WATER MANAGEMENT AND THE DRIFT OF LARVAL FISH IN THE FLOODPLAINS OF BANGLADESH

Practical experiences of the Compartmentalization Pilot Project with "fish friendly" regulators

Gertjan de Graaf
Nefisco Foundation
Lijnbaansgracht 14 C
Amsterdam
The Netherlands
deGraaf@NEFISCO.org
www.NEFISCO.org

Abstract

Larval fish drift and distribution patterns were studied in the Lohajang River, a tributary of the Jamuna River (Bangladesh) during the monsoon seasons (June-October) of 1992, 1993 and 1994. Larval fish drift pulsed with peaks related to water levels of the Jamuna River In all three years Indian carps *Catla catla, Labeo rohita, Cirrhinus mrigala* were associated with the first pulses but were absent from drift samples after September. *Hilsa* species and other non-identified fish species were found throughout the monsoon season. The highest larval fish densities were found in the upper strata of the river, near the shore. Drift densities for these fishes were temporally homogeneous within days. Water turbidity probably influenced vertical and horizontal distribution patterns and the absence of diel distribution patterns. The results were used for the design and construction of a major regulator for the water management of Lohajang River and its surrounding floodplains. The regulator consisted of three main vents for water regulation and two side vents for passages of drifting fish larvae. In 1998/99 the impact of the regulator on drifting larvae was measured indicating a mortality rate of 10% for larvae passing through the fish gates and mortality rates of 11.8% and 44% for larvae passing through the main gates if operated in respectively overshot and undershot mode. This impact is discussed in relation to declining yields of riverine fish and the construction of fish passes in the floodplains of Bangladesh and it was concluded that improvement of existing regulators to wards operating in overshot mode could be more cost effective then the construction of new fish passes.

Key words: larval fish drift, Indian carps, Hilsa spp., diel and spatial distribution patterns, flooding, water management, sluice gate management, fish passes, Bangladesh.

Introduction

Fisheries production in Bangladesh, as in other exploited floodplain fisheries around the world, is strongly related to flood sequence. Floodplains inundated during monsoons are nutrient rich and play a significant role as nurseries for many larvae and juvenile fish species (Welcomme, 1985; Bayley, 1988; Junk *et al*., 1989). Between 1970 and 1990, around 2.1 million ha of floodplain were removed from river fisheries production because of the construction of levees (Siddiqui, 1990). In Bangladesh, like in many other countries, water entering floodplains is controlled in one way or the other. One way to manage the water entering a floodplain is with a regulator and over the last 20 years, about 7000 regulators were constructed for this purpose in Bangladesh. However, the water entering the floodplain (mainly in the beginning of the monsoon) contains large numbers of riverine fish larvae (de Graaf *et a*l., 1999) and a major question is *“How to manage the water without adverse impact on fisheries “*

The Compartmentalization Pilot Project, a water management project in Tangail, Bangladesh (Figure 1) studied different aspects of larval drift and water management during its design, construction and implementation over the period 1992-2000. The major results of this study are presented in this paper.

