ONSET OF MIGRATION AND BIOENERGETICS OF SELECTED FISHES OF BANGLADESH

A thesis submitted to the University of Dhaka, Bangladesh for the fulfillment of the degree of Doctor of Philosophy (Ph.D.)

Submitted by

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Dedicated

To

My beloved parents

MRS. MANJURI AKHTER and **LATE.MD. ANSARUZZAMAN**

Without their loveand encouragement this research could never been completed.

CERTIFICATION

This is to certify that thesis entitled "**Onset of Migration and Bioenergetics of Selected Fishes of Bangladesh**"submitted to the Department of Zoology, Faculty of Biological Science, University of Dhaka, Dhaka, Bangladesh, in fulfillment of the requirement for the degree of Doctor of Philosophy is a record of bonefide research work carried out by Ms. Maria Zaman (Registration No. 27, Session: 2012-13) under my supervision and suggestions. I have read this dissertation and that in my opinion it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy. Experimental work described in the thesis has been carried out by the author in the field and Department of Zoology, Dhaka University. The work is original and to the best of our knowledge, no part of this work has been submitted before any other degree or diploma.

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Declaration

I do hereby declare that the whole work submitted as a thesis entitled "**Onset of Migration and Bioenergetics of Selected Fishes of Bangladesh**" in the Department of Zoology, Faculty of Biological Sciences, University of Dhaka, Dhaka, Bangladesh, for the degree of Doctor of Philosophy is the result of my own investigation. No part of this thesis has been presented before for any degree, diploma or any other similar title to any University.

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ABSTRACT

The damming of rivers and canal has been a major contributor to the decline of fish migration and population in Bangladesh. Fish are confronted to a challenging hydrodynamic environment when they swim upstream. Nevertheless, the knowledge of fish behaviour in these conditions is limited, particularly for coarse species such as cyprinids. The principle focus of the study is to evaluate fish swimming behaviour in different hydrological condition, onset of migration, fish migratory behavior, swimming speed and survival in different of water velocity condition. *In situ* experiment in Sariakandi shows fish fry, hatching, juvenile and adult movement from Jamuna to Bangaliriver. After construction of the fish pass, the diversity of fish species of the Bengali River is increased. *Ex situ* experiments have been conducted in an indoor full scale vertical slot fish pass model with different sizes (fry, fingerling, juvenile and sub-adult) of cyprinid species Rui (*Labeorohita*), Catla (*Catlacatla*) and Mrigal (*Cirrhinusreba*) as well as some other test fishes. Different water velocity used to study fish cruising, sustained and burst swimming activity, indicating some degree of anaerobiosis occurs during crossing passage. Energy used by individual fish to pass the fish friendly structure varied greatly due to different migration behavior, passage routes, and the time it takes to pass related to water current. Mortality risk to the migrant is estimated. Results identified areas of difficulties in a fish passage that may be modified to help decrease energy use of upstream migrating fishes. The results emphasize the value of achieving a deeper understanding of fish requirements in these devices and show the potential of the methodology developed to fulfil this objective. Results can contribute to develop robust guidelines for future fishway designs in Bangladesh.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

LIST OF ABBREVIATIONS

ADV	Acoustic Doppler Velocimeter
BFRSS	Bangladesh Fisheries Survey Statistics
BRE	Brahmaputra Right Embankment
BW	Body Weight
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering and Technology
CEGIS	Centre for Environmental and Geographic Information Services
cm	Centimeter
CPP	Compartment Pilot Project
^{0}C	Degree Celsius
DoF	Department of Fisheries
DU	Dhaka University
DWRE	Department of Water Resources Engineering
FAP	Flood Action Plan
FCDI	Flood Control Drainage and Irrigation
FFS	Fish Friendly Structures
Fp	Fish Passes
FPP	Fish Pass Pilot Project
GBM	Ganges-Brahmaputra-Megna
g%	Gram percentage
h	Hour
IUCN	International Union for Conservation of Nature
Kcal	Kilo Calorie
L	Litre
m	Meter
mg/l	Milligram/ Litre

mm	Millimeter
m/sec	Meter/sec
min	Minute
μs	Microsecond
MRP	Manu River Flood Control and Irrigation Project
N	Normality
NWMP	National Water Management Plan
PPM	Parts Per Million
SD	Standard Deviation
TDS	Total Dissolved Solid
TL	Total length

INTRODUCTION

Bangladesh has the reputation of being very rich in inland openwater capture fisheries production. From the time of immemorial, river plays important role on the civilization and livelihood patterns of the people of Bangladesh. Being in the location in the delta of Ganges, Brahmaputra and Meghna, rivers and tributaries and distributaries are created. The overflow of the banks causing flood to the extensive low laying areas during monsoon. This creates a unique ecosystem for aquatic life for migration. During the monsoon period, the floodplains become the primary source of reproduction and increase of fish biomass in open water fisheries system. Fishes move out into floodplains for feeding, grazing, growth and reproduction during floods. Inundation of the floodplains provide the spawning grounds, nursery areas and major feeding opportunities for a wide range of fish and prawn species (Minkin 1989; Ali 1991). There are in total 265 species of freshwater fishes under 154 genera and 55 families in Bangladesh (Rahman 2005) and of which a good number of fishes are migratory. Many of these species travel considerable distance under the stimulus of rising of waters to reach their spawning grounds and also move over the floodplains when the water extends laterally (Tsai and Ali 1986; Ali 1990). The nature of fisheries ecosystem and the movement of the fishes are dictated by seasonal changes in water levels and discharge rates in extensive floodplain systems (Welcomme 1985). As the floodplains become inundated by rainfall and overbank flooding, some species of fishes, such as major carp begins a longitudinal migration to spawn. Over river begins to flood most fishes make lateral migration into the many distributary channels of the rivers. From these channels fishes start to move to floodplains to exploit the food resources of the flooded area. Fish species migrate from floodplain to river as the floodwater recedes (Aguero 1989). The migrations of fishes are due to searching for food or spawning ground (Jones 1968). The migration and spawning success of carp depends on the hydrology and other physico-chemical factors of the water (Tsai *et al*. 1981). Various physical-chemical factors are responsible for the onset of migration (Prchalová *et al*. 2006), however onset of monsoon rainfall onset the migration of fishes like carp (Tsai and Ali 1986), Hilsha, Pangus, Shrimps etc (Jhringran 1991).The migration intensity depends on the interaction of water temperature and physiological changes related to the photoperiod and diel changes in light intensity (Lucas and Baras, 2001) in temperate region. In tropical waters, these habitats may have been dispersed for a number of geographical, climatic and ecological areas. It is important that fish arrive at the right location at right time to fulfill its physiological requirement. For example for carp spawning good number of male and female fish are needed in the spawning ground at right time. Thus the triggering of fish migration in flowing water for fish is important question to ask.

Migration is an important feature of the biology of many fish species. Migratory fishes travel from upstream to downstream to reach larger body of water where food is available. During the monsoon period, the floodplains become the primary source of reproduction and increase of fish biomass in open water fisheries system. Fishes move out into the floodplains for feeding, grazing, growth and reproduction during the full monsoon floods. Inundation of the floodplains provides the spawning grounds, nursery areas and major feeding opportunities for a wide range of fish and prawn species (Ali, 1991).

In order to permit fish migrations in rivers it is necessary to maintain conditions, which help migrants, reach their spawning grounds. The phenomenon of migration, although manifested to different degrees, is characteristic of both anadromous and semi-anadromous fish, as well as for some species which live only in fresh water bodies. The common biological significance of all migrations is that they provide complex use of the full range of a species according to its changing requirements at different stages of its life cycle (Pavlov, 1979). In rivers fish migrations are associated with currents, although during the life cycle, the direction of fish movement with respect to the current often changes. Active migrations against the current (spawning migrations) generally occur together with passive, or active-passive, migrations of juveniles and recently spawned brood stock.

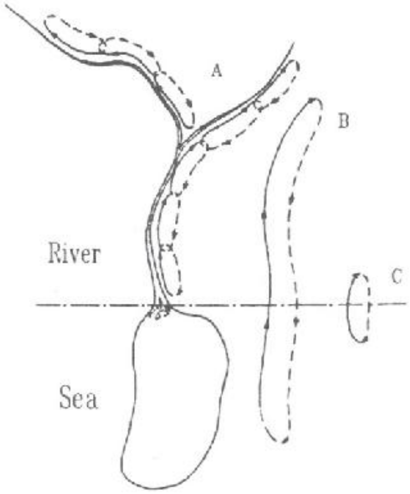


Fig 1. Migratory paths of fish. A. fluviatile species. B. anadromous species. C. semi-anadromous species. Continuous line for spawning migration, broken line for drift migration. (Pavlov, 1979).

Fish migrations in inland water-bodies can be indicated by means of ‘migratory rings’ (Fig. 1) which are ‘superimposed’ upon the existing system of currents: river-sea and river-lake. Unlike the idea of a migratory cycle, the term ‘migratory ring’ emphasizes the closeness of migrations in space, but not in time. A movement against the current during the spawning migration, and one with the current during the downstream migration, is typical of most species. However, the spatial extent of these movements differs. The ratio of the reproductive to the trophic part of a species’ range has been resolved differently for different species by natural selection, but within a single species it is resolved by the actual conditions a given population experiences. The diversity of behavioral mechanisms studies (Pavlov 1979), particularly that of downstream drift migrations, creates a definitive base for adaptive plasticity in migratory species, by contrast with the narrow specialized base of relatively settled species. Nevertheless within a settled species one may recognize a transition from resident to semi-diadromous forms, and this markedly affects population size.

There are few direct observations on the migration of fishes in the rivers of Bangladesh. It appears that the greatest number of migratory species in Bangladesh exhibit category (ii) migrations; observations in India suggest that *Catla catla*(Jhingran 1968), *Labeo rohita* (Khan and Jhingran 1975) and *Cirrhinus mrigala* (Jhingran and Khan 1979) all show only local movements upstream and primarily migrate laterally onto the flood-plain after spawning along the margin adjoining the river. However, it has been suggested that the major carps carry out long distance migrations beyond the borders of Bangladesh to spawn (Tsai and Ali 1986), but evidence of fry catches along the banks of the Padma suggest local spawning grounds given that there is little possibility for upstream migration with the presence of the Farrakah Barrage just over the border in India. It is probable that the spawn is locally produced as in Kaptai River (Tsai and Ali1987).

In Bangladesh, the species that reside on the flood-plain and beels at the height of the dry season tend to be those with adaptations to withstand limiting conditions. The majority of species are however migratory. Of these, some are restricted to a small geographical area and make only short migrations (20-30 km). Some, however, migrate substantial distances up to several thousand kilometers between widely different habitats. The migration timing varies with category of fish (species). The peak migration time for carp and catfish from May to July. Small fish are not migratory but required active river flow to move one floodplain to other. The winter breeder breed during January and February, but these fish or not migratory. The migration timing depends on interaction between physiological state of the fish and external triggering factors in the environment (Hoar 1958, 1976; Meier and Fivizzani 1980; Northcote1984). The thyroid hormones and the corticosteroid are the important factor for migration (Godin *et al.* 1974) but also for orientation (move upstream or downstream). The thyroid activity also may in part be timed by the lunar cycle (Grau 1982). Furthermore due to thunder some of the catfish in the beel also triggered in the preparation for thyroid activity. Hilsha can migrate from sea to fresh water as it body has osmoregulatory capability to adjust both saline and non-saline condition but carp cannot. The sensor system of a fish received signals from the environment and effect its migratory behavior. The environment stimulus such as hydrology, water currrent, light or temperature may later fish orientation and thereby act as a “director” of movement. Both longitudinal and lateral migration is strongly influenced by hydrology and its seasonality. Table 3.2 summarized the influence of hydrology on fish activity. At the onset of monsoon, March to May, rain starts with thunder and water accumulated in low pockets and beels. The river water level start rising and eventually inundates the floodplain. Water from river and with the rainfall run off brings more food in the beels for aquatic ecosystem. The rapid growth of fish food in the floodplain making it suitable for spawning, feeding and growth of fish. During early part of the pre-monsoon the major carp moves longitudinally from the beels and duars against the river current in the river to the spawning ground.

