidence presented here and reported by Hoggarth *et al* (1999) suggests that both biodiversity and fish production

benefits from more frequent gate openings, particularly during the rising flood period. Monitoring catch rates (biomass indices) of immigrating fish outside sluice gates to determine the best times to open gates during the rising flood period is not recommended because these catch rates will, themselves, be dependent upon the sluice gate operation (Section 7.2). Procedures therefore need to be developed to provide guidance on the timing of gate opening possibly based upon monitoring fish abundance in main channel including the *savar* net fishery.

9. **Minimise the turbulence of water outside the gate.** In some cases, turbulence appears to act as an obstacle to the induction and smooth passage of fish through the gate (Section 8.2). The advice from hydrologists or engineers should be sought on how best to operate gates to minimise turbulence.

10. **Ensure that ebb flow velocities do not exceed the maximum sustainable swimming capacities of fish**. These velocities can be easily calculated from empirical formulae using estimates of the mean length and weight of sampled fish immigrating during the ebb flow period (Section 8.3).

11. **Attempt to create ebb flows that attract the most fish to towards the sluice gate**. These optimal attraction velocities can be easily estimated by sampling liftnet catch rates and corresponding water velocity estimates during the ebb flow period (Section 8.4.1).

12. **Control fishing activities along channels connecting the gate to the main rivers.** With more than 50% of fish potentially being caught before they even reach the entrance of sluice gates in some cases, controlling fishing activities along channels connecting gates to main rivers is likely to be equally, if not more, important as fine tuning sluice gate operations, particularly for gates which typically remain are permanently open like the Jugini (Section 9.3). Such interventions might offer a first step towards improving the recruitment of fish to modified floodplains that is acceptable to farmers and other stakeholders who might be disadvantaged by increased flows of water into flood control schemes during the rising flood period. Closing the fishery in channels connecting sluice gates during the flood period should also benefit the local fishery. Activities during this period exploit sexually immature fish that are still growing rapidly. Reducing the effort during this period could potentially increase the size of spawning stocks thereby improving overall yield, as well as yield-per-recruit both inside and outside flood control schemes. Fishing activity along these channels might be permitted to resume during the ebb flood when (i) passage success through gates into flood control schemes such as the PIRDP appears insignificant, (ii) most fish have reached sexual maturity, (iii) and seasonal rates of growth have slowed (Annex A and Halls *et al.*, 1999).

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Appendix A – Length Frequency Distributions

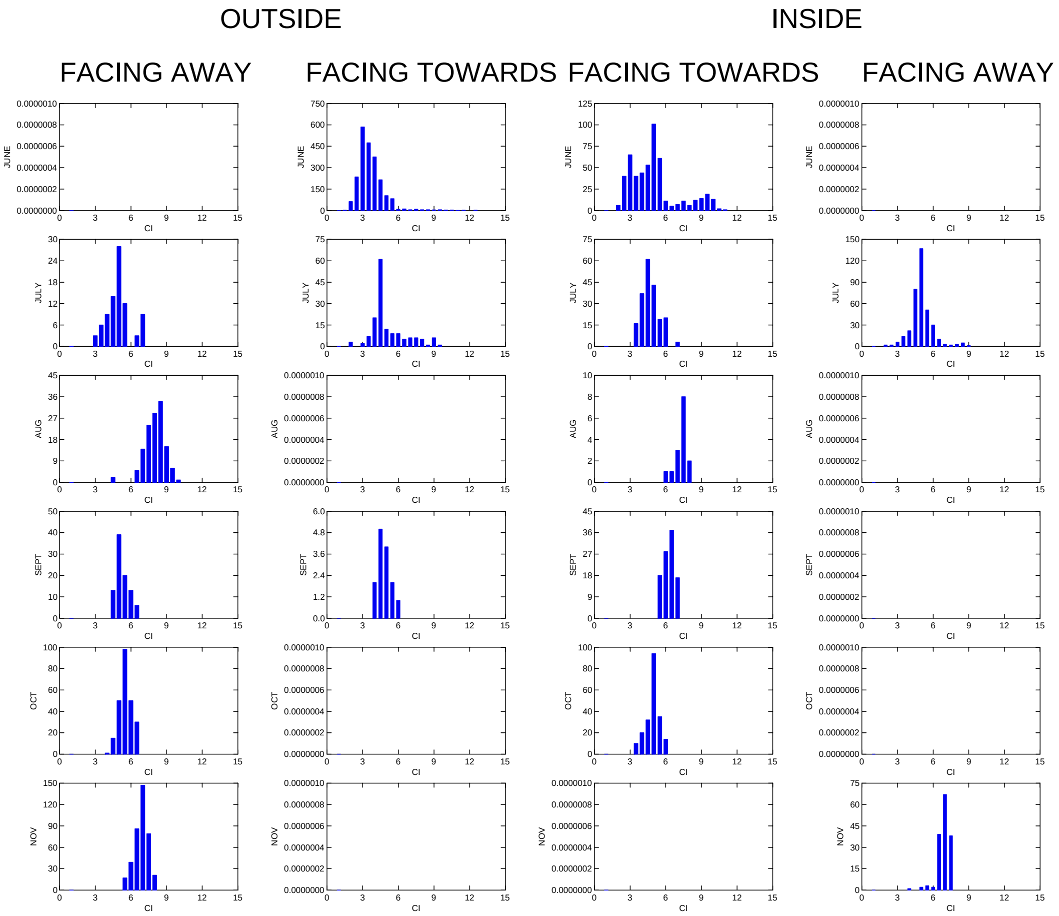

Figure 33 Length Frequency distributions of *Puntius Sophore* sampled from interceptory gears operating inside and outside and facing away from and towards the Talimnagar sluice gate between June and November of study year 1.