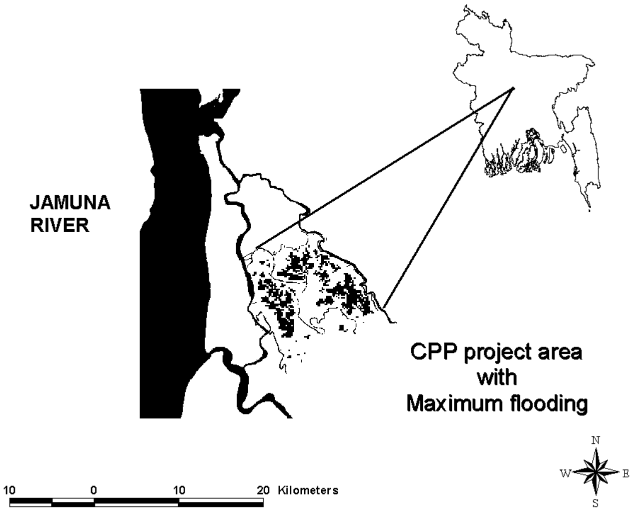


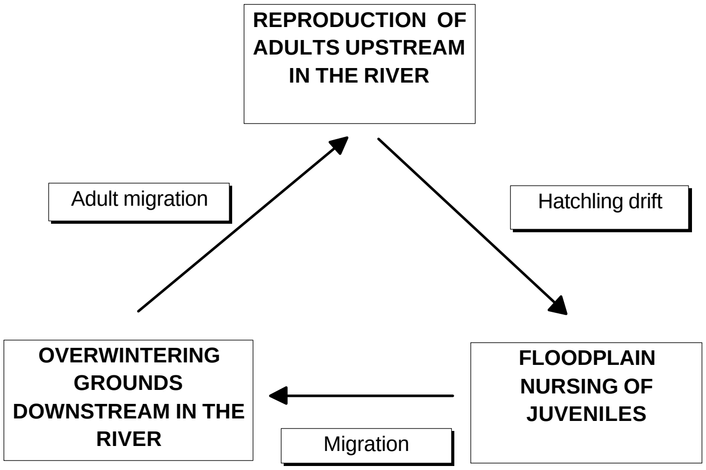
Figure 1: The CPP project in Bangladesh

First, general characteristics of hatchling drift in the main river were studied. The results were incorporated in the design and construction of the main regulator in the project area. After construction of the regulator, it was tested to see if the concept worked The results were used to formulate new design or management criteria for regulators in Bangladesh and compared with the construction of fish passes.

Fish migration and larval drift in Bangladesh

On the basis of their behaviour, mainly related to migration and reproduction, the fish species of Bangladesh can be divided in two groups: “whitefish” and “blackfish” (Sao-Leang and Dom Saveun, 1955). “Blackfish” species are able to tolerate the de-oxygenated water conditions of dry season floodplain water-bodies and may spend most of their lives in a single water-body. These include species such as snakeheads (*Channidae*), catfish (*Heteropneustidae*) and climbing perch *(Anabas testudineus*). “Whitefish” migrate upstream and laterally to the inundated floodplains adjacent to the river channel in the late dry season or early rainy season in order to spawn in the nutrient-rich waters. The eggs and larvae of these species are drifting downstream and are entering the floodplain with the floodwater, where they feed on the developed plankton. At the end of the rainy season, the adults and young of the year escape/migrate to the main river channel in order to avoid the harsh conditions of the floodplain during the dry season. Whitefish or riverine fish in Bangladesh consist mainly of the Indian carp like *Catla catla, Labeo rohita ,* and *Cirrhinus mrigala*, and they compose 5-10% of the total inland catch of Bangladesh (, 1999, de Graaf et al., 2001)

Figure 2: Riverine fish migration in Bangladesh



Migration and spawning of the major carp in Bangladesh was first studied by Tsai and Ali in 1983-85 (Tsai & Ali, 1986). They found that the major carp in Bangladesh were comprised of three stocks: the Brahmaputra stock, Padma stock and the Upper Meghna stock. The Brahmaputra stock is the largest stock in Bangladesh, and its spawning grounds are located in the Southern tributaries of the Brahmaputra river in the Assam Hills and Letha Range, Assam, India (Alikhuni, 1957 and Jhingran, 1991). Upstream migration of adult major carps in the Jamuna/Brahmaputra River starts in March, coinciding with the gradual rise of water level. Spawning starts in May, with the onset of the Southwest monsoon, and continues until the end of July (Azadi, 1985, Shaha and Haque, 1976 and Tsai and Ali, 1986).

The long range of the migration of riverine fish and the return of the larvae makes them vulnerable. Large numbers of adults are caught before they reach the spawning places. The newborn larvae are searched for by predators and fishermen, and encounter numerous water management structures such as sluices and regulators before they are back in the floodplains. Consequently, their numbers decline significantly on their way down towards the floodplain as indicated by Tsai and Ali (1986).

Larval drift in the CPP project area

1.1.1 Introduction

In order to minimise the negative impacts of controlled flooding on hatchling migration, it must be known, where, when, and how the larval fish are moving through the river. Almost no information was available on this and therefore CPP investigated the larval movement and larval distribution patterns in the Lohajang River during the monsoon of 1992, 1993 and 1994 (de Graaf *et al*., 1999, de Graaf et al., 2001) and the major results are summarised below.