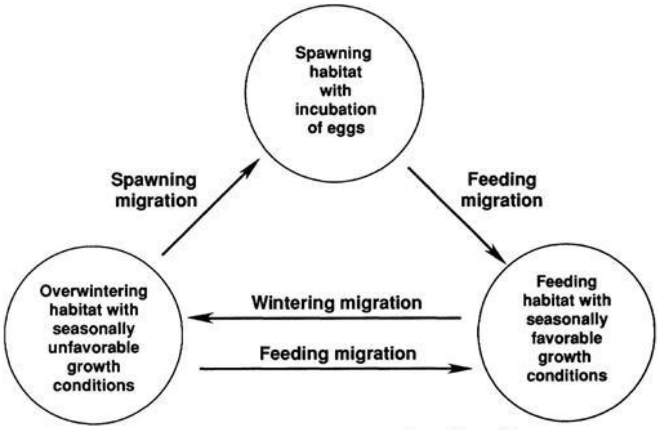
At the recession of monsoon, the fish start migrating to the deeper water bodies. After spending three to six months in the floodplain, some of the fish species at all growth stages migrate back through the canals to the river. This outward migration, predominantly passive migration, start from mid-September and continue upto November. Some fish migrate from river to the beels and remain refuge in the winter. Early rainfall and flooding enhance and widen the spawning and spawning migration while late monsoon can delay or migration and productive activities.

Fishes in the rivers generally migrate for three major events; wintering, feeding and spawning. The young fish that emerge from the spawning habitats used previously by their parents, either passively or actively move to the first feeding grounds. Later on, juveniles move from their first feeding to a growing habitat when unfavorable condition occur (winter and turbidity). When this cycle of feeding and refuge habitat over, the fish start reproductive migration to an appropriate spawning habitat. Broadly there are three principal categories of migrations (Schlosser 1991).

a. Reproductive (spawning) migration

b. Feeding (tropic) migration

c. Refuge migration



Credit: © Schlosser, 1991

Fig 2. Fish migration principal category

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 *etal*. 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 al*., 1999).Almost all the native fish fauna perform local and daily movements for their basic biological needs.

Fish migration and larval drift in Bangladeshdepends of their behavior, 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 bodiesand 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 (de Graaf *et al*., 1999 and Graaf *et al*.,2001).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).

Fisheries sector requires urgent attention to tackle the challenges occurred from unplanned flood control structures. Capture fishing on the floodplains and the haor basins, a traditional activity of the poor, is declining rapidly and will disappear altogether unless proper measures are taken. Due to interruption in the natural sequence of flooding in the floodplain of Bangladesh, food chain and life cycle of natural fish and other aquatic species have been vulnerable (NWMP, 2001). The impact on fish migration for flood control embankment and regular appears to be of major concern to the perpetual survival of the natural fish stocks utilizing rivers and floodplain in many parts of Bangladesh (FAP-6, 1993, 1994 ; FAP-17, 1994).

The water regulatory structures like dams and weirs cruising river fragmentation play a major role in declining the freshwater fishes (Lucs and Frear, 1997; Cowx and Welcomme, 1998; Lucas and Baras, 2001). The fishes that complete their migrations within the river system are mostly affected by such arrangements (Nicola *et al.*, 1996; Poulet, 2007). If no arrangement is made in the weir or the dam, to enable the fish to pass upstream, then such migratory fish have been found to be striking against the water current in their efforts to move up, till death. Non-provision of an arrangement for fish to pass upstream, may thus, lead to large scale destruction of fish life. If simply an open gate is left in the weir for this migration, the velocity of flow through such an opening will be very high. Therefore, even the strongest fish will not be able to travel upstream; resulting in large scale destruction of fish near the downstream and of fish gap (Garg, 2008).

A fish pass is a hydraulic structure that enables fishes to overcome obstructions in the passage to the spawning grounds and other upstream migrations and is built when it is required for ecological, economical and legal considerations. Fish passes are so designed to attract fishes readily and allow them to enter, pass through and exit safely with no undue stress, injury and especially without any undue delay for adult spawners (Bell, 1973; Clay,1995; Katopodis, 1990).

The concept of fish pass was introduced in Bangladesh in the 1990s and since then 4 fish friendly structure and fish passes have been built. Among them Sariakandi fish pass is most recent and modern one, which was constructed at Sariakandi on the Janmuna to the Bangali River in Bogra from 1999 to 2001 (Kabir, 2009). Jamuna and Bengali Rivers had plenty of freshwater fishes before implementation of the Brahmaputra Right Embankment (BRE) project. After the construction of BRE, fish production in Bengali river was reduced drastically due to the disruption of the natural fish migration routes between these two rivers. As Jamuna and Bengali Rivers are the closest to each other near integral component of BRE system which was designed as a vertical slot fish pass (Biswas, 2007).Vertical slot type fish pass provides more area and time for resting of different aquatic species during their migration from upstream to downstream (Kamula, 2001; Rajaratnam *et al*., 1986, 1992). It allows for variations in discharge and permits fish to ascend the fish pass at any depth they choose (Liu *et al*., 2006). In addition, the path of a fish ascending the fish pass is not tortuous and the fish pass provides resting locations for fish (Clay 1995).

Although the hydraulics of vertical slot fish pass has been studied by several investigations around the world (Rajaratnam *et al*., 1992; Liu *et al*., 2006), the understanding of the characteristics of the overall flow hydraulics and fish behavior appears to be incomplete for common Bangladeshi fish species like Rui, Catla and Mrigel etc. Based on this , an experiment research approach combining both the onset of migration and fish behavior has been carried out inside a distorted physical model of Sariakandi fish pass which has been developed in the laboratory flume. The behavior of Carp species (Rui, Catla and Mrigel) of different sizes such as fry, fingerling and juvenile has been observed in different hydrodynamics conditions in this study.

Objectives: The objective of the present study is to assess the onset of migration of selected fishes at different water flows. The physiological cost will be assessed by using some biological parameters of the fish. The specific objectives are:

- To assess the abundance and distribution of fish in simulated hydrological condition
- To identify factors determining the onset of migration in selected fishes
- To assess the biological cost of migration; and
- To determine critical migration speed in selected fishes.

CHAPTER 2: LITERATURE REVIEW

The information on the migration of fishes of Bangladesh is a few. The migration of fishesw included the study of fish biology, physiology, behavior, motivation, migration and swimming behaviour, fish pass drive design, construction criteria for fish passes some features on the biological characteristics of fishes are needed to understand along with the fish behavior and response inside the fish pass. The literatures related to fish migration are reviewed under some broad heading.

2.1 Migration of fishes

Binder *et al*. (2011) observed environmental variables influence migration is a popular theme in the study of migratory biology. The greatest challenge in environmental factors influence migration is the fact that environmental variables are often highly correlated with one another.Changes in photoperiod provide calendar information that is used to initiate and synchronize the migratory activity of individuals within a population. Long-duration migrations such as the spawning migrations of Pacific salmon and Pacific lampreys (*Lampetra tridentata*) appear to be particularly dependent on photoperiod for synchronizing migratory activity. This probably reflects the fact that other environmental factors (temperature) that vary on a seasonal scale are more variable, and, therefore, less reliable. The daily (diel) alternation between night and day synchronizes migratory activity. Diel activity patterns fall into three categories – diurnal, nocturnal, and crepuscular. It is not clear for most fishes whether the diel pattern of migratory activity is a true endogenous circadian rhythm. There is a high degree of correlation between the length of day (photoperiod) and water temperature. Moreover, the relative importance of each environmental factor dependent on the local characteristics of the habitat in which the migration is occurring. Nonetheless, despite these challenges, a number of environmental factors have repeatedly influence migration in fishes.

Cech*et al.* (2002) describedfish migration and passage, physiology and behavior. In watersheds throughout the world, the environmental requirements of resident and migratory fishes conflict with society's needs for land and fresh water. Land and water development - the damming of rivers, alteration of natural flow regimes, loss of riparian and wetland habitat, and diversions of water for urban, agricultural, and industrial use - have resulted in massive changes to freshwater and estuarine habitats, threatening the fishes that depend on these environments for rearing, migration, and reproduction. Dwindling fish populations at critically low levels, have heightened the sense of urgency and challenged. Successful strategies will be based on understanding the physiological capabilities and behavioral tendencies of the resident and diadromous fishes that use these waterways as essential conduits to complete their life. through investigations of the physiology and behavior of affected fishes, to advance our knowledge in these areas to ensure the conservation of these fishes for wise harvest, ecosystem integrity, and perpetuation of our natural heritage.

Lucas *et al.* (2001) reported migration of freshwater fishes.The migrations of fish in freshwater environments have played an important role in the settlement of human populations, and even to the casual observer, the movement of large aggregations of fish in shallow water or at obstructions is an astonishing sight. Indeed it is often only when such movements are obstructed and fish aggregate that they are noticed. Large-scale movements and migrations of fishes have been recognised through history. Migratory movements of fish need not involve their aggregation in high concentration, but such movements tend to follow particular pathways at a regular periodicity and so there is, inevitably, a concentration in space and time, to a variable extent, depending on environmental harshness. Before the advent of efficient fishing gear and fish location devices (especially sonar), the detection and capture of fish at sea and in large lakes was relatively inefficient. By contrast, the concerted movement of large numbers of fish through a restricted space at a particular time of year provided the advantage needed to enable the capture of significant numbers of fish by humans using simple nets, spears and traps.

Mallen and Cooper (1999) reportedthe mystery out of migration in south-eastern Australia. The migration of freshwater fish is a widespread phenomenon and many of the general patterns of migration are well known. However the terminology that is generally used to describe these fish tends to underestimate the significance of migrations that appear to be facultative, and over simplify the ecology of these fish communities. The major cues for migration of these fish are season, stream flow, and water temperature, which are sometimes overlaid by diel period. Large rises in river level ofren stimulate large fish to migrate, but small rises and low flows are very significant cues for the movement of smaller immature fish, and these can be severely affected by river regulation.

Moumita*et al.* (2011) conducted this study to know the impact of Sariakandi fish pass on fisheries diversity of Bangali river, Bogra, Bangladesh. Data were collected directly from fishermen, fish traders and organizations related to this field. A total of 59 fin fish species and 9 non fin fishes were recorded in Bangali river after construction of fish pass whereas the number was low before establishment of fish pass. Results indicate that fish pass has positive impact on fisheries diversity of Bangali river at Sariakandi Upazila, Bogra Bangladesh.

Myers *et al.* (2001) studied ocean distribution and migration patterns of Yukon River chinook salmon. Direct information from high seas tagging studies indicates that Yukon River Chinook salmon are concentrated in the Bering Sea. These results are supported by scale pattern analysis (SPA), which estimates that immature western Alaska (particularly Yukon River) Chinook salmon are the dominant population in the northwestern and central Bering Sea in summer and in the southeastern Bering Sea (west of 170°W) in winter. SPA indicates that immature Yukon chinook salmon are also distributed well offshore in the central North Pacific Ocean (north of 46°N) in spring-early summer (June). Parasite analysis of chinook salmon continental origins supports scale pattern results for Bering Sea distribution of western Alaska salmon. Existing data are inadequate for inferring the distribution and migration routes of juveniles in their first year at sea and adults in their last spring at sea. New ocean research on salmon distribution, carrying capacity, ecology, run forecasting, response to climate change, and stock and fishery interactions is recommended.

Smith (1985) observed fish migration is important and spectacular and worked on a group of Pacific salmon moving upstream at dawn symbolizes the many interacting factors that typify the control of fish migration. The flowing water provides chemical, mechanical, thermal, and visual stimuli that direct the migration. The rising sun allows sun compass orientation and serves as an important timing stimulus. The fish travel in a social group that allows synchronization of migratory activity and protects the fish from predators. Migratory fish gather energy in one portion of the environment and transport it to other areas, where it often becomes available to humans or to other elements in the ecosystem. Migration brings fish into situations that allow easy harvest as they concentrate along migration routes. Their journeys also make them vulnerable to human intereference at critical points along their route. Salmon, for example, may harvest plankton in the open ocean and transport that food energy to coastal and inland regions, where it is captured by fisheries or deposited in inland streams and utilized by the flora and fauna of the region. These salmon are able to complete journeys of thousands of kilometers from their natal streams to oceanic feeding grounds and back to the same home streams, an accomplishment that strains our credibility. There is no single factor guiding these fish. Instead, they are dependent on the presence in their environment of a great variety of appropriate orienting and timing stimuli. These stimuli are vulnerable to human interference. The more widespread and easily available the information on these requirements, the more readily fish can be protected from such interference. Where interference with natural migration is inevitable, then greater understanding of the controlling mechanisms at work in fish migration will allow us to compensate for the interference more successfully.