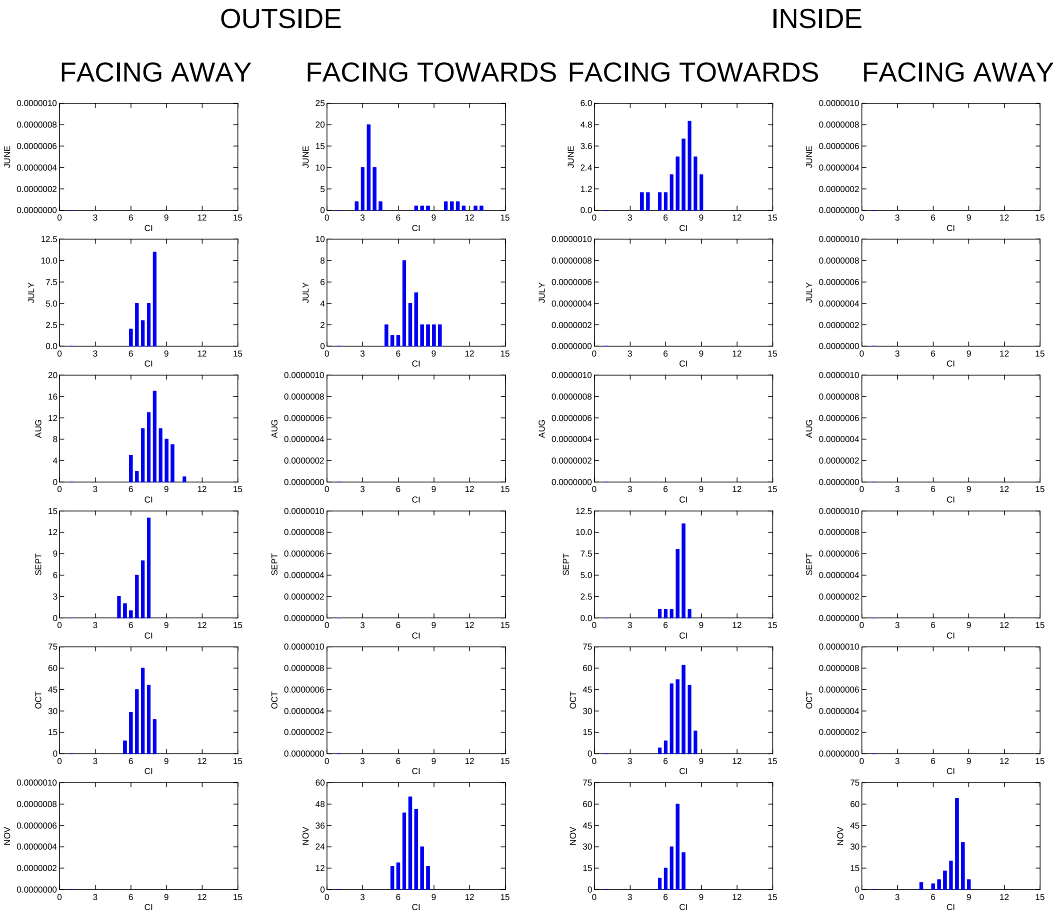

Figure 34 Length Frequency distributions of *Mystus vittatus* sampled from interceptory gears operating inside and outside and facing away from and towards the Talimnagar sluice gate between June and November of study year 1.

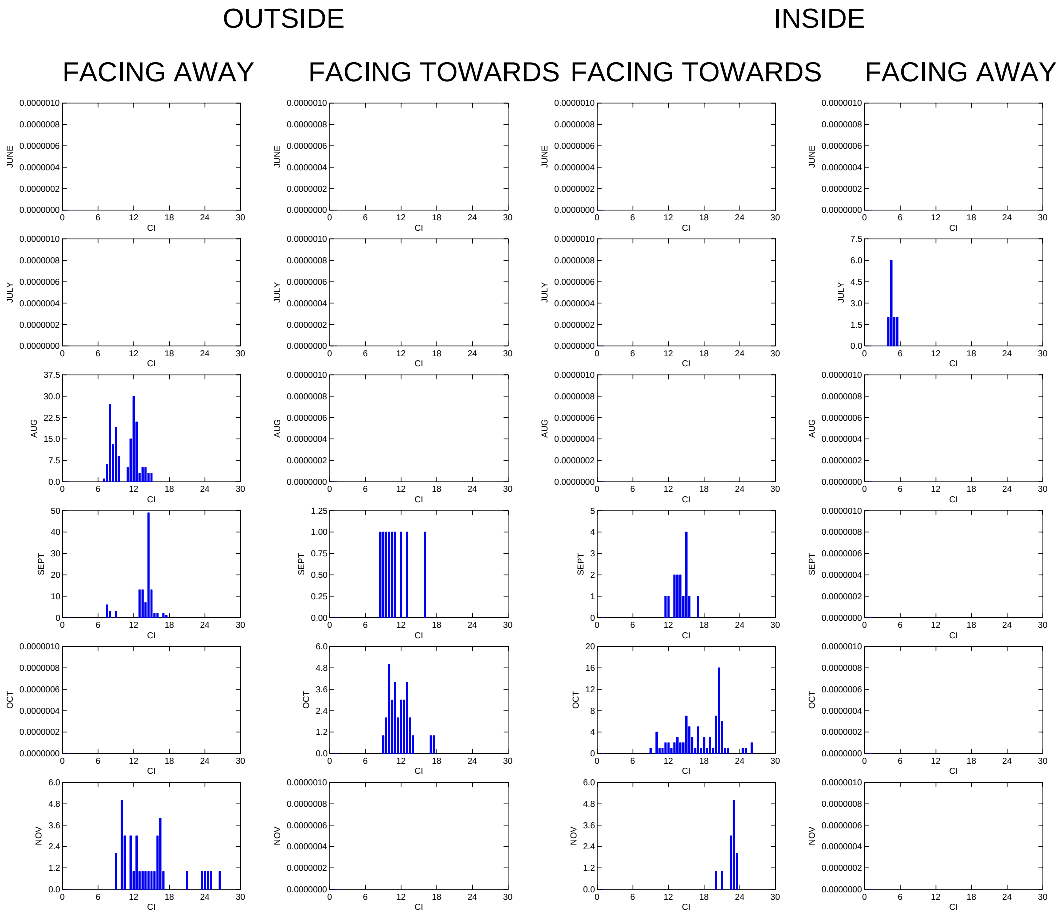

Figure 35 Length Frequency distributions of *Labeo Rohita* sampled from interceptory gears operating inside and outside and facing away from and towards the Talimnagar sluice gate between June and November of study year 1.