1.1.2 Material end methods

Nets with a mesh-size smaller then 0.5 mm were placed in the Lohajang River. The opening of the net was made of iron rod and had a surface area of 0.125 m2. At the side and at the middle of the river a net was placed 30 cm above the bottom of the river and a second net just below the surface. The flow rate of the water was determined with a floating object, and during 1993, the 'real' flow rate was measured three times a week with a flow meter. The nets were placed at daytime and at nighttime for 1 hour. The caught larvae were preserved in formalin (8%), counted and identified in the laboratory. Results of the sampling programme were calculated/expressed in hatchling density or the number of fish larvae per cubic meter of water (No/m^{-3})

1.1.3 Results and discussion

The larvae were coming in waves (Figure 3, Figure 4 & Figure 5) and it seems that the peak of the waves is related to peak water levels of the Jamuna River. In all three studied years, larvae of Indian carp: *Catla catla, Labeo rohita , Cirrhinus mrigala* were found within the first waves only and were absent after the first of September. Hilsa *spp. (Tenualosa)* and other non-identified species were found throughout the monsoon.

Figure 3: Hatchling drift in the Lohajang River 1992

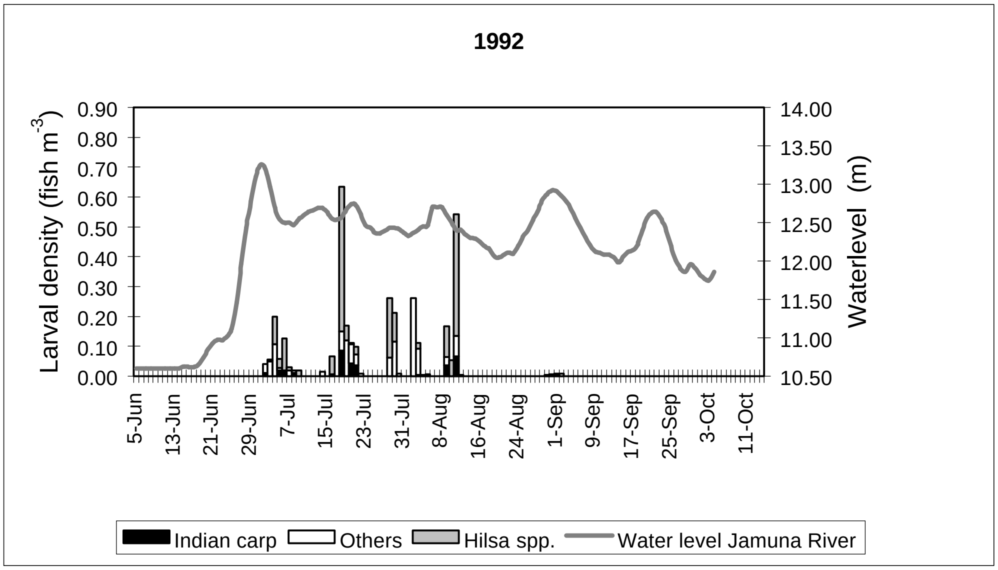


Figure 4: Hatchling drift in the Lohajang River 1993

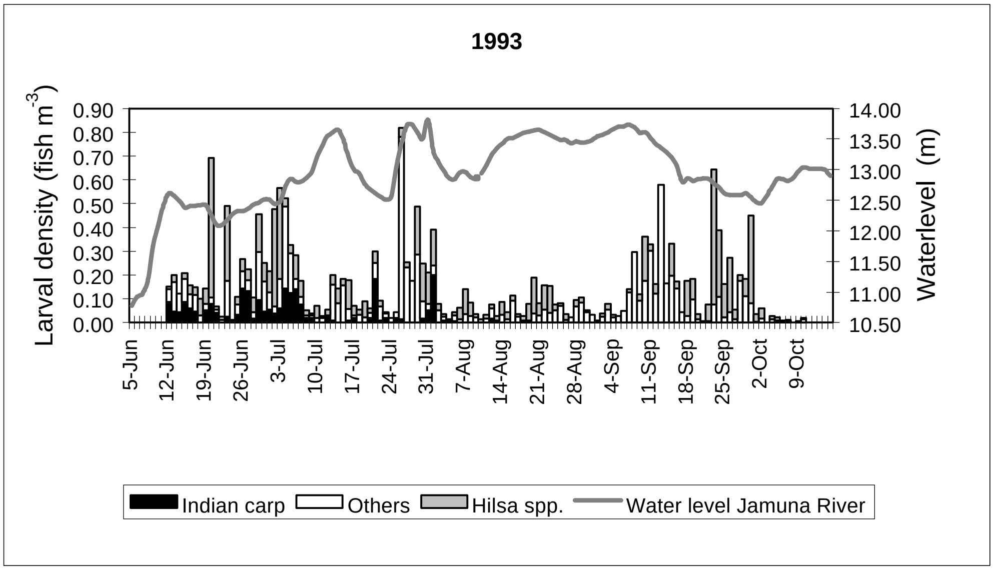
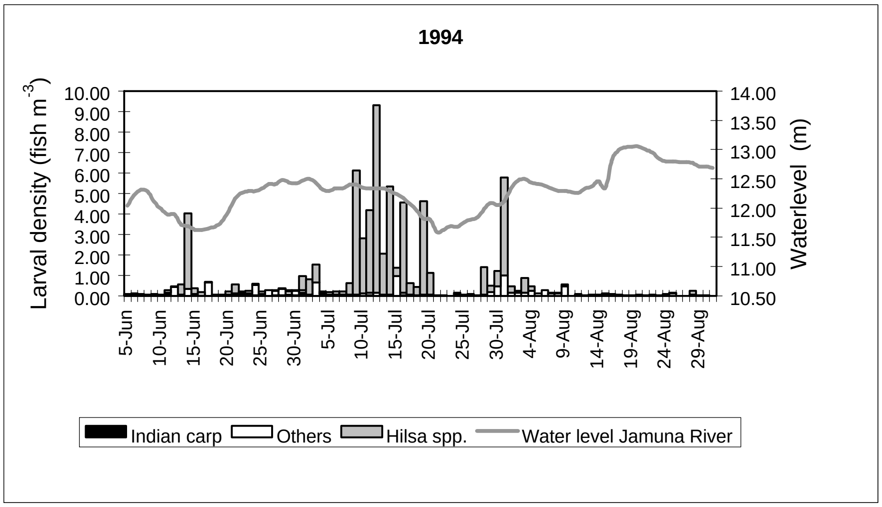


Figure 5: Hatchling drift in the Lohajang River 1994



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

Further, significantly higher hatchling densities were found in the surface layer of the river near the embankment and no diurnal (night versus day) distribution patterns were found (Table 1 and 2).

Table 1: Mean density (Fish*m^{-3}, ± s.e.m) of all larval fish, collected at daytime, during 1993 using nets placed in the channel and along the shoreline near the surface and bottom of the Lohajang River. Different superscripts indicate significant differences ($P \leq 0.05$)

Location in water column	Mean density Shore location	Mean density Middle location
Surface	0.165 ± 0.015^a	0.094 ± 0.012^b