Thiem *et al.* (2011) reportedspawning migrations of sturgeon have been affected by the construction of dams, which create barriers to migration and have contributed to the imperilment of sturgeon. Although devices have been installed to facilitate the upstream passage of fish at barriers, they have been generally unsuccessful and not designed for sturgeon. We examined fine-scale movements of adult lake sturgeon *Acipenser fulvescens* during passage through a vertical slot fishway located on the Richelieu River in Quebec, Canada, to determine passage success, passage duration and inter-individual differences in fishway use. Migratory lake sturgeon (n = 107, range 939 to 1625 mm total length [TL]) were captured immediately downstream of the fishway, tagged with passive integrated transponder (PIT) tags and released into the fishway entrance basin over a period of 2 wk (water temperature 11–20°C). An array of 16 PIT antennas acted as gates to enable quantification of movements within the fishway. Volitional entry into the fishway occurred for most individuals (82.2%), 32 individuals successfully ascended the entire fishway, and overall passage efficiency was 36.4%. Sturgeon exhibited an ability to traverse the fishway quickly (minimum duration of 1.2 h upon entry into the fishway); however, the duration of successful passage events was variable (6.2–75.4 h following release). Neither passage duration nor maximum distance of ascent was correlated with TL or water temperature. Passage behaviour was variable, in some cases resulting in cumulative upstream movements 3 times in excess of fishway length. Passage durations through the 2 turning basins were disproportionately longer compared with other basins; however, the activity of individuals within these and other locations remains unknown and represents an important knowledge gap. Collectively, data from this study contribute to understanding how fishways can be used to facilitate the upstream passage of imperiled sturgeon at dams.

2.2 **Fish Pass for fish migration**

Bunt *et. al.* (2000) asseseda denil fishway in Dunnville, Ontario was built to provide upstream passage for walleyes (Stizostedion vitreum) from Lake Erie to the Grand River. Few walleyes have been observed to use this fishway. Coded radiotelemetry was used to track 24 adult walleyes (12 male, 12 female) downstream from the fishway to explore reasons for limited use. Activity was monitored by a fixed array of three antennas within the fishway that continuously scanned for signals from all radio-tagged fish, and by mobile tracking. In April and May 1997, 17 attempts to use the fishway by 3 male and 2 female radiotagged walleyes were recorded. During this period, the attraction efficiency of the Dunnville Fishway was approximately 21%. All attempts took place between 1600 and 0600 hours, with most activity near midnight. Walleyes occupied the first resting pool of the fishway for up to 17 h. Subsurface water velocity during the study was approximately 2 m/s. No radio-tagged walleyes passed through the Dunnville Fishway. Behavior modifying hydraulic conditions including turbulence, entrained air, backcurrents and whirlpools in fishway resting areas may delay or prevent successful upstream passage of walleyes. There was also evidence of large-scale movements by walleyes that may have spawned in the Grand River downstream from Dunnville.

The Coastal Conservancy (2004) Reported Inventory of barriers to fish passage in California's Coastal Watersheds; California's salmon, steelhead, and other species are vitally dependent on the ecological integrity of dozens of streams and rivers that flow into the Pacific Ocean along the State's 1,100-mile coastline. These streams provide habitat required by salmonids during the spawning and juvenile phases of their lives. However, the construction of roads, dams, bridges, water diversions, and other structures has fragmented that critical habitat, contributing to the decline of salmon and steelhead resources. Restoring fish populations depends on reopening that habitat through the improvement of fish passage and the modification or removal of barriers. Fish passage improvement depends, in turn, on the correct and rigorous identification of barriers within watersheds. In order to help restore salmon and steelhead populations, the Conservancy conducted an extensive inventory of fish passage barriers in California's coastal watersheds. This inventory was made possible with an appropriation from the salmon habitat restoration program sponsored by Senator Byron Sher (D-Palo Alto), and was conducted in a fashion consistent with the Coastal Conservancy's 2003 Strategic Plan.

Exelon (2012) reported American Shad Passage Study: Susquehanna River American Shad Model. Exelon distributed a revised study plan (RSP 3.4) for a study to model the effects of restoration measures on the Susquehanna River American shad population returning to Conowingo Dam (and upstream) to spawn. During 2011, the modeling study proceeded: existing Susquehanna River American shad data were compiled and reviewed; some potential limitations to American shad recovery that were not addressed in the modeling effort were reviewed; and an annual step numeric model was developed and refined. Potential limitations that were discussed included predation, bycatch (particularly in offshore fisheries), competition with other aquatic species for food resources, and climate change impacts.

Rajaratnam *et. al.* (1986) reported the results of an experimental study on the hydraulics of vertical slot fishways. Seven designs, including some conventional designs, were tested. A conceptual uniform flow state has been defined for which a linear relation has been found between the dimensionless flow rate and relative flow depth. Non-uniform flow of the Ml and M2 types has been analyzed using the Bakhmeteff-Chow method. Some observations have also been made on the velocity profiles at the slot and circulation patterns in the pools.

Solomon *et. al.* (2004) researched on Fish Pass design for Eel and Elver. In 2001 the Environment Agency produced its “National Eel Management Strategy” against a backdrop of a decline in European eel recruitment which has been apparent for the past twenty years or more. Restricted access to potential rearing areas is considered to be a factor in this decline, and there is no doubt that man-made obstructions to migration and dispersion are limiting eel stocks in many parts of the UK and Europe. The strategy states that the Agency will seek to both encourage and fund the construction of eel passes to restore access to areas where it has been denied or restricted by artificial barriers. The overall aim of this study is to produce design criteria and best practice designs for Eel and Elver passes. This Technical Report uses a review of eel biology and existing installations to develop design criteria for passage facilities for eels and elvers. It should be read in association with the Manual which sets out specific design criteria for eel and elver passes. This report presents a detailed review of those aspects of the biology and life history of the eel that influence migratory behaviour. These include the seasonal timing of migration, effects of water temperature, river discharge, light, tide, lunar cycle and time of day on migratory activity, climbing ability, dispersion and rate of upstream migration, vulnerability to predation, sizes of fish involved, and swimming ability. From this a series of biological and non-biological design criteria are developed for upstream passage facilities for eels and elvers. A similar approach is used to develop design criteria for the protection of downstream migrants. 6. The report briefly explores fundamental approaches to providing upstream passage facilities as an introduction to the analysis of existing installations. These are channel passes, pass-traps, pumped-supply passes, pipe passes, lifts and locks, easements, and removal of the structure. The fundamental approaches to protection of downstream migrants are also discussed.

Thiem *et al.* (2012) observed multispecies fish passage behavior in a vertical slot fishway on the Richelieu River, Quebec, Canada. A shift from target species to ecosystem restoration has generated interest in developing fishways that are capable of passing entire fish communities. Although a number of multispecies fishways now exist in North America, evaluations of these fishways are lacking. There used a passive integrated transponder antenna array to quantify passage success and passage duration of fish using a vertical slot fishway (85m in length, 2.65m elevation rise, 12 regular pools and 2 turning basins) at a low head dam on the Richelieu River in Quebec, Canada. Fourteen of the 18 tagged species re-ascended the fishway and passage efficiency was highly variable among species (range 25%–100%) however, it was >50% for five of the species well represented in this study (n>10) (Atlantic salmon, channel catfish, smallmouth bass, walleye and white sucker). Passage duration was likewise highly variable both among and within species (e.g. 1.0–452.9 h for smallmouth bass, 2.4–237.5 h for shorthead redhorse). Although this fishway design was not uniformly successful in passing fish of all species, this study does reveal the species that have problems with ascent and provides an estimate on the time spent in the fishway that is an important component of passage delay. Such information could be used to inform future design refinements to facilitate passage of the entire assemblage with minimal delay.

White *et al.* (2011) reported Movement of three non-salmonid fish species through a low-gradient vertical-slot fishway. Barriers to fish passage contribute to the widespread decline of freshwater fish in Australia, by obstructing migration paths and interfering with life-history processes. Well-designed fishways have assisted in restoring migrations and rehabilitating riverinefishspecies in all continents. The performance offishways varies greatly with their type, design and operating regime, and with the species involved. Vertical-slot fishways arewidely used to overcome low-level barriers, especially for non-salmonids. Important issues remain in the design of fishways to meet performance and cost criteria, including the relationship between fishway bed gradient and the fish that ascend, and whether resting pools are needed. Models of species' movement patterns can inform fishway designers about likely fish response to various design options, and can lead to improved efficiency and effectiveness. Models of general movement patterns of three potamodromous non-salmonid fishes in the Murray River, Australia, were developed from empirical data in a low-gradient vertical-slot fishway. The models integrate data on times of entry and exit, ascent rates, and whether fish continued to ascend during the night. These fish species did not favour resting pools. Ascent rates of fish120mm were more closely related to fish behavior than to length; for a given fishway height, reducing bed slope by increasing the number of pools may slow the ascent of such fish, whereas enlarging pool volumes increases costs.

2.3 Swimming behavior at fish passes

de Graaf *et al.* (1999) studied on water management and the drift of larval fish in the floodplains of Bangladesh. 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.

Hoover *et al.*(2012) observed swimming performance of carp is evaluated using test chambers as other fish species, native minnows, paddlefish, and sturgeon. Fish are collected in the field or at aquaculture facilities by seining, moved Fish are maintained in large static holding tanks that permit unimpeded natural movement and behavior (including schooling). Holding tanks are 2800-L aquaculture tubs, half- to three-quarters full, circulated with a Little Giant Water Wizard Model 5 MSP submersible water pump, filtered with a 200-L canister containing carbon, ammonia-absorbing resin chips, and foam. Holding tanks are established two to six weeks prior to receiving fish. Fish are fed commercial dry fish foods ad libitum two to four times daily: slow-sinking granules and/or floating flakes. Because wild-caught carp are reluctant to feed in captivit, sub-adult fish are housed with domestic goldfish (Carassius auratus), which provide carp with visual cues that stimulate and reinforce feeding. Water quality is monitored weekly and partial water changes are made semi-monthly or as needed. Individual fish of both species have been successfully maintained using this protocol for more than 2 years in captivity. Fish facility and protocol are inspected and evaluated every six months by the U.S. Army Engineer Research and Development Center (ERDC) Institutional Animal Care and Use Committee (IACUC).

Silva *et al.*(2010) investigated cyprinid swimming behaviour in response to turbulent flow. Turbulence is a complex phenomenon which commonly occurs in river and fishway flows. It is a difficult subject to study, especially biologically, yet turbulence may affect fish movements and fish passage efficiency. Studies on quantifying fish responses to turbulence, particularly within fishways, are lacking. This study investigated the swimming behaviour of 140 adult Iberian barbel (Luciobarbus bocagei) of two size-classes (small fish: $15 \leq TL < 25$ cm, large fish: $25 < TL \leq 35$ cm) under turbulent flow conditions created by three submerged orifice arrangements in an experimental pool-type fishway: (i) offset orifices, (ii) straight orifices and (iii) straight orifices with a deflector bar of 0.5bo located at 0.2L from the inlet orifices, where bo is the width of the square orifices ranging from 0.18 to 0.23 m and L is the pool length (1.90 m). Water velocity and turbulence (turbulent kinetic energy, Reynolds shear stress, turbulence intensity and eddy size) were characterized using a 3D Acoustic Doppler Velocimeter (ADV) and were related with fish swimming behaviour. The influence of turbulent flow on the swimming behaviour of barbel was assessed through the number of successful fish passage attempts and associated passage times. The amount of time fish spent in a certain cell of the pool (transit time) was measured and related to hydraulic conditions. The highest rates of passage and the corresponding lowest times were found in experiments conducted with offset orifices. Although size-related behavioural responses to turbulence were observed, Reynolds shear stress appeared as one of the most important turbulence descriptors explaining fish transit time for both size-classes in experiments conducted with offset and straight orifices; furthermore, swimming behaviour of larger fish was found to be strongly affected by the eddies created, in particular by those of similar size to fish total length, which were mainly found in straight orifices with a deflector bar arrangement. The results provide valuable insights on barbel swimming behavioural responses to turbulence, which may help engineers and biologists to develop effective systems for the passage of this species and others with similar biomechanical capacities.