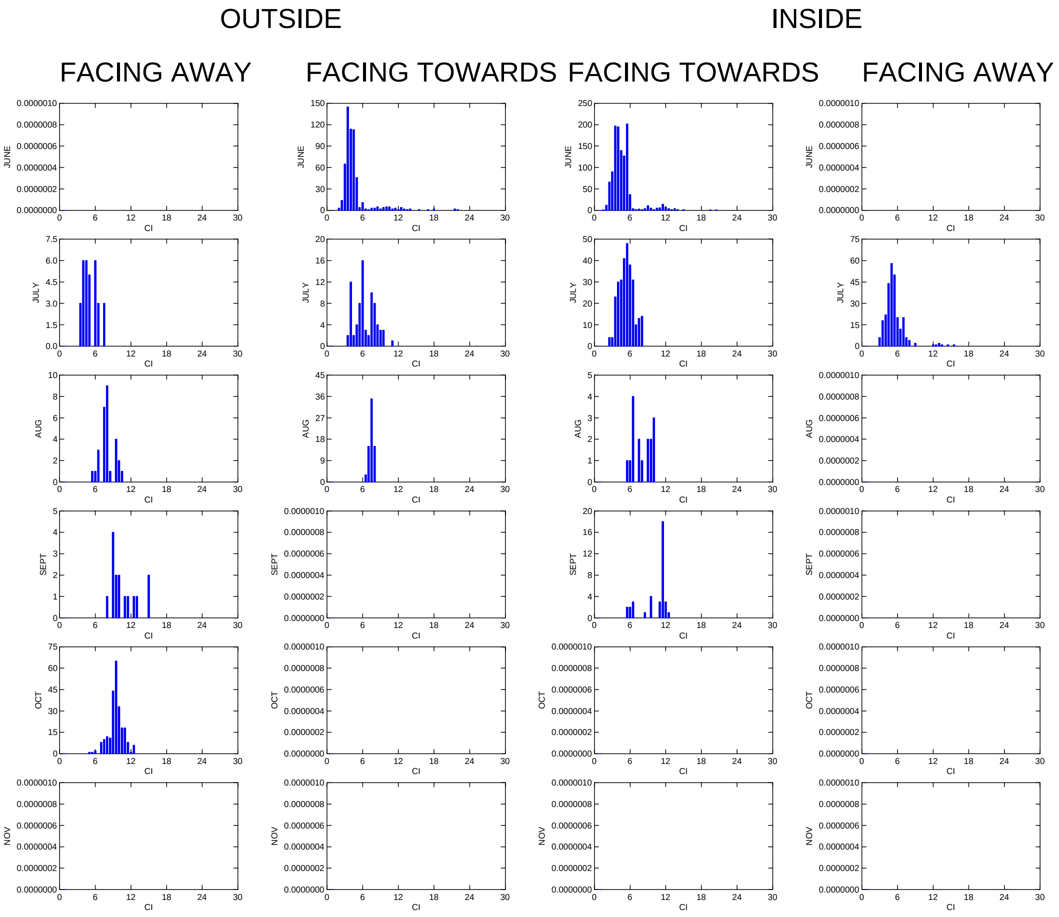

Figure 36 Length Frequency distributions of *Glossogobius giuris* sampled from interceptory gears operating inside and outside and facing away from and towards the Talimnagar sluice gate between June and November of study year 1.

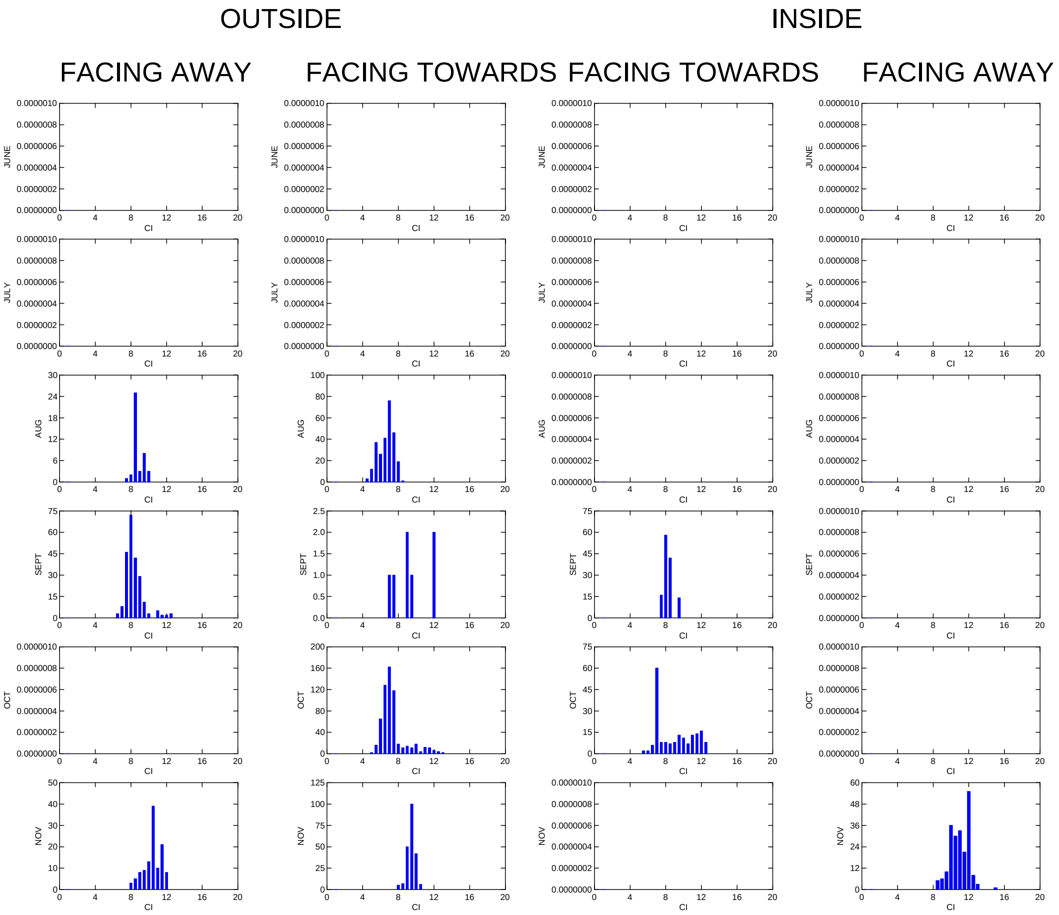

Figure 37 Length Frequency distributions of *Cirrhinus reba* sampled from interceptory gears operating inside and outside and facing away from and towards the Talimnagar sluice gate between June and November of study year 1.