Bottom	0.126 ± 0.016^a	0.023 ± 0.005^b

Table 2: Mean density (Fish*m$^{-3,}$ ± s.e.m) of all larval fish, collected during day and night samples, in 1992 and 1993, in nets placed near the surface along shorelines of the Lohajang River. Different superscripts indicate significant differences ($P \leq 0.05$) between surface and bottom samples within one year

Location in water column	Mean larval density 1992 (Fish.m^{-3})		Mean larval density 1993 (Fish.m^{-3})	
	Day-time	Night-time	Day-time	Night-time
Surface	0.076 ± 0.020^{a}	0.129 ± 0.034^{a}	0.165 ± 0.015^{a}	0.153 ± 0.014^{a}
Bottom	0.051 ± 0.012^{b}	0.064 ± 0.014^{b}	0.126 ± 0.016^{b}	0.164 ± 0.019^{a}

The turbidity of the river water is most likely the force behind the presence of vertical and horizontal distribution patterns and the absence of diurnal distribution patterns. Similar results were reported for fish larvae in the Amazon River. Pavlov et al. (1995) found that larvae from the same taxonomic group drifted in different layers of the water column in different rivers. In a turbid river, e.g. the Amazon River, *Characiformes* larvae migrated through the mid-depth/surface, while in a clear-water river, e.g. the Nanay River, they migrated through the mid-depth layer. The Lohajang River is a turbid river and its turbidity or sediment load may be a regulating force in vertical and horizontal distribution patterns of fish larvae.

The implication of the study results for water management and design of the main regulator in the project area

There is sometimes confusion about fish passes and fish gates, especially as related to maximum flow rates. A fish pass allows adult fish at the end of the winter to migrate, actively against the current, towards the spawning places. In general, flow rates for Indian carp should not exceed 0.7-1.0 m*sec^{-1} if we apply Weihs optimum for sustainable swimming speed (Weihs, 1973). Otherwise, the fish will not able to pass. Fish gates are regulators constructed in such a way that fish larvae drift smoothly with the current into the floodplain. Here not the current but the physical design and mode of operation are more important.