Taki *et al.* (1975) reported geographic distribution of primary freshwater fishes in four principal areas of Southeast Asia. Southeast Asia is one of the world's centers of abundance of freshwater fishes. The freshwater fish fauna of the region is characterized above all by the predominance of the Cyprinidae (carps and minnows) and their allies. The fauna is rather uniform in its composition throughout the region except for the Song Koi (Song Hong) drainage, where the fish fauna closely resembles that of southern China including Hainan and there is a sharp distributional boundary along the Song Koi-Mekong watershed. They all explain the affinities by land connections existed during geological times between the mainland and They all explain the affinities by land connections existed during geological times between the mainland and the islands and between the islands, referring to the Sundaland. The general and fundamental characters of the freshwater fish fauna of Southeast Asia are thus rather clearly delineated, but the detailed structure of local fauna of each subarea composing the region and the origin and dispersal of the fauna still require further elucidation on an extensive basis.

2.4Fish biology and physiology of migration

Bone and Moore (2008) observed biology of fishes and interested in fishes because a wide range of living fish to study, from hagfish to lungfish, but also in being able to examine fishes adapted to every kind of aquatic habitats. In consequence, they examined fascinatingly different designs for special modes of life, as well as ways used by different fish for solving problems common to them all. Most fish live and move for all their lives through water. And the great majority of these swim by oscillating flexible bodies that end in a tail fin. Movements of the body or fins resulting from muscle contraction affect the surrounding water in such a way as to move the fish through it. It is true that there is a handful of fairly successful mechanical fish that swim by oscillating their bodies (like the roboshark used for photographing shark feeding frenzies), but these all came later. The hulls of submarines are quite similar to the solid of least resistance drawn from the body of a trout by the great pioneer experimental aerodynamicist Cayley. The density and viscosity of the medium dictate the same streamlined shape, but there is an obvious and significant difference between the two. In most fish, the myotomal power plant itself is involved in the movements that produce thrust, whereas in submarines the engine is held in a non-flexing hull and movements within the engine are divorced from the aft propellor. Consequently, one can make models and test them in wind or water tunnels, and, using well-established formulae, calculate the thrust required (and the power output of the engine) to overcome the drag of the hull and move it forward at any given speed. For fish that oscillate their bodies as they swim, the formulae for rigid bodies are inappropriate.

Brown. M. E. (1957) describedthe physiology of fishes and oxygen requirements of a species can be derived from a combination of the active and standard rate of oxygen consumption. the levels of standard metabolism, the vertical bars the levels of no excess activity which at 20° C. are, respectively, 1.1 mg. 02/l. for C. auratus, 1.7 mg. 02/l. for P. flavescens, and 2.8 mg. 02/l. for S. fontinalis. Of these three species, C. auratus has the lowest level of no excess activity not only by virtue of its ability to extract more oxygen from water in which the oxygen content is reduced but also because it has a lower rate of standard metabolism. These points are the levels of no excess activity for individuals acclimated to approximately air saturation levels at the temperature indicated. Size differences in the tolerance of fish to low oxygen arise from the interplay of the standard metabolic rate and the curve for respiratory dependence. Levels of no excess activity for the different sizes of S. fontinalis are shown on it by marking the points on the dependence curves where they are depressed to the standard metabolic rate appropriate for the size. With increasing temperature relating the metabohc rate to size under conditions of active metabolism in S. fontinalis, there is a drift in the effect of size on the level of no excess activity. At 5° C. large trout have a lower level of no excess activity than do smaller ones; at 20° C. the reverse is true and older fish have a lesser sensitivity to oxygen lack will not always hold.

Evans *et al.*(1969) reported the physiology of fishes, muscle plasticity, metabolism and membranes, oxygen sensing, endocrine disruption, pain, cardiac regeneration, and neuronalregeneration. Muscle phenotype is the result of interactions between an animal's genotype and the environment. A single genotype can result in multiple phenotypes depending on environmental influences in what is known as phenotypic plasticity. In adult fishes, phenotypic plasticity occurs seasonally or with movement across environmental clines, and these changes are thought to be reversible. In contrast, environmental influences during ontogeny can lead to distinct and irreversible muscle phenotypes as an expression of different developmental trajectories. The importance of early life experience on the muscle phenotypes expressed later in life has long been recognized, but only recently has the influence of developmental exposures on muscle plasticity and swimming performance in adult fish been explicitly demonstrated. Skeletal muscles play numerous important roles in fishes, from powering locomotion to regulating whole-body metabolic homeostasis. Since muscles constitute a significant proportion of a fish's body mass, the ability to modulate the mechanical and metabolic properties of this tissue, in-line with environmental optima, is an important feature allowing species to adjust to changing environmental conditions. Phenotypic plasticity of the muscle is thus an important mechanism assuring that ecologically relevant tasks can still be performed in the face of environmental, mechanical, and energetic stress.

Hoar *et al.* (2006) observed the physiology of Tropical Fishes and gather information about the large and important group of fishes that live in the tropics. Tropical environments are as diverse as are the groups of fishes living there and described areas of the physiology of tropical fishes, related to their physiological adaptations to tropical environments, which they have shaped during their evolutionary history, and what make tropical fishes an amazing group to study. The Physiology of Tropical Fishes hopes to broaden understanding of what is so special about freshwater and marine tropical habitats that makes tropical fishes one of the most diverse groups of vertebrates in the world. Indeed, subjects such as Growth, Biological Rhythms, Feeding Plasticity and Nutrition, Cardiorespiration, Oxygen Transfer, Nitrogen, Excretion, Ionoregulation, Biochemical and Physiological adaptations are all presented and discussed in the light of their specific fitness to tropical environments such as intertidal pools, coral reefs, and the Amazon’s different types of waters, all of them typically hypoxic and warm water bodies. Tropical species and also their many interactions with their everchanging environments. The conviction that tropical fishes are barely studied and the adaptive characteristics that allow them to survive extreme tropical environmental and biological conditions.

Hogàsen (1998) described physiological changes associated with the diadromous migration of salmonids, the two main migrations undertaken by salmonids, leading to the sea or back to freshwater. Also describe a number of external and internal factors that are thought to regulate onset of migration, knowledge concerning the motor activity of fish during migration and the physiological adjustments associated with bursts of swimming are exposed. An estimation of metabolic needs and the ways by which these are covered are discussed. Finally, putative mechanisms used for orientation during river migration are presented. It is therefore important that significant variations may exist between species, stocks, individuals, and years. Available knowledge concerning development of migratory readiness and onset of migration in salmonids mainly concerns seaward migration of smolts. Regulation of the return migration of salmonids has received less attention. Difficulties associated with studies in the open sea are probably one reason for this.

Ueda and Tsukamoto (2014) describes the physiology and ecology of fish migration, among 30,000 species of fish, migratory species account for only 165 species, but they show very interesting biological phenomena and life histories. Most migratory fishes are very important fisheries resources. Migratory fishes move either alone or in schools from their birth place to their growth habitats, and then usually return to their place of birth for reproduction. These migrations allow fishes not only to exploit different food availabilities and to adapt to environmental changes, but also to regulate population density and widen their distribution. Study on physiology of imprinting and homing migration mainly in anadromous chum salmon from the Bering Sea to Japan as well as lacustrine sockeye salmon in Lake Toya and Lake Shikotsu. Using these model fish, three different approaches (physiological biotelemetry researches on salmon homing migration, endocrinological researches on salmon imprinting and homing migration, and neurophysiological researches on salmon olfactory imprinting and homing ability) have provided valuable new understanding of the physiology of imprinting and homing migration in Pacific salmon. However, many questions remain unanswered, such as the sensory mechanisms of open water orientation, the hormonal control mechanisms for sensory systems and the central nervous system, accurate and false homing. Despite the difficulties of a temporally limited spawning season, research from molecular biology to behavioral biology will provide new concepts for physiology of imprinting and homing migration in salmon.The recent rapid development in biotelemetry techniques, such as ultrasonic and radio telemetry, data logging and pop-up satellite telemetry, make it possible to investigate wild fish behavior both in freshwater and seawater.

2.5Bioenergetics of fish migration

Barnham and Baxter (1998) reported Condition Factor, K, for Salmonid Fish. Anglers frequently refer to fish they have caught as being in poor, good or excellent condition. This qualitative measure is usually based on a visual assessment of the fish, taking into account the general shape of the fish, its length and weight, and its appearance (which usually equates to how “fat” the fish is) compared to memories of previous catches. On the basis of comparison of the K value with general appearance, fat content, etc, the following standards have been adopted by the Department for trout and salmon: K value comments 1.60 Excellent condition, trophy class fish. 1.40 A good, well proportioned fish. 1.20 A fair fish, acceptable to many anglers. 1.00 A poor fish, long and thin. 0.80 Extremely poor fish, resembling a barracouta; big head and narrow, thin body. The "K Chart" indicates the relationship between salmonid length and weight. It can be used within the limitations of the scales on the chart to assess the approximate K value of salmonid fish and compare the value with the Department's standard above. Examples of the range of K values are also illustrated.

Fausch (1984) proposed that bioenergetics models could also be applied to habitat management and restoration by estimating the expected net energy gain in relation to habitat as a means to describe habitat quality. For good fitness, an organism must maintain balance between the energy it gains from its microhabitat and the energy it requires for growth, metabolism, and losses. Also reported any environmental disturbance can be considered a potential source of stress, as it prompts a number of responses in the animal to deal with the physiological changes triggered by exterior changes. If the internal perturbation of the fish, either directly or as a result of alterations of the environment, overwhelms the physiological mechanisms of the animal for response and adaptation to new conditions, survival can be threatened and death can result.

Kitchell *et al.* (1977) reported applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*),integrated a fish bioenergetics model into a spatially explicit water quality model for application to menhaden in Chesapeake Bay. Although fish are usually thought of as victims of water quality degradation, it has been proposed that some planktivorous species may improve water quality through consumption of algae and sequestering of nutrients via growth. Within most numerical water quality models, the highest trophic level modeled explicitly is zooplankton, prohibiting an investigation of the effect a fish species may be having on its environment. Conversely, numerical models of fish consumption do not typically include feedback mechanisms to capture the effects of fish on primary production and nutrient recycling. In the present study, a fish bioenergetics model is incorporated into CE-QUAL-ICM, a spatially explicit eutrophication model. In addition to fish consumption of algae, zooplankton, and detritus, fish biomass accumulation and nutrient recycling to the water column are explicitly accounted for. These developments advance prior modeling efforts of the impact of fish on water quality, many of which are based on integrated estimates over an entire system and which omit the feedback the fish have through nutrient recycling and excretion. To validate the developments, a pilot application was undertaken for Atlantic menhaden (Brevoortia tyrannus) in Chesapeake Bay. The model indicates menhaden may reduce the algal biomass while simultaneously increasing primary productivity.

6. Fish Pass and it's status in Bangladesh:A fish pass is a hydraulic structure that enables fishes to overcome obstructions in the passage to the spawning grounds and other upstream migrations and is built when it is required for ecological, economical and legal considerations. Fish passes are designed to attract fishes readily and allow them to enter, pass through and exit safely with no undue stress, injury and especially without any undue delay for adult spawners. Most commonly used fish passes are divided into four groups: pool and weir, denil, vertical slot and culvert fish passes (Bell 1973, Clay 1995, Marmulla and Larinier 2011).