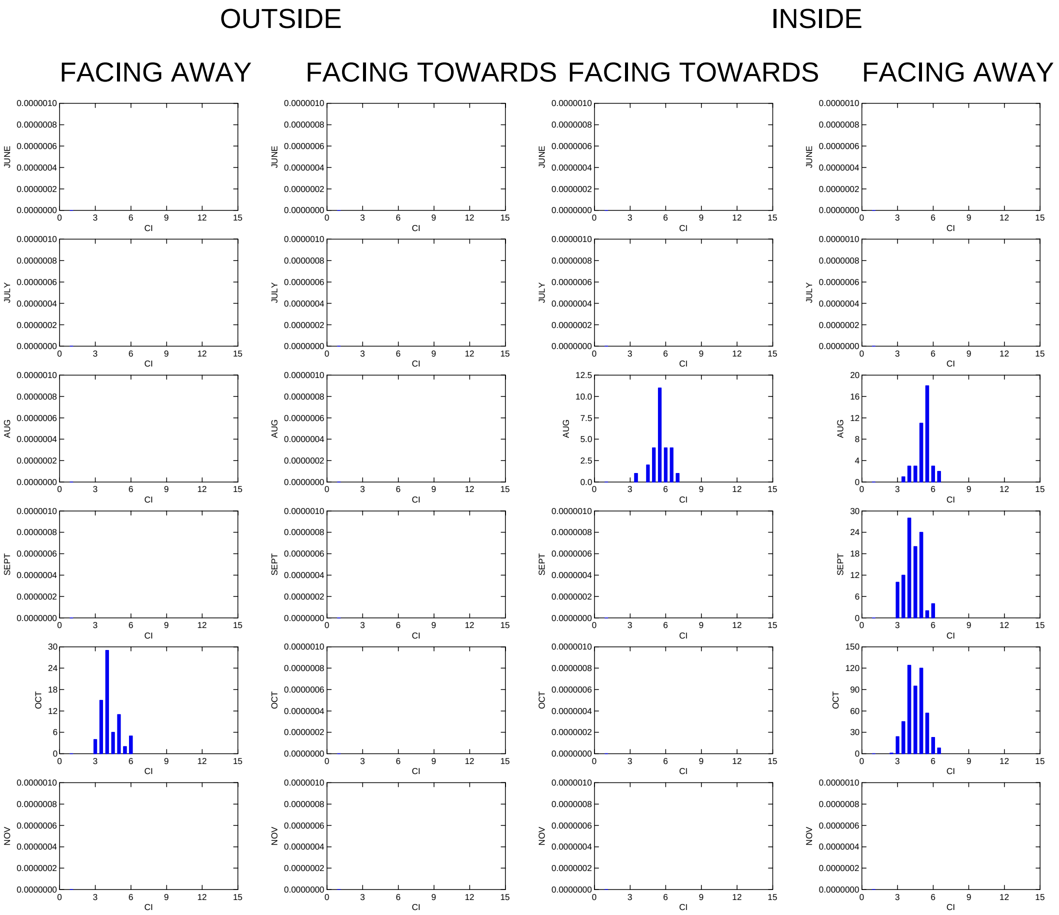

Figure 38 Length Frequency distributions of *Puntius sophore* sampled from interceptory gears operating inside and outside and facing away from and towards the Baulikhola sluice gate between June and November of study year 1.