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

The results of the study showed that spawning of major carp in the Jamuna River only takes place during the first 8-10 weeks of the flood. Maximum recruitment of Indian carp is therefore obtained if the routes between the river and the floodplain are maintained open during this period.

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

1.1.4 The design and construction of the major regulator

The function of the main inlet regulator was to provide security and protection for the project area during high floods, and to maintain an appropriate water level in the Lohajang River, which would facilitate controlled flooding and drainage in the project area. Moreover, the main inlet regulator should be controlled and operated, in such a way that it should not be detrimental to fish migration from the main rivers into the floodplain.

The main inlet regulator in the Lohajang River had a regional function. The head-loss from the discharge through the structure had to be not too high for a typical peak flow in the Lohajang River that was estimated at about 80 m^3 sec^{-1}. A three-vent structure with 3 m by 3 m vent sizes would give this discharge, with a head-loss over the structure of 0.7 m.

For the design the following preliminary criteria were formulated in respect to larval fish drift:

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

Combining these findings, the main regulator was designed and constructed as a five-vent regulator (Figure 6). The three central vents are two part undershot gates of 3x3 m; the two outer vents (1.5x3 m), the "fish gates", are operated as free surface vents. The side vents would be the last to be closed in extreme water level situations, The divider piers for the outer vents would be extended to reduce interaction with the turbulence of the undershot gates. With these conditions, it was expected that the gate operation could be developed to give the required control of the downstream water level throughout the monsoon season, while the impact on the drift of fish larvae was limited to some extent. However, its major function was still "water management".

Figure 6: The main regulator in the Lohajang River

Impact of the constructed regulator on drifting fish larvae

The main regulator constructed in the Lohajang River could be called “fish friendly” if only the location of the drifting fish larvae was considered. It was, however, not known what happens with the fish larvae once they pass through the fish gates or main gates of the regulator. This aspect was first studied in 1998/99. Fingerlings/hatchlings of Indian carp obtained from commercial hatcheries, were released in front of the regulator and were caught just before and just after the regulator, after which mortality rates of the two groups were compared with a non-treated control group.

Results of one of these experiments are presented as an example. The head difference during this experiment was 0.95 meters (upstream 11.95, downstream 11,0); only the fish passes were open, and the average weight of the larvae was 0.30 grams. 20 000 were released immediately after arrival at the site. A sufficient number of fry could be caught (upstream 854, downstream 700). After 72 hours, 32% of the downstream larvae, 23% of the upstream larvae, and 8% of the control group were dead. The experiment indicated that even the *“fish friendly fish gate”* has a negative impact on passing larvae. However, the results presented here were obtained from a clear experiment; not all the experiments confirmed these results, and no firm conclusion could be drawn.

In 1999, the experiments were repeated (Marttin and de Graaf, 2001). A mix of larvae consisting of *Labeo rohita* L., *Catla catla* L., *and Cirrhinus mrigala* L. was used. At least 20000 larvae were used per experiment with an average weight of 0.21 grams ± 0.13. The larvae were released upstream of the regulator, after which they were caught just before and just after passing the regulator. One to two hours after the release of the hatchlings, mortalities of a non-treated control group and the upstream and downstream groups were compared, to determine the impact of the regulator and the two gate settings. Unfortunately, the monsoon of 1999 was very dry and experiments could be carried out at *the main gates only*.

The results of the 1999 experiments are presented in Table 3

Location	Mortality (%)	n
Control group	$7.2^{A} \pm 1.5$	10
Upstream regulator	$16.6^{A} \pm 2.2$	10
Downstream regulator	$41.4^{C} \pm 7.2$	10

Table 3: Mortality rates (± s.e.m)) of released carp hatchlings caught in front of the regulator and after passing the main gates of the regulator in comparison to a non-treated control group (different superscripts indicate significant difference *P£0.05*

These results indicate that on average 25% of all fish larvae passing the main gates of the regulator are dying because of this passage.

During the experiments, the regulator was operated in two different modes: *Overshot, Undershot* (Figure 7) and this highly influences the mortality rates. The mortality rates of the regulator on the fish larvae for the different modes of operation are presented in Table 4.