Vertical Slot Fishways: In the vertical slot fishway, baffles are installed at regular intervals along the length to create a series of pools (Fig. 3) Fish easily maintain their position within each pool. Travel between pools, however, requires a burst effort through each slot. Water velocities at the slots remain almost the same from top to bottom. The main advantage of the vertical slot fishway is in its ability to handle large variations in water levels. Usually the difference between water levels in successive pools is 300 mm for adult salmon and 200 mm for adult freshwater fish. Vertical slot fishways usually have a slope of 10% (Katopodis 1992).

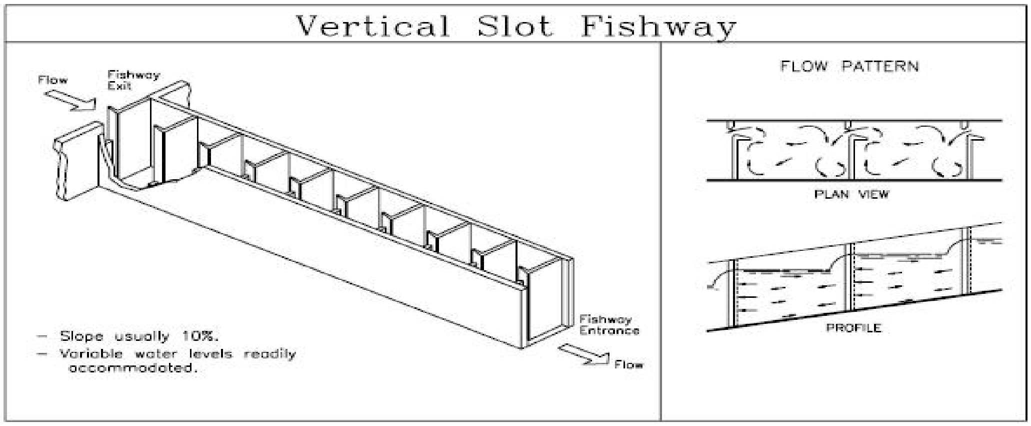


Fig3.Vertical slot fish pass

Denil Fishways: Denil fishway consists of a rectangular chute with closely spaced baffles or vanes located along the sides and bottom. The plain Denil contains a series of planar baffles pointing upstream, at an angle of 45 degrees with the fishway floor. Baffles in the steeppass. Denil also point in the upstream direction but are angled away from the walls of the chute (Fig.4). Slopes for Denil fish passes usually range from 10% to 15% for adult freshwater fish and 15% to 25% for adult salmon (Katopodis *et al.* 1984).

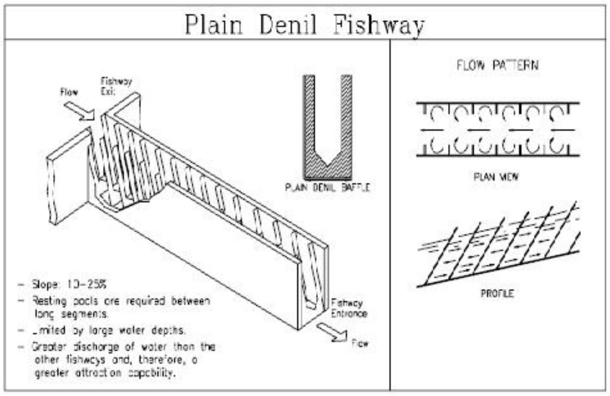


Fig4. Denil fish pass

Weir Fish Pass: The weir fish pass consists of a number of pools arranged in a stepped pattern separated by weirs, each of which is slightly higher than the one immediately downstream (Fig. 5). The fish, attracted by the flowing water, move from pool to pool by jumping or swimming (depending on the water depth) until they have cleared the obstruction. Movement between pools usually involves burst speeds. Fish can rest in the pools, if necessary as they move through the fish pass. Weir fishways usually have a slope of 10% (Rajaratnam *et al.* 1992).

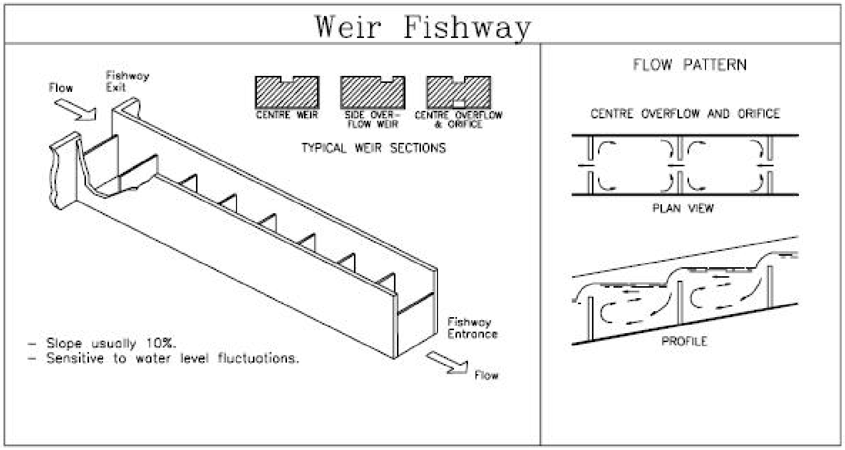


Fig5: Weir fish pass figure

Culvert Fish Pass: Culverts are used to convey water from one side of a roadway embankment to the other. Culverts are built with circular, elliptic, pipe-arch, rectangular or square cross-sections. If a culvert is required to pass fish, special considerations are needed to ensure that fish can enter, pass through and exit the culvert without undue or harmful delay (Figs. 6a and6b). Mainly associated with roadway construction, culvert fish passes usually have slopes of between 0.5 and 5% (Rajaratnam *et al.* 1991).

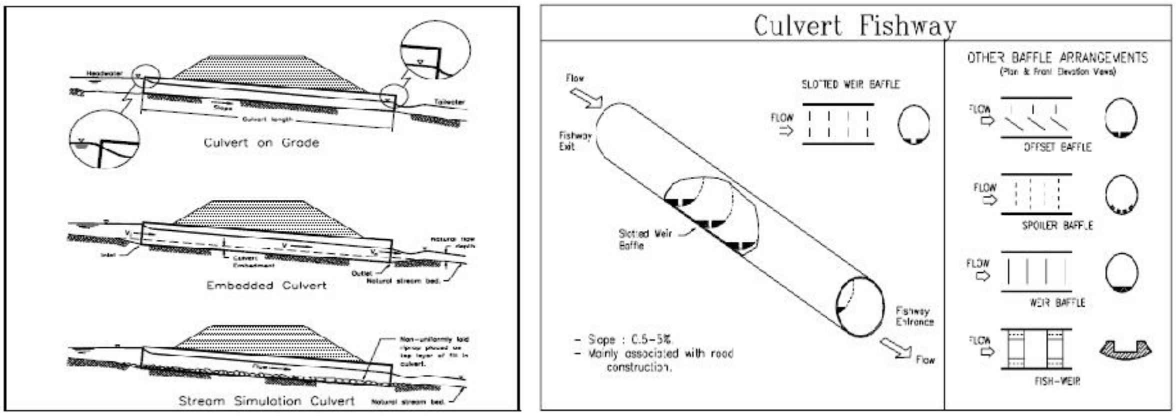


Fig6. (a) Culvert placement and (b) Culvert fishpass

Fish Pass and Fish Friendly Structures in Bangladesh: In 1987 and 1988 the country experienced disastrous floods. Immediately after 1988 flood, several studies were carried out by the Government of Bangladesh and international community to find a sustainable solution for the flood problem. In June 1989, the World Bank agreed with the GoB to co-ordinate various flood control and related initiatives from which the flood action plan (FAP) emerged. The Action Plan, covering the five year period 1990 to 1995 is the first of several stages in the development of a comprehensive system of flood control and drainage works in Bangladesh. FAP received much attention from the donors as the flood of 1988 level happens once in 100 years (FAP 6 1995).The concept of fish pass was introduced in Bangladesh in the 1990s and since then four (4) fish friendly structures and fish passes have been built (IUCN 2002). There are only two fish passes , they are:

- Shariakandi Fish Pass in Jamuna to Bangali River at Sariakandi in Bogra 1999-2001
- Kashimpur Fish Pass in Kawadighi Haor of Monu River in Moulvibazar 1995

Besides there are two fish friendly structures in Bangladesh, they are:

- Fish Friendly Structure in Lohajong river of Tangail 1996
- Fish Friendly Structure at Morichardanra in Chapainawabganj 1997

Sariakandi Fish Pass, Bogra: Sariakandi Fish Pass is most recent and largest fish pass, Jamuna River is on the east and Bangali River is on the west of the fish pass. The construction of Brahmaputra (Jamuna) right embankment (BRE) in the late 1960, affected the flooding pattern and fish production in the Bengali river, which had directly affected livelihood the adjacent fisher community, to overcome the effects later structure was built. The fish pass is rectangular in shape, Vertical slot in type (Fig. 7). Total length 92.4 m and width is 15m. It has three separate vents composed of 16 pools in each vent. Each pool has 0.7m opening with width and length of 3.5m and 4.5m. Gate size is 6.42 m X 0.82 m each. Slot opening (height) is 0.7 m, pool length 4.8 m, width 4.2 m (Kabir, 2009; Biswas, 2007). After construction of the fish pass, the water volume and fish species of the Bengali River is increased. There is an increased fish diversity and fish biomass, resulting is an improved livelihood of the rural people living at the villages around the fish pass. More than 60 species of fishes are available in therivers and a total of 22 finfish species found to use the fish pass for migration (Moumita *et al*. 2011).

Fig 7. Sariakandi fish pass in Bogra

Fig 8. View towards Bangali River

Kashimpur Fish Pass, Moulvibazar: Kashimpur fishpass is the first known application in the world of a vertical slot fish way to a flood control and irrigation project. The Fish pass pilot project was designed to re-store the fish migration between the Kushiyara River and Kawadighi Haor which was disrupted by the flood embankments constructed under the Manu river flood control and irrigation project. Kawadighi Haor was one of the richest open water fisheries, fish breeding ground and mother fishery in the north eastern region and Bangladesh (FAP 6 1995).

Fig 9: Kashimpur fish pass view towards the Kawadighi Haor

Jugini Fish Friendly Structure, Tangail : Jugini Regulator was constructed on the Lohajang to regulate the water level inside the Compartment Pilot Project (CPP) at Tangail in 1994-95. The hydraulic structure consists of 5 vents of which 3 vents are main regulator. Additionally two vents were constructed on the two sides of the main regulator with an objective to maintain the fish migration between Dhaleshwari to the Lohajang River to its floodplain. The main purpose of this gated regulator is to ensure controlled flooding and drainage by maintaining appropriate water levels in the Lohajang river inside the compartment. With the fish friendly structure, the project manage to reduce fisheries losses and facilitate the hatchling movement from river to the floodplain in the early monsoon (Hassan 2002).

Fig 10. Jugini Fish Friendly Structure (a) in winter and (b) in monsoon period in Tangail

Morichardangra Fish Friendly Structure, Chapainawabganj: The fish friendly structure is located at the Mahananda river inlet to Morichadanra beel. Strategically this point of construction is crucial as far as the turtle's migration is concern. Long chains of beels are mainly dependent on this structure for receiving floodwater upon which the wetland biodiversity depends for their survival. From Chapai Nawabganj upto Bholahat this unique wetland ecosystem is one of the last strongholds of wetlands biodiversity in the Northwest region. From the fish catches assessment it was observed that Rui, Catla, Mrigel,Kalbaush, Tengra and Puti were found in the Bashbaria Digor Beel under Nawabganj District. It was also reported that the exotic species Silver carp, Grass carp and Bighead were also found in the Beel (IUCN 2002).

Fig 11. Morichardangra Fish Friendly Structure at Chapainawabganj

3.1.1 *In Situ* Experiments in Bogra and Moulvibazar: Two field study were carried out in our two fish passes area to assessing the availability of fishes in the fish pass during the flood season. Two fish pass area were Sariakandi fish pass,Satiakandi,Bogra and Kashimpur fish pass, KawadighiHaor, Moulvibazar. Daytime sampling was carried out in the fish pass. Three fishing gears including cast net, seine net and drag net and one fishing trap were employed to collect fishes. To perform case study sampling of fishes andinterviewed on structured questionnaire were used. Water quality parameter data and fish species diversity data were collected.