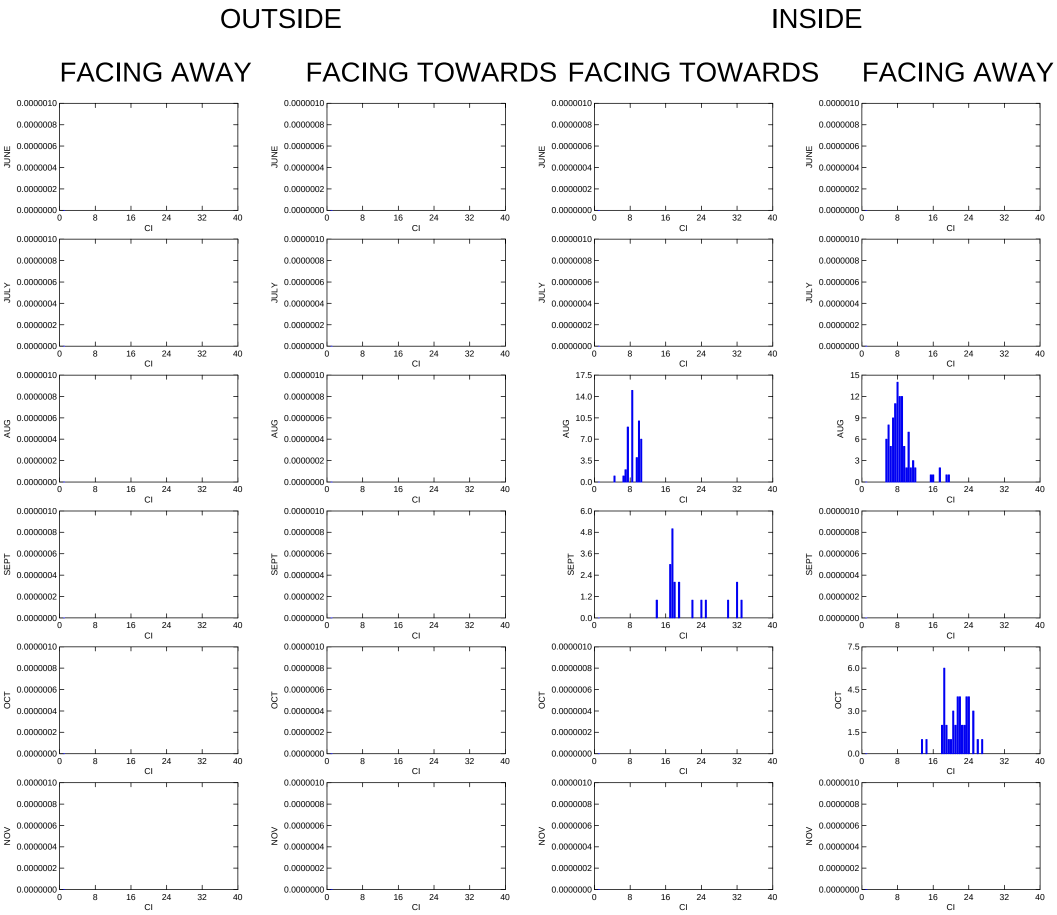

Figure 39 Length Frequency distributions of *Labeo rohita* sampled from interceptory gears operating inside and outside and facing away from and towards the Baulikhola sluice gate between June and November of study year 1.

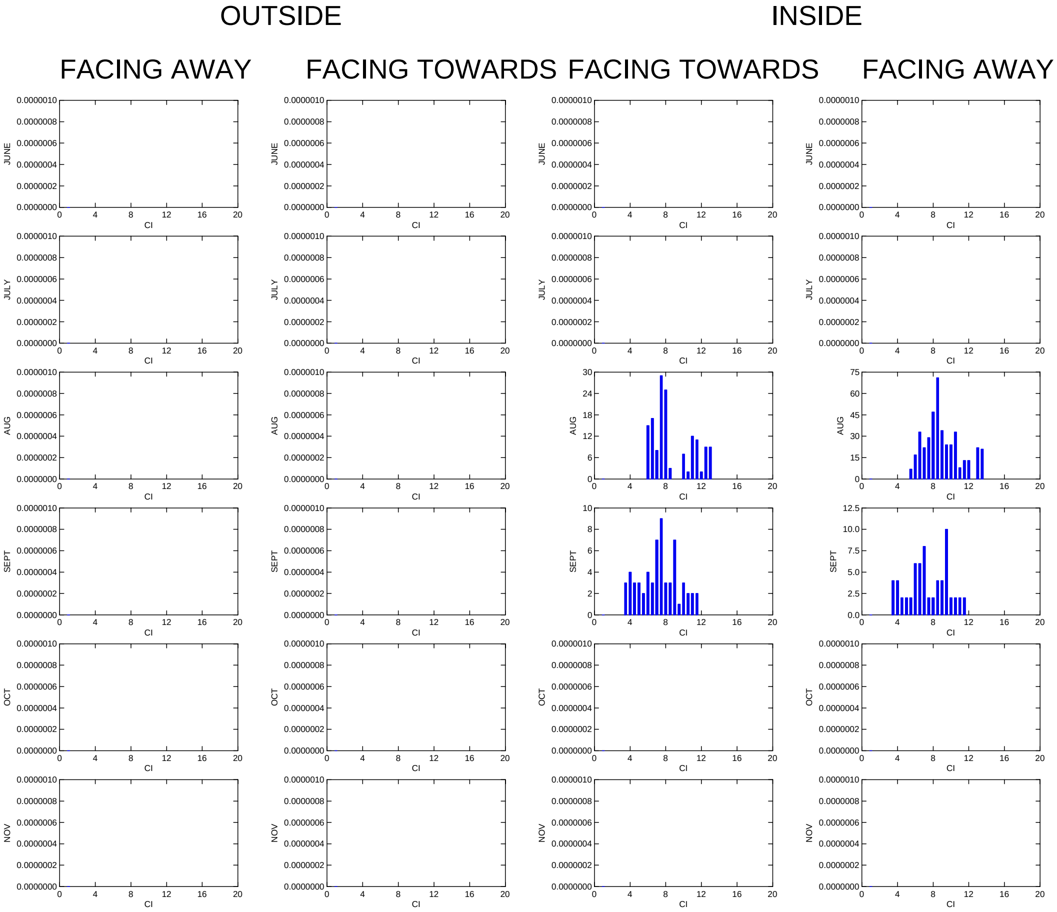

Figure 40 Length Frequency distributions of *Glossogobius giuris* sampled from interceptory gears operating inside and outside and facing away from and towards the Baulikhola sluice gate between June and November of study year 1.