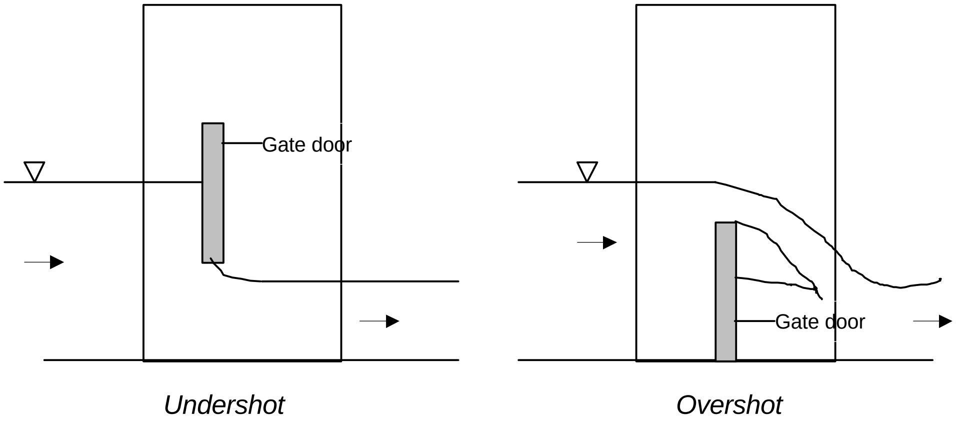


Figure 7: Illustration of under and overshot operation of the main regulator

Mode of operation	Mortality rate (%)	n
Overshot	$11.8^{B} \pm 3.6$	6
Undershot	$44.0^{A} \pm 5.6$	4

Table 4: Mortality rates of carp hatchlings (± sem) for under and overshot operation of the main gates of the regulator.

About 44% of the hatchlings died within 2 hours after passing the main gates of the regulator if used in an undershot mode, which is the standard mode of operation in Bangladesh. When the main gates of the regulator were used in an overshot mode the mortality reduced significantly to about 11%.

From the results it can be concluded that the main gates of the constructed regulator have a huge impact on passing fish larvae especially if used in an undershot mode of operation. It is generally believed in Bangladesh that regulators should be designed for and operated in an undershot mode However, hydrological modelling indicated that the regulator in CPP can be operated without any adverse impact on water regulation completely in a *“fish friendly”* mode with overshot operation of the vents only (de Graaf et al., 2001). It is therefore strongly recommended to include this aspect in future design and construction of regulators in Bangladesh and other comparable floodplain ecosystems.

Fish gates or fish passes

The first fish pass in Bangladesh was constructed in the early 90’s and presently a Worldbank funded project envisages the construction of a number of new fish passes in the floodplains of Bangladesh. The question arises whether this intervention will mitigate the problem of *“declining catches of migratory fish species in Bangladesh”*

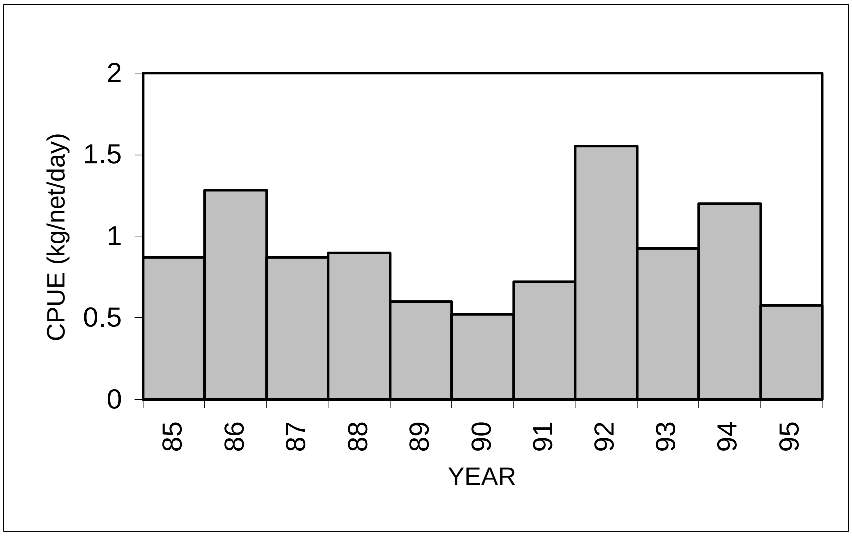
In numerous fisheries studies carried out in Bangladesh in the last decade, blockage of migratory routes is mentioned as a major problem for migration of riverine species (FAP 17, FAP 16, CPP, 1994). If migration of riverine species is discussed, the understanding of the different forms of migration/drift is of importance as each type can be hampered in different ways and requires different interventions to improve the present situation. In principle, riverine migratory fish species in Bangladesh have two types of migratory behaviour:
The outward active migration of the adults from the deeper water bodies towards the river in the pre-monsoon and further upstream migration towards the spawning grounds located upstream in the rivers. If this migration is blocked then a “fish pass” could be used to improve the situation. A fish pass is a structure that facilitates spawning migration against the current towards the river system. This is the reason why flow rates in a fish pass are critical, as the adults must be able to swim against the current. Once the adult fish have spawned upstream in the river system, millions of eggs and larvae drift passively with the current towards the floodplains located downstream in the