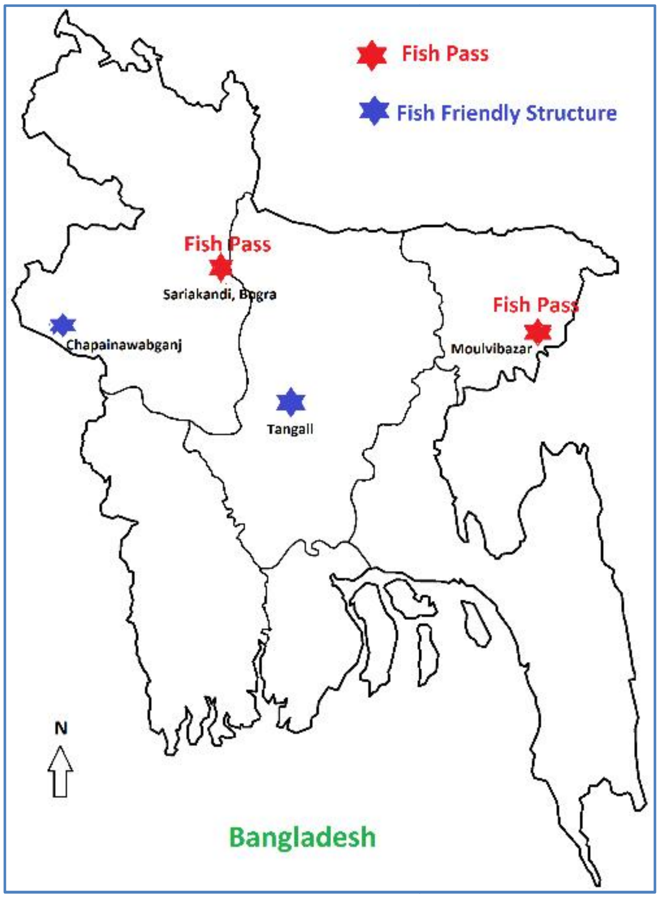


Fig12.Fish passes location in Bangladesh map

3.1.1.1Sampling Site

- Shariakandi Fish Pass in Jamuna to Bangali River at Sariakandi in Bogra1999-2001
- Kashimpur Fish Pass in KawadighiHaor of Manu River in Moulvibazar1995

Study Time: Field study conducted in Sariakandifrom June 12, 2015 to June 17, 2015. In Kashimpurfrom June 9, 2016 to June 13, 2016.

3.1.1.1a Sariakandi Fish Pass, Bogra: Sariakandi Fish Pass is most recent and largest fish pass, is located between 24°'44' and 25°03' N latitudes and between 89°30' and 89°45' E longitudes. The fish pass is located at village Debganga of Kutubpur Union of SariakandiUpazila. Jamuna River is on the east and Bangali River is on the west of the fish pass. The fish pass is at the nearest corridor between Jamuna and Bangali Rivers.

Fig 13.Sariakandi fish pass, BograFig 14. Questionnaire survey in fish pass area

3.1.1.1b Kashimpur Fish Pass, Moulvibazar: The Fish Pass Pilot project was designed as Vertical Slot type to re-store the fish migration between the Kushiyara River and KawadighiHaor which was disrupted by the flood embankment constructed under the Manu River Flood Control and Irrigation Project. KawadighiHaor was one of the richest open water fisheries, fish breeding ground and mother fishery in the North Eastern Region and Bangladesh. The Haor was designed one of the high abundance of fish and greatest spawning activity in the region. It is situated in between 24°'60' N latitudes and between 91°75' E longitude.

Fig 15.Kashimpur fish pass KawadighiHaor

Fig 16. Inside Kashimpurfish pass view.

3.1.2 *Ex Situ* Experimentin Laboratory with Sariakandi Model: It has been observed from the studies conducted by experts around the world that velocity fields inside the pools of the fish pass have significant effect on the biological characteristics of fish species. To understand the fish behavior with the different hydrodynamic conditions a relevant experimental setup was arranged in the laboratory flume. The experimental arrangement consists of an adverse slope of 6% followed by a 3.4% mild slope built in a rectangular laboratory flume. The fish pass is constructed on the mild slope portion which contains four pools. Total 18 sets of experiments were conducted by maintaining upstream water level of 40 cm, 50 cm and 60 cm for different ranges of velocities. This experiment was carried out in the Hydraulics and River Engineering Laboratory of the Department of Water Resources Engineering of Bangladesh University of Engineering and Technology. Different experimental runs have been conducted in the laboratory flume by varying water depth and pump discharge.

3.1.2a Laboratory set-up: The laboratory set up and equipment that have been used for carrying out the experiments and collecting necessary data.Other necessary accessories that were used to conduct the experiments are laboratory pumps, discharge reading meter, wire screens to stop the fish to go insider the pumps and reservoir of the flume.

3.1.2b Laboratory flume: The experiment has been conducted in a 70 feet (21.34 m) long, 2.5 feet (0.762 m) wide and 2.5 feet (0.762 m) deep rectangular tilting flume in the Hydraulics and River Engineering Laboratory.


Fig17. Flume used for fish migration study in laboratory

Fig18. Inside view of flume


Fig19. Fine net were used for screen preparation

Fig20. Two wire net screens were built

The side walls of the flume are made of clear glass and they are vertical. The water resistant color has been used to paint the flume bed to avoid the development of any unnecessary bed friction. In the upstream and downstream end of the flume, two wire mesh screens were placed to stop the fish to go inside the pumps and reservoir of the flume. An adverse slope of 1:16:67 was placed at the upstream portion and a mild slope of 1:29.17 was placed at the downstream portion of the physical model. The entire model structure including the sloping portion was painted with protective coating to prevent the decomposing of wood from the effect of hydraulic flow. Flume bed has been maintained as horizontal and it is supported on an elevated steel truss system. Two pumps were used to supply and head tank from the laboratory sump and the discharges were measured by means of magnetic flow meters located in the supply lines. Necessary steps were taken to prevent any unnecessary damage in the flume structure while conducting the experiment.

Fig21.Machines used to supply water to head tankFig 22. Two pumps were used

3.1.2c Water Reservoir: The water reservoir used in the flume was made of steel. Water required to supply during the experiment was stored in the reservoir. The water supply can be controlled by existing facilities in the reservoir.

3.1.2d Construction and Placement of the Structure: The sloping portion of the structure was made of mango wood and the vertical portion was made of the gamari wood. The adverse portion of the slope was connected to the mild portion with screws. The vertical portion of the structure was placed on the mild slope portion and it was kept fixed inside the flume by using pudding on the side glass and screw connection with the sloping portion.



Fig 23.Fish pass construction Fig 24. Fish pass placementFig 25. Structure set-up

3.1.2e Developed Physical Model: The physical model of the structure was developed as a vertical slot fish pass. The structural design that has been applied in this study is the design 1 (Rajaratnam et al., 1992), which is widely used for designing vertical slot fish pass all over the world. The structural set up consists of an adverse slope 6, followed by a mild slope of 3.4%. The adverse slope is 2.54 m in length and the mild slope is 4.45 m in length. The fish pass is constructed on the mild slope which contains four pools. Each of the pool is approximately 1 m long, 0.762m wide and 0.60 m high. The width of the opening of each pool was 0.127 m. Each component of the overall structure was built the wooden sheets. Physical model is shown in Figure 24 and 25.

Fig26.Upstream portion of the model

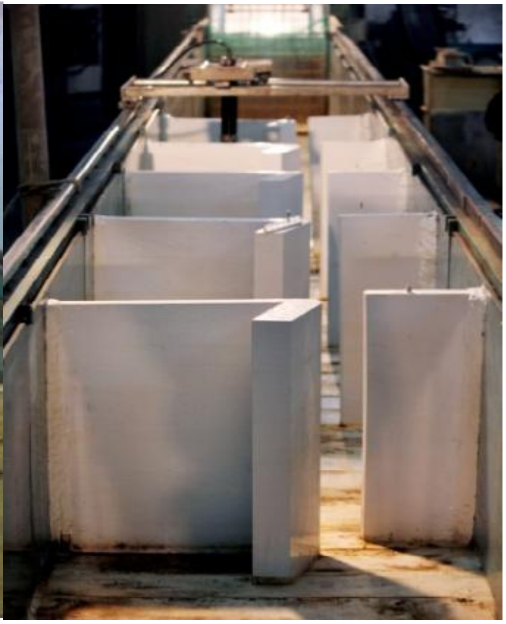


Fig27. Downstream portion of the model

3.1.2f Schematic diagram of fish pass structure:

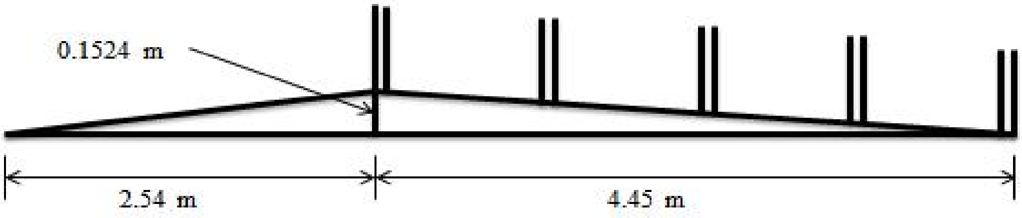


Fig28. Side view of the schematic diagram of physical model

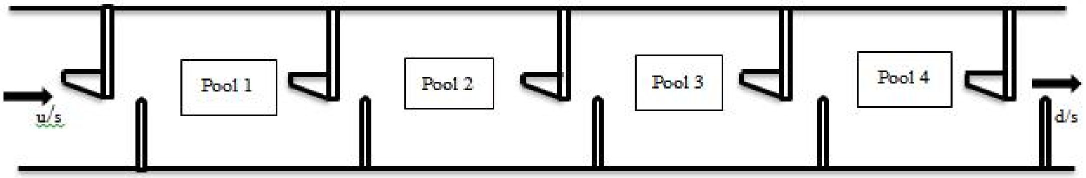


Fig29. Plain view of the schematic diagram of the physical model

A comparison of geometric dimensional parameters between the prototype in Sariakandi and developed physical model in laboratory flumeis given in Table1. Detailed drawing of the physical model developed in the laboratory flume are given in Annexture A.

Parameters	Sariakandi Prototype	Physical Model in Flume	Scale Ratio
Langth	4.5 m	1m	4.5
Width	3.5m	0.762 m	4.6
Height	5.9m	0.6 m	9.8
Pool Opening	0.7m	0.127 m	5.5

Table 1: Comparison of geometric dimensional parameters of prototype and model

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m3/hr)	Total Head Loss, Ah (cm)
1	50	81	6
2	50	94	8.6
3	50	104	12.1
4	50	118	19.5
5	50	55	1.75
6	50	68	3.35
7	40	65	6
8	40	75	10.75
9	40	87	16.67
10	40	96	29.17
11	40	37	1
12	40	52	3.5
13	60	100	5.75
14	60	110	7.4
15	60	125	10.75
16	60	145	15.75
17	60	70	2
18	60	84	3.33

Table2 : Specifications of the Experiment Runs

3.1.3 Selected Fish Samples

Carps and Catfishes are the two most important groups of fish of Bangladesh and a large number of carps and catfishesare migratory in habit.

Carps: Cypriniformes is an order of ray-finned fish, including the Carps. This order contains 11-12 families, over 400 genera, and more than 4,250 species.This is one of the largest families of fish, and is widely distributed(Rahman, 2005). Most species are strictly freshwater inhabitants. Amongst the group of cyprinids known as the Indian carps, three species are of greatest economic importance, known as major carps, they are: Catla (*Catla catla*Hamilton 1822), Rohu/Rui (*Labeo rohita* Hamilton 1822), and Mrigal (*Cirrhinus mrigala*,Hamilton 1822) (Rahman, 2005).