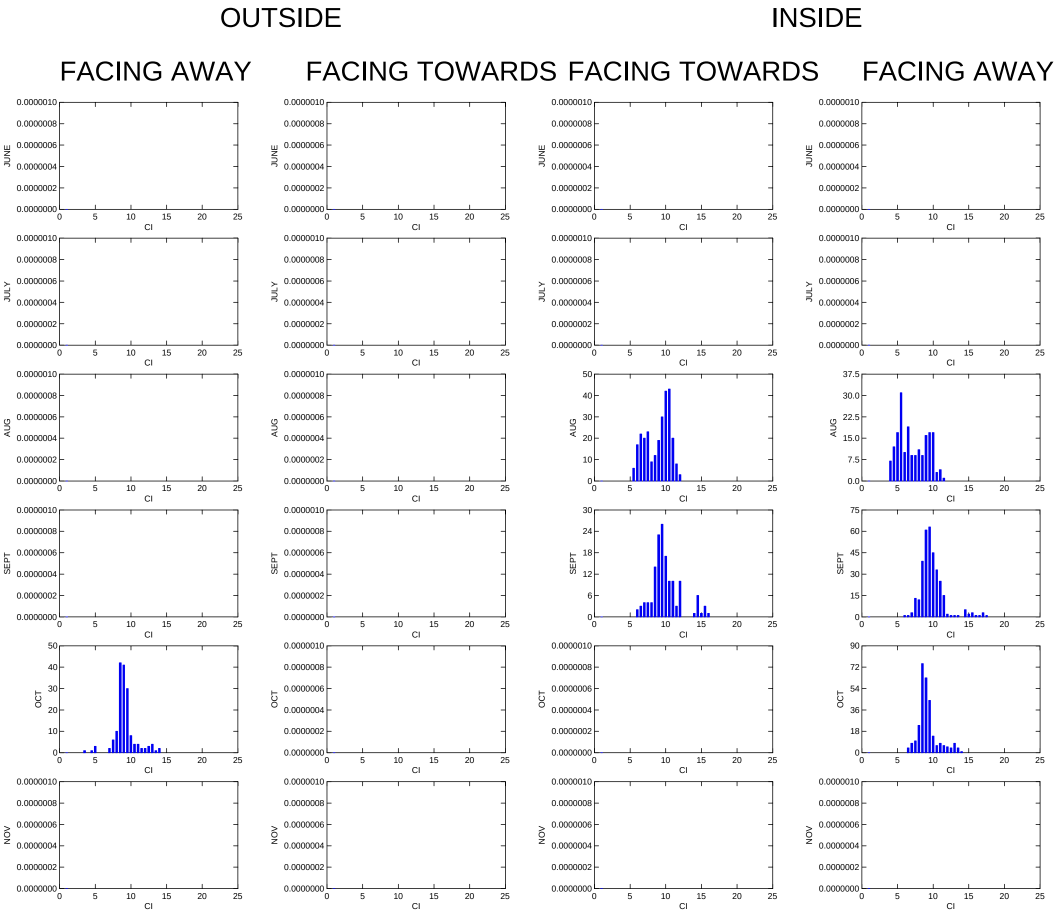

Figure 41 Length Frequency distributions of *Cirrhinus reba* sampled from interceptory gears operating inside and outside and facing away from and towards the Baulikhola sluice gate between June and November of study year 1.

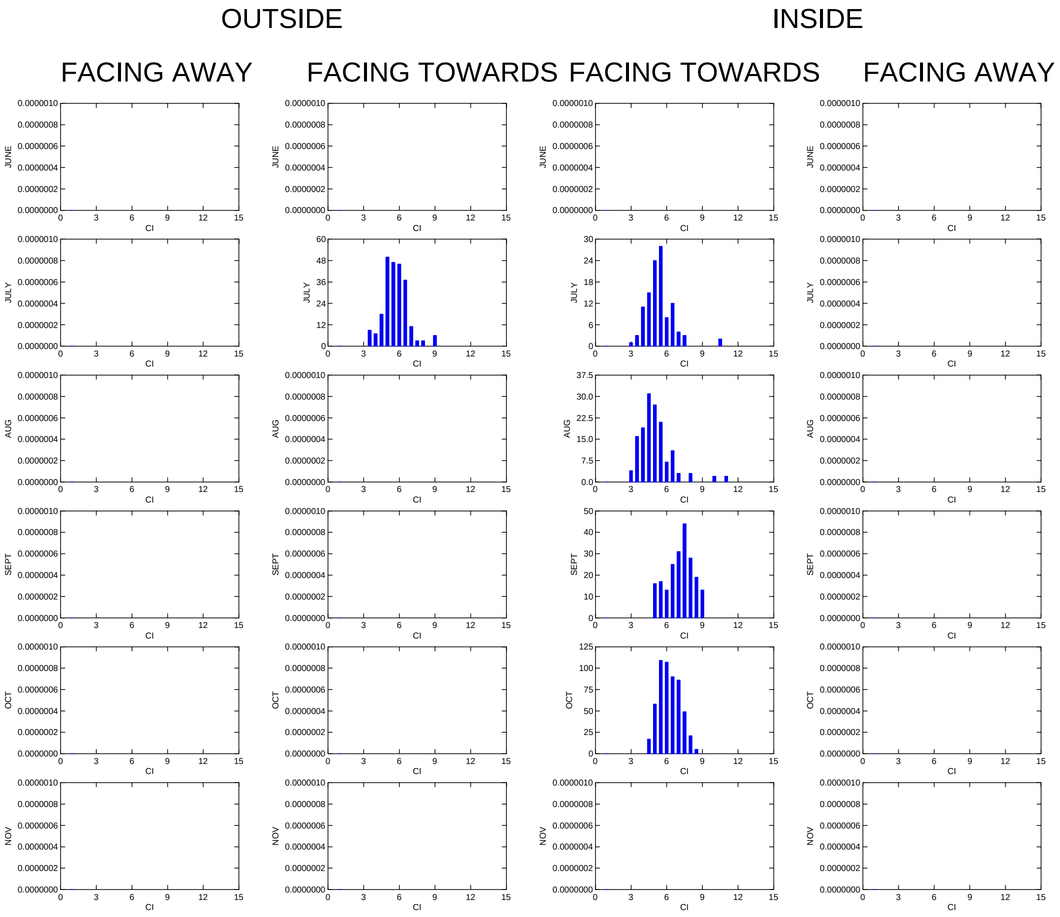

Figure 42 Length Frequency distributions of *Puntius sophore* sampled from interceptory gears operating inside and outside and facing away from and towards the Jugini sluice gate between June and November of study year 1.