system. On their way downstream, the larvae die in large numbers due to: predation, natural mortality, fishing activities and all the regulators they have to pass before they arrive at the floodplain. The latter can be enormous as the results from our study indicated that 44% of fish larvae passing a regulator operated in undershot mode die within 24 hours.

Interventions in the form of the construction of fish passes are based on the philosophy that the number of larvae in the system is decreasing due to the blockage of the migration route towards the spawning places. The assumption is that the stocks will recover by improvement of the spawning area and by enlarging of the spawning stock and this is obtained by the construction of fish passes

The first question is: did the number of larvae drifting in the major rivers in Bangladesh decline in the last decade?
Surprisingly, the official statistics of the BFRSS on the catch of larval fish in the major rivers seem to indicate that there have been no changes in the Catch per Unit of Effort of the Savar nets, nets that catch larvae of Indian carp, which are sold to fish farmers over the period 1985-1995 (Figure 8). The CPUE is an indication of the abundance of the larval density, and it would mean that since 1985, the larval density of Indian carp in the major rivers did not change significantly. What the situation was before 1985, we do not know.

Figure 8: The average CPUE of the Savar nets in the major rivers of Bangladesh (source BFRSS, 85-95)



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

The problem could be looked upon from another angle. We monitored hatchling drift during three years and the results indicated that about 35-40 million larvae were entering the project area annually, resulting in a catch of 10-20 Mt/year of riverine fish, which encompasses about 3-8% of the total annual catch (de Graaf et al., 2001). Combined with the results of the experiments on the mortality rates of the larvae passing the main regulator it could be concluded that:

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

If this were also the case for the whole of Bangladesh it would mean that a major impact could be expected if a programme would focus on the improvement of the management and where possible on the adaptation of existing regulators in the river system, i.e. a change towards the use of the regulators in *“overshot mode”* in stead of the conventional *”undershot mode”*

The latter could be more cost effective as illustrated by the following example

Annually 40 million larvae are entering the CPP project area of which at least 20 million die due to the regulators operated in undershot mode. In order to bring 20 million larvae back into the natural system, a “fish pass” has to be constructed, which allows 2,200[1] *adult fish to migrate each year upstream towards their spawning places.*

It is therefore strongly recommended to look at all these aspects more in detail before interventions are implemented. This as the construction of fish passes only, without addressing the operation of the regulators could be ineffective.

Further, we have to look at the regional differences. For example, a fish pass in the CPP area would be a waste of money because there are no carp left to migrate back to the river system and because the hydrological connection between the main river system and the beels takes place too late in the season. However, this situation could be completely different in areas with large water bodies and permanent connections with the major river system or in water bodies where the outward migration is seriously hampered and where recruitment is a major bottleneck for maintaining a sustainable natural population

---

[1] Calculated with 5% survival from egg to 3-day-old larvae under natural conditions and a fecundity of 3 000 000 eggs per female (www.fishbase.org)

Acknowledgement

The work reported in this paper was carried out as part of the Compartmentalisation Pilot Project carried out by the Ministry of Irrigation, Water Development and Flood Control. The project was funded by the Government of the Netherlands and the Federal Republic of Germany. The views and conclusions in this paper were expressed earlier in a final report of the Compartmentalisation Pilot Project and in a number of publications (de Graaf et al, 1997, de Graaf et al, 2001 and Marttin and de Graaf, 2001). These are the responsibility of the authors only and do not imply the expression on the part of the Government of Bangladesh, the Government of the Netherlands or the Government of the Federal Republic of Germany.