Selected Major Carps:

- Rui (*Labeorohita*,Hamilton 1822)
- Catla (*Catlacatla*, Hamilton 1822)
- Mrigal(*Cirrhinusmrigala*, Hamilton 1822)

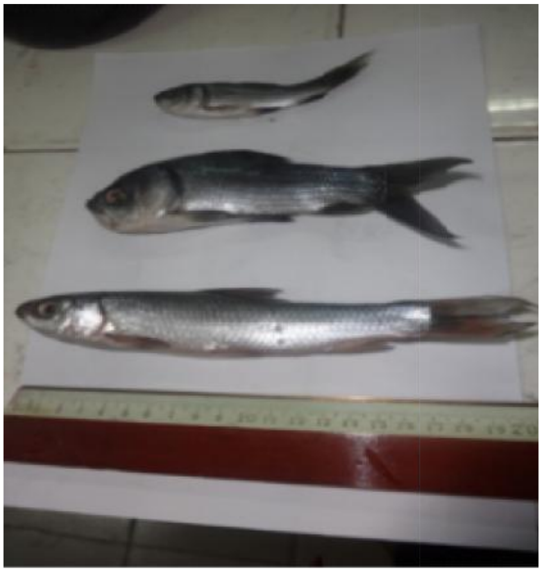


Fig 30. Sample major carps: Rui, Catla and Mrigal fishes.

Size of Fishes: Adults, sub-adults, juveniles, fingerlings and hatchlings(fry) are tested in same fish pass in wide flume which provide a wide range of water velocities and uniform, rectilinear flow. Fish are acclimated in the bowl before experiment for approximately 10 minutes, initially at no flow and subsequently at slow flow conditions, before each timed trial is conducted in pre-determined water velocity. Sample fishes were measured by ruler in cm. Collected fish samples were different size; hatchlings 1-2 cm fingerling 2.5-3.5 inch or 7-10 cm, juveniles 4-8 inch or 10-20 cm and sub adults 8-12 inch or 20-40 cm and adults were 15-30 inch or above 60 cm.

Fig31. Catla sample

Fig 32.Rui sample

Fig 33. Mrigal sample.

Fig34. Frysample fishes

Fig35. Fingerling sample fishes

Fig36. Juvenile sample fishes Fig37. Sub-adult sample fishes

Catfish: The Catfish has an elongated body shape is mainly coloured gray or grayish brown. This catfish has long-based dorsal and anal fins, several pairs of sensory barbels. The skin is scale less but covered with mucus which protects the fish when it is out of water (Rahman, 2005). Collected fish sampleswere juveniles 8-12 cm and sub-adults were 15-25 cm for experiment.

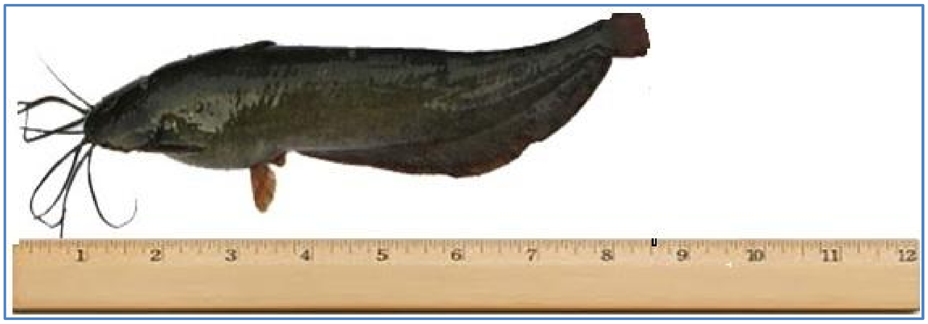


Fig 38. Sample juvenile Shingi fish (*Heteropneustes fossilis*)

Selected Catfishes:

- Shingi (*Heteropneustes fossilis,* Bloch 1794)
- Magur(*Clarius batrachus,* Linnaeus, 1758)

Fig39. Catfish (Shingi) for experiment. Fig40. Catfish (Magur) for experiment.

Fish Collection: Halda River strain fish samples are collected from Narshingdi, Tongi and Jaltarabari Fish Farm. Other fish samples collected from different hatcheries of Dhaka.

- Fry Samples: 500 fry samples collected from Tongi fish farm.
- Halda strain carp samples: 600 samples in different size of Rui, Catla & Mrigal
- Catfish samples: 60 Samples collected.

Fish Transportation: Fishes were collected from fish farm and hatcheries and werecarried in plastic bags. Oxygen gas were taken in each bags to carry fishes from hatchery to fish tanks of Curjon Hall Zoological Garden, Dhaka University, Dhaka, Bangladesh. Live sample fishes were taken in BUET and DU laboratory for experimental run and analysis with the help of covered plastic bucket with water.

Fig41. Fish Collection from Fish Farm

Fig42. Oxygen gas applied in the bag

Fig43.Sample fishes in the oxygen bag

Fig44. Plastic bags were used to transport fishes

Fish Rearing: Samples of fishes weretaken into the Tanks of Zoological Garden, University of Dhaka,Curzon Hall.And reared for experimental analysis. Fish research work done in these tanks for 4 years.

Time of Research : 4 (Four) years, the period of March 2013- March 2016.

Fig 45. Fish samples collected from hatchies and released in tanks of zoological garden.

Fig46.Tanks were netted and water exchange were done dailyFig47. Tanks used for Fish Pass Study

3.2METHODS:

3.2.1 Onset of migration and swimming behavior study: Eye observation methods were used to detect fish swimming behavior inside the flume. Fish movements were recorded in photography and continuous videography. Three types of research taken for the onset of migration and swimming behavior study.

- Fry fishes
- Carp Fishes
- Carps and Catfishes

3.2.2 Water parameters: Throughout the study period physic-chemical parameters of water samples, pH, dissolved oxygen, TDS, conductivity and air temperature were measured. Lutron portable dissolved oxygen meter, model no. DO 5509, range is 0 to 20.0 mg/L and resolution: 0.1 mg/L were used to detect oxygen in water. pH measured using Orion field pH meter model 210A, Orion Laboratories, U.S.A. Fig. Ultrapen^{TM} PT1 TDS, conductivity, salinity and temperature pocket pen was used to detect conductivity, temperature and TDS.

Fig 48. Oxygen meter

Fig 49. pH meter

Fig 50. TDs meter

3.2.3 Length-weight relationship and condition factor : Fish were measured in terms of weight loss. Total length (TL) was measured to the nearest 0.1 mm using a 30 cm ruler as the distance from the tip of the anterior most part of the body to the tip of the caudal fin. Analytical balances with precision of 0.01 g were used to record body wet weight, recorded in gram. The length-weight relationships were determined by linear regression analysis and scatter diagrams of length and weight were plotted. The length-weight relationship of the experimented fish is worked out as per cube law given by Le Cren, (1951). Forty fingerlings (average length = 8.64 ± 0.3145 cm, average wt. = 7.961 ± 0.1348 g) of *carps a*nd forty juveniles (average length = 16.51 ± 0.248 cm, average wt. = 24.18 ± 0.127 g) of *carps a*nd twenty sub-adults (average length = 22.72 ± 0.452 cm, average wt. = 56.71 ± 0.251 g) of *carps.* Fulton's condition factor (K) was calculated according to Htun-Han (1978) equation as per formula given: $K = \frac{W \times 100}{L3}$, here W=weight of fish (g), L=Length of fish (cm).

3.2.4 Migratory bioenergetics: The minimum oxygen requirement of five different fishes; Rui (*Labeo rohita*), Puti (*Puntius sarana*), Shingi (*Heteropneustes fossilis*), Taki (*Channa punctatus*) and Koi (*Anabas testudineus*) were detected that cause point of no return to these fishes. Experiment is conducted in running water and stagnant water. In each experiment 2 aquaria were used. One aquariam sealed with cork to prevent atmosphere mixing of oxygen, and one aquariam was kept uncapped, which is considered as a controlled environment by keeping the lid open with fishes. Fish gulping also measured. Relationship of water parameters; total dissolved solid and conductivity compare to air temperature and time were also measured.

Fig51. Fish bioenergetics model

Fig52. Fish gulping observed

3.2.5 Physiological Cost: Experimented carp fishes in migration study were analyzed for proximate composition and amino acid content. Non experimented fishes were taken as control. Moisture (Oven Drying Method), Protein (Micro-Kjeldahl Method), Fat (Cold Method), Ash (Gravimetric Method) performed in triplicate. Proximate composition was determined by following protocol of the Association of Official Analytical Chemists (AOAC, 2005) procedures.

Fig 53. Digestion of sample for protein analysis

Fig 54. Fat Extraction

Analysis of Amino Acids: Rui fishes were chopped and fine paste was made by mortar and pestle and transferred in 250 ml round bottom flask place in heating mantle at 11^0C for 24 h with 6N HCl. This solution obtained was kept in an evaporating dish to evaporate HCl on water columned with 0.1N HCl. The solution was run through an Amino Acid Analyser (Schimadzu. Japan). The analyser showed the standard solution curve for sample solution. By comparing the two curves the amount of amino acid was calculated.

3.2.6 Hydrological data analysis : Hydraulic measurements have been carried out in all the four pools for the critical and good conditions to obtain the velocity fields, contours and vertical velocity profiles.Measurements were carried out using an ADV as shown in Figure 37 and 38 ADV has become a useful instrument in point of wise measurement of 3D velocity fields in laboratory and field environments by recording the doppler shift produced by acoustic targets in the flow (Kraus *et al.*,1994, Lohrmann et al., 1994, SonTek, 1997). Velocities are measured in a sampling volume located 10 cm away from the probe head.

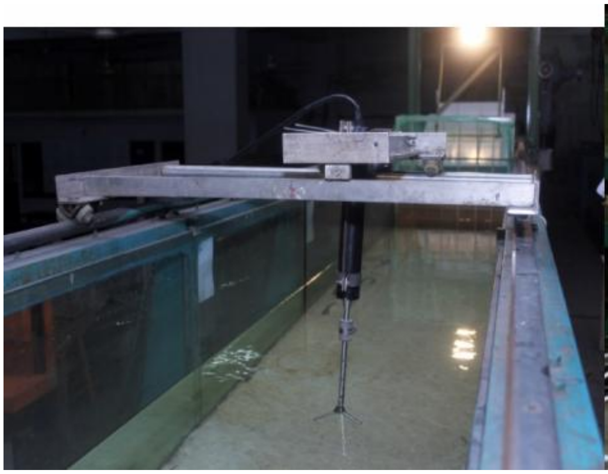


Fig 55. Placement of ADV for

Fig 56. ADV data collection

Fig 57. Acoustic Doppler Velocimeter (ADV)

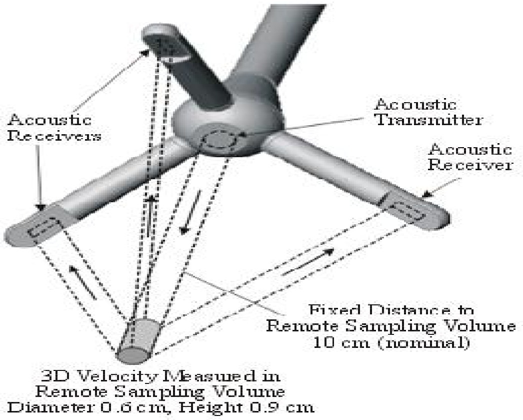


Fig 58.Working principle of ADV

3.2.7 Statistical Analysis: Statistical analysis were performed using SPSS 22.0 software (SPSS Inc. Chicago, IL). Results were subjected to analysis of variance (ANOVA). The values of $p<0.05$ were considered significant and those $p< .01$ and $P < 0.001$ were highly significant.

RESULTS AND OBSERVATIONS

4.1 *In situ* Experiment: Fish migratory behaviour study

4.1.1 Sariakandi fish pass study: Fish fry and hatching movement from Jamuna to Bangali river was the main objective of Sariakandi fish pass project. After construction of the fish pass, the water volume and fish species of the Bengali River is increased. There is an increased fish diversity and fish biomass, resulting is an improved livelihood of the rural people living at the villages around the fish pass.During the monsoon Carp fish is the dominating migratory species. Carp fish migrates in a higher velocity, whereas, Catfish migrates in a lower velocity. During both upstream and downstream movements, the major carps passes the fish pass through either side of the passage. The species like Chital, Batasi and Catfishes preferred the middle section of the pass. The spawns and hatchlings were found to drift through the middle part of the pass also. The study also found that there were 15 migratory species in the fish pass from sampling. They are Rani, Bata, Chanda, Chital, Batashi, Catfishes, Gulsha Tengra, Shol, Pabda, Bele, Puti, Rui, Catla, Mirror Carp and Mola.