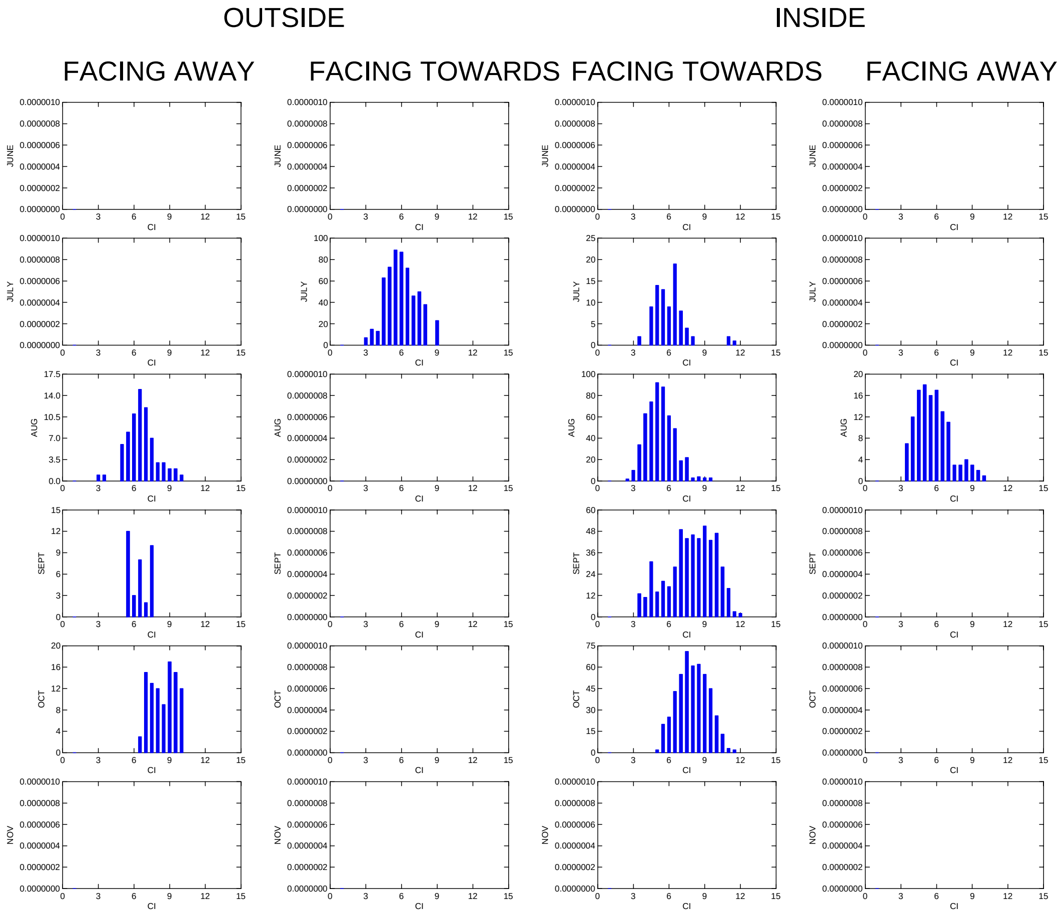

Figure 43 Length Frequency distributions of *Mystus vittatus* sampled from interceptory gears operating inside and outside and facing away from and towards the Jugini sluice gate between June and November of study year 1.

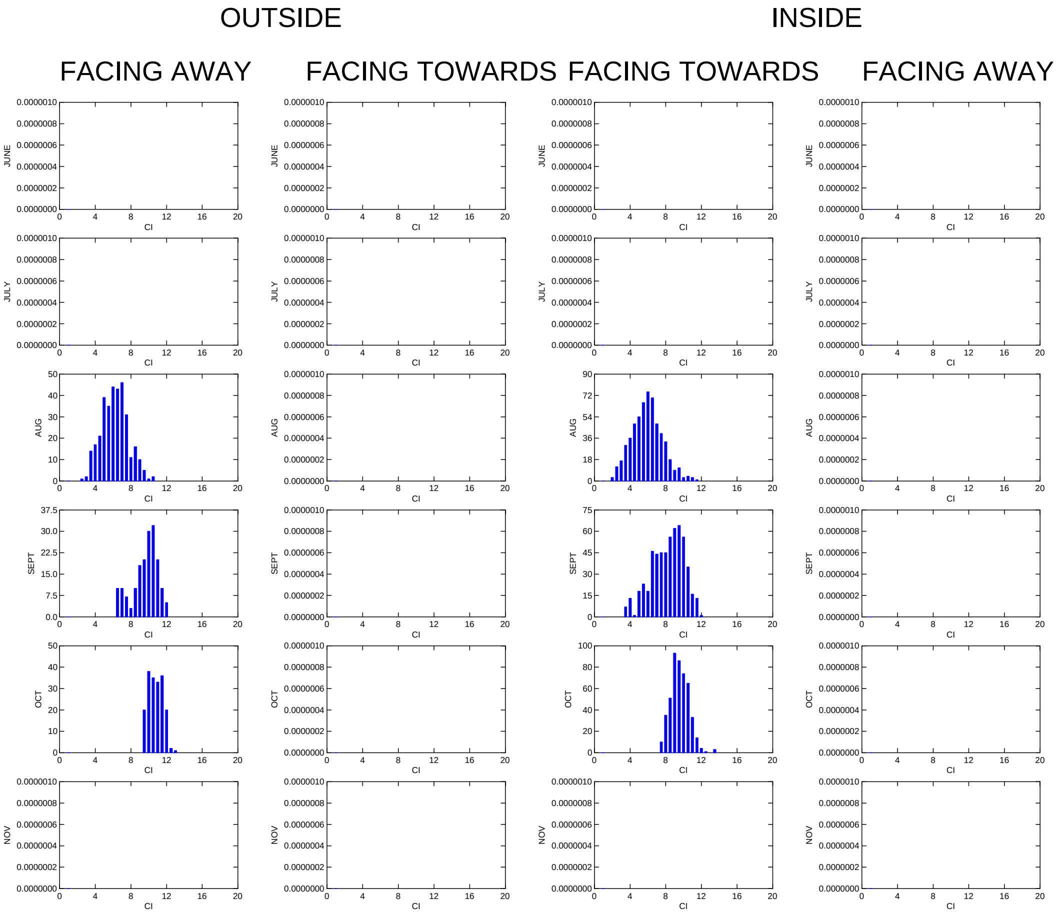

Figure 44 Length Frequency distributions of *Mystus cavasius* sampled from interceptory gears operating inside and outside and facing away from and towards the Jugini sluice gate between June and November of study year 1.