The field experiments could only be carried out thanks to the excellent work the CPP monitoring staff; Mr. Leonus Gomez, Mr. Nuruzzaman, Mr. Rafiquel Islam, Mr. Liakat Ali and Mr. Jamal Uddin. Finally, the continuous support of the different team leaders and project directors of the CPP project is greatly acknowledged

References

Alikhundi K.H. (1957) Fish culture in India. Bulletin Indian Council Agriculture Research 2, 144 pp.

Azadi M.A. (1985) Spawning of commercial freshwater fish and brackish and marine water shrimps of Bangladesh. Bangladesh Fisheries Information Bulletin 2, 74 pp.

Bayley, P.B. , 1988. Factors affecting growth rates of young tropical floodplain fishes: seasonality and density-dependence. Environmental Biology of Fishes 21; 127-142

Compartmentalisation Pilot Project (FAP20), 1994. Final Report Special Fisheries Study. Technical Note TN 94/1. 86 pp.

Compartmentalisation Pilot Project (FAP20), 2000 (a). Final report, Fisheries annex. 55 pp.

de Graaf, G.J., Born, B., Uddin, A.M.K. and Huda, S., 1999. Larval fish movement in the Lohajang River, Tangail, Bangladesh , Journal of Fisheries Management and Ecology, 6: 109-120.

de Graaf, G.J., Born, B. Uddin, K.A. and Marttin, F. 2001. Floods Fish & Fishermen. Eight years experience with floodplain fisheries, fish migration, fisheries modelling and fish biodiversity in the compartmentalization pilot project, Bangladesh. The University Press Limited, Dhaka, 108 pp.

Department of Fisheries (DoF), 1983-1999, Fish catch statistics of Bangladesh, Department of Fisheries, Dhaka, Bangladesh, 330 pp.

FAP (Flood Action Plan) 17, 1995. Final report-Main volume. Overseas Development Administration, UK.

FAP 16, Potential impacts of Flood control on the biological diversity and nutritional value of subsistence fisheries in Bangladesh, ISPAN, Environmental Study, Dhaka, Bangladesh, 72 pp.

Jhingran V.G. (1991) Fish and Fisheries of India. Delhi: Hindustan Publishing Corporation (India). 727 pp.

Junk, W.B., P.B. Bayley and R.E. Sparks, 1989. The flood pulse in river floodplain systems. In D.P. Dodge (ED.) Proceedings of the International Large River Symposium. Can Spec Publ Fish Aquat. Sci., 106:110-127.

Marttin, F. and G.J. de Graaf, (2001, in press) The effect of a sluice gate and its mode of operation on mortality of drifting hatchlings in Bangladesh. (Fisheries Management and Ecology).

Mitra G.N. (1968) Production of quality fish seed of Indian major carps in the Mahani river system in Orissa. Proceedings of seminar on production of quality fish seed for fish culture. ICAR/CIFRI, Barrackpore, India.

Pavlov D.S., Nezdoliy V.K., Urteaga A.K. & Sanches O.R. (1995) Downstream migration of juvenile fishes in the rivers of Amazonian Peru. Journal of Ichthyology 35, 227-248.

Shaha M.S. & Haque A.K.M.A. (1976) Qualitative and quantitative study of samples of fry and fingerlings of major carps from the old Brahmaputra River at Mymensingh. M.Sc. thesis, Dept. of Fisheries Biology and Limnology, Bangladesh Agriculture Univ. Mymensingh, Bangladesh.

Siddiqui, M.H. 1990. Flood control and drainage development: Physical Environmental issues. In: A.A. Rahman, S. Huq and Conway, G.R. (Editors), Environmental aspects of surface water systems of Bangladesh. University Press Ltd. Dhaka, pp.104-108.

Soa-Leang and Dom Saveun (1955) Apercu general sur la migration et la reproduction des poissons d’eau douce du Cambodge. Proc IPFC, 5: 138-162.

Tsai, C.F. & Ali, L., 196. Carp spawn fishery in the Padma (Ganges)-Brahmaputra river system, Bangladesh. Indian J. Fisheries. 33, no 4: pp. 386-401.

Weihs, D., 1973. Optimal fish cruising speed for migrating fish. Nature, 245: 48-50.

Welcomme, R.L., 1985. River Fisheries. FAO Fish Tech. Paper 262. 330 pp.