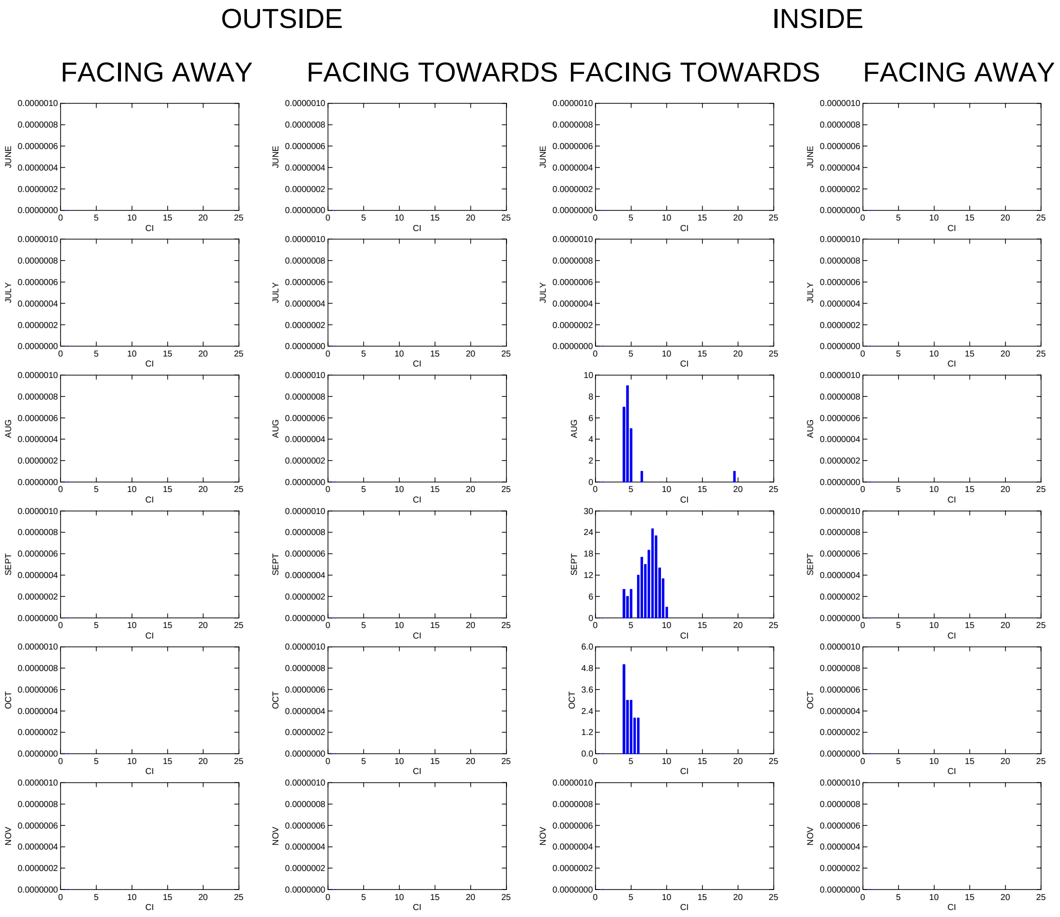

Figure 45 Length Frequency distributions of *Hilsa ilisha* sampled from interceptory gears operating inside and outside and facing away from and towards the Jugini sluice gate between June and November of study year 1.

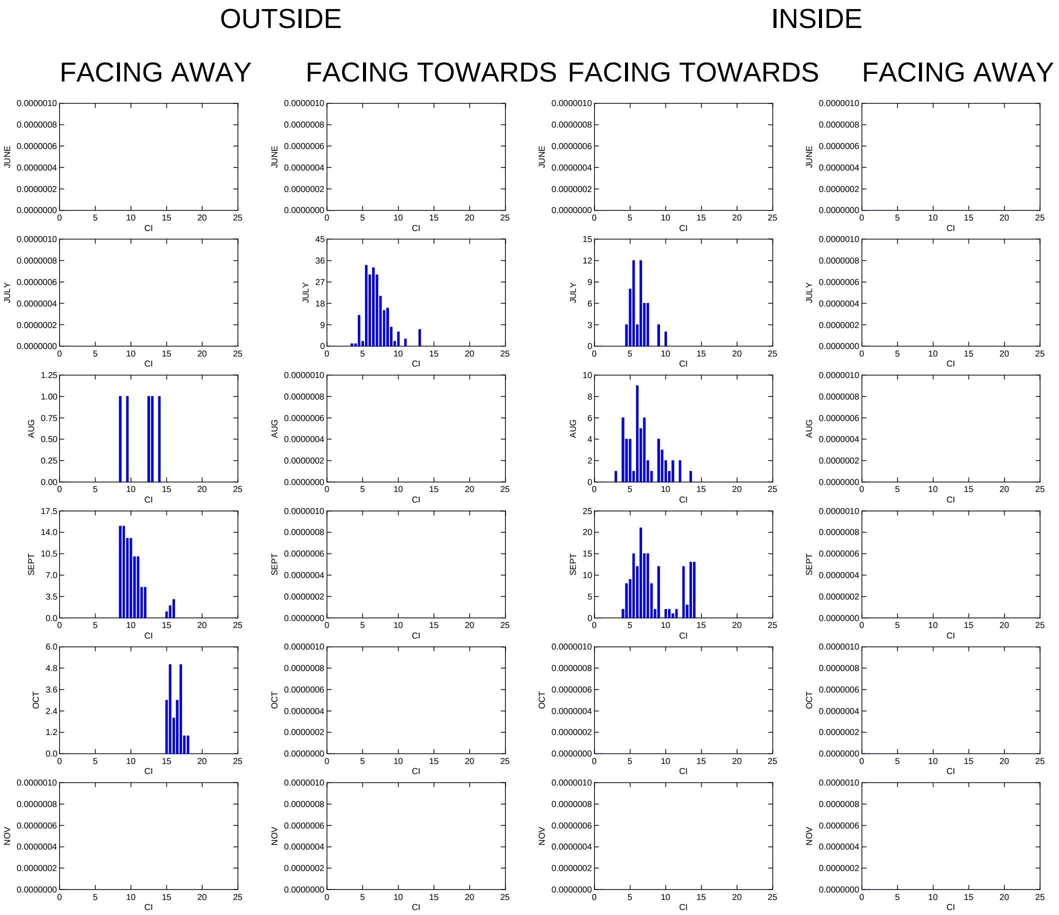

Figure 46 Length Frequency distributions of *Glossogobius girius* sampled from interceptory gears operating inside and outside and facing away from and towards the Jugini sluice gate between June and November of study year 1.

Annex B: PowerPoint presentation delivered at the project dissemination workshop in Dhaka, January 30, 2005.