From questionnaire survey the data received, before establishment of fish pass 12 fish species recorded in Bengali River (Rui, Katla, Mrigel, Jat puti, Boal, Bajuri Tengra, Kajuli, Kholisha, Chanda, Bele, Gonti)

After establishment of fish pass 60species of fin fishes were recorded in Bangali River, those are Chapila, Kachki, Foli, Chital, Phaisa, Chela, Darkini, Dhela, Mola, Rui, Katla, Mrigel, Sarputi, Tit puti, Rani, Jat puti, Kalbaush, Gutum, Batashi, Tinkata, Taila Air, Boal, Bajuri Tengra, Kajuli, Kholisha, Chanda, Bele, Gonti, Tara Baim, Tal Chanda, Veda, Gonti, Shilong, Rita etc. In which 14 are endangered and threatened fishes: Potka, Sarputi, Kalibaush, Bata, Rani, Gulsha Tengra, Pholi, Veda, Shol, Chanda, Tin kata, Guchi, Shilong, Kani Pabda.

4.1.1a Water Parameters: Field study conducted in Sariakandi at 27.8^{0}C temperature. pH found 8.4 in upstream and 8.0 in downstream.Dissolved oxygen found 7.8 mg/L in upstream, 8.2 mg/L in pool and 8.7 mg/L in downstream. TDS level found 14 ppm. Water depth and flow condition found extremely good in Sariakandi fish pass. Water velocity found 1-1.49 m/sec.

4.1.2 Kashimpur fish pass study: From sampling inside the fish pass. The most frequently occurring taxa were small species Chanda, Puti, Chela, Mola, Rani, Icha, Kaikka, Chapila. From questionnaire survey fish species data received: Major Carp (Rui, Mrigal, Kalibaush), Large Catfish (Ayr, Boal, Rita), Knifefish (Chitol) and Minor Carp (Gonia, Bata, Lachu) were frequently present in fish pass.

4.1.2aWater Parameters: Kashimpur fish pass study conducted at 25^{0}C. pH foundin pools 6.4. Oxygen found 5.6 mg/L. TDS level found 38 ppm. Water depth found low and almost no flow in Kashimpur fish pass. Water velocity found 0.4 m/sec.

Ex situ Experiment :Fish migratory behavior study

4.2.1aFry Fishes: Study conducted on 500 fry cyprinids in a vertical slot fish way. Main focus of the study is to evaluate fry fish migratory behavior, swimming behavior and survival in different water velocity condition. Velocities were in the range of 0.3 m/sec to 0.8 m/sec. Mortality risk to the migrant is estimated.

Experiemntal Design: The physical model of the structure was developed as a vertical slot fish pass. Fish species (Rui, Catla) of fry have been used in this study to analysis the migratory behavior. Water depth was 40, 50 and 60 cm and pump discharge was 37- 145 m^3/hour and water velocity 0.3-0.8 m/s. 500 fry sample were experimented. Experiment done in 3 days 2 hours daily for each depth.

Acclimatization: Fries are acclimatized in 5 plastic bowl in normal temperature of water. They kept there for 1 hour to acclimatize. Then they release into the fish passage for the study.

Fig 59. Fry sample acclimatization

Fry migration behavior in 40 cm depth: Fishes are too small to move themselves. They move with the water current. Fishes were released in upstream portion, with the water velocity 0.3-0.5 m/sec they moved to different chamber with water current, they move very little to the passage and downstream. They stayed in A1, A2, A3 chambers preferably. When the velocity raises, they moved B, C, D corners. In 40 cm depth and high velocity was so unfriendly for fishes, they just float with the current, it became bursting speed for fishes (0.6-0.8 m/sec) butno fishes were moved, they just float. In bursting speed no fish occur death for speed.

Fig 60. Fry migratory behaviour in depth 40 cm (a) opening of fish pass (b) 1st chamber

Fry migration behavior in 50 cm depth: Fish fry moved with the water current. Fishes were released in upstream, they swims with the water current slowly. In water velocity 0.3-0.5 m/sec they moved freely. Their favorite corners were M, A, B in this depth of water. Some stayed in the same place and some moved. But when the velocity raises they stop moving to different chamber. Some move to the passage and downstream with the water current. 50 cm depth is good water depth for fishes. Bursting speed occur in 0.7 and 0.8 m/sec water velocity condition. No fish fry were died.

Fig 61. Fry migratory behaviour in depth 50 cm (a) upstream (b) 2nd chamber

Fry migration behavior in 60 cm depth: Fish friesare too small to move but they move with the water current. Fishes were released in upstream. 60 cm is quiet good depth for the fish passage and the pools. Fishes were seen to stay at A, B, C, N and Q corners. In low velocity field (0.3 -0.5 m/sec) they stayed in the same chamber where they releases, move very little to the passage and downstream. When the velocity raises, they moved in different chamber and downstream with the water current. Experiment done from 0.3-0.8 m/sec which is very high velocity for fishes, fishes just float with the current, but no fish died. In 0.3-0.6 m/sec velocity some fishes swim and move to one place from another, but from 0.6-0.8 fishes moved with the water current. They just float and try to survive, it was bursting speed for fish, but no fryoccur death.

Fig 62. Fry migratory behaviour in depth 60 cm (a) downstream (b) 3rd chamber

Fry fish samples swimming behavior in fish pass

- Fry fishes survived 100% , no mortality occur for high velocity swimming study.
- They can tolerate different range of water velocity 0.3-0.8 m/sec and survived.
- They can enter into the fish pass opening with water flow and reached upto downstream without injury.
- Study showed fry fishes can pass the fish pass with the water velocity 0.5-0.8 m/sec.

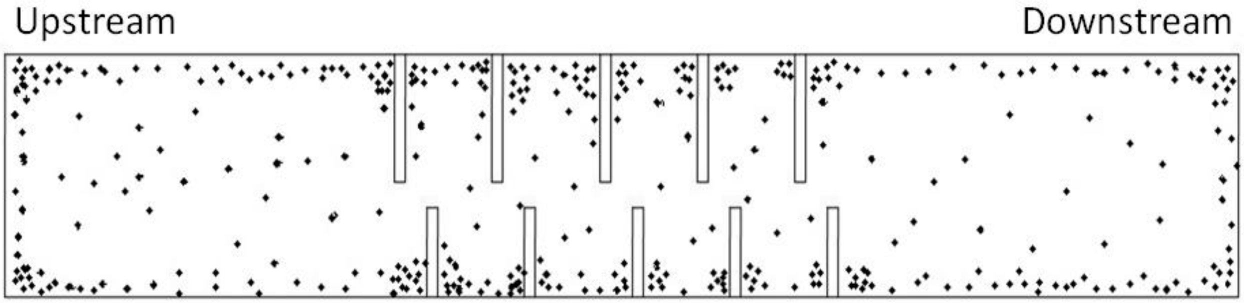


Fig 63. Fry fish distribution patter in the flume in different velocity condition.

4.2.1b CarpMigratoryBehavior:

The physical model of the structure was developed as a vertical slot fish pass. The structural design that has been applied in this study is the design 1 (Rajaratnam*et al*., 1992) which is widely used for designing vertical slot fish pass all over the world. Experimental study has been performed with a distorted physical model in the flume of Hydraulics and River Engineering Laboratory, Department of Water Resources Engineering (DWRE), BUET by down scaling the existing prototype fish pass at Sariakandi, Bogra.The experimental arrangement consists of an adverse slope of 6% followed by a 3.4% mild slope. The model structure consists of four pools. Each of the pool was approximately 1 m long, 0.762 m wide and 0.60 m high. The width of the opening of each pool was 0.127 m. The experiments were conducted by maintaining upstream water level of 40 cm, 50 cm and 60 cm for different ranges of velocities. Velocities were in the range of 0.3 m/s to 0.8 m/s and discharges were in the range of 37 m^3/hr to 145 m^3/hr. Total 18 sequences of experiments have been conducted for this study. Every sequence or run conducted for six hours minimum. Temperature was 20-32^{0}C For each set of experiments, three dimensional velocity data were collected at 0.4, 0.6 and 0.8 hydraulic depth by using an ADV (Acoustic Doppler Velocimeter(Navera, *et. al*., 2015).Selected species were Major Carps:Rui (*Labeorohita*)**,** Catla (*Catlacatla*) and Mrigel (*Cirrhinusmrigala*). Sample Fishes: Fish with different sizes (Fry, Fingerling**,** Juvenile and Adult) were chosen. The response of the selected fish species of different sizes with respect to different hydrodynamic conditions has been analyzed.

Sequence-1

Water depth = 50 cm

Pump discharge= 81 m^3/hour

Velocity= 0.5 m/sec

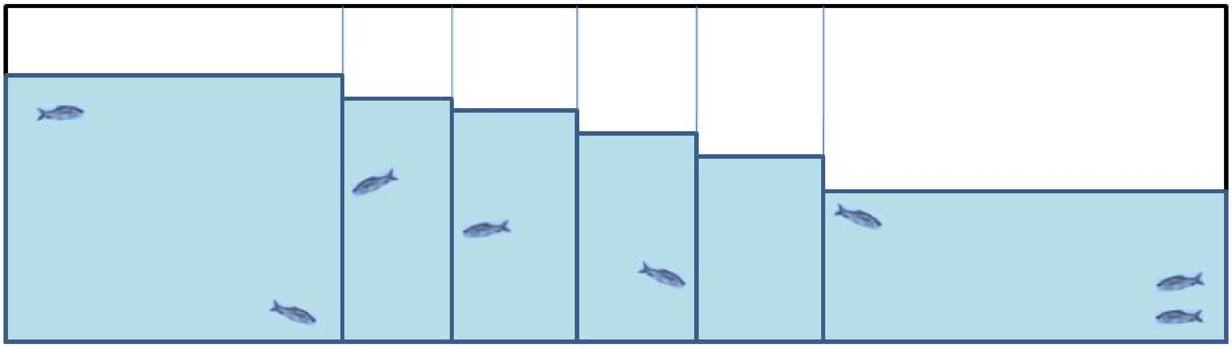


Fig 64.Sequence 1, depth 50 cm, fish showing cruising behavior in 0.5 m/sec velocity field.

Fish Behavior Observation:Fishes are released in upstream position of the fish pass. After an hour of the release,three fishes positionthem in upstream.Threemoves at the entry of the fish pass and the rest are in the first pool.The larger Mrigel initially was in the first chamber; within a few minutes it goes in the third chamber and then goes toward downstream.After sometime three fishes of upstream crossed the fish pass and went toward downstream. On the way two fishes enjoyed swimming in the first chamber by their own accord. Water was calm without any turbulence. After two hoursthree fishes (RuiandtwoCatla)were swimming in the second chamber of the fish pass.OneCatlawas just lying on the ground for an hour. It looked like it was dead. But when it was poked with a stick, it ran to the next chamber and afterwards then toward downstream. For the first 1.5 hours after the experiment started, no fishes were moving toward downstream. No school/group were observed to be forming.It was seen that the fishes were swimming individually to search for food.

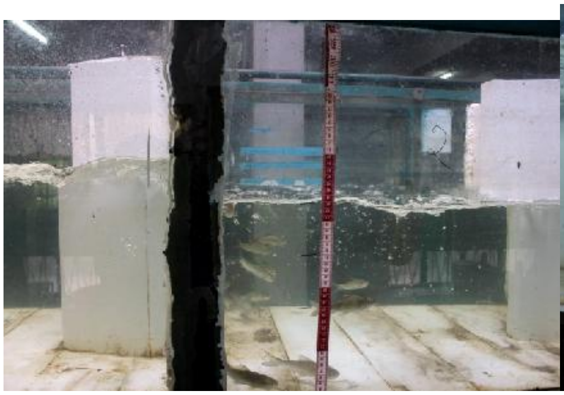


Fig 65. Fish moves normally towards the water velocity Fig 66. Fishes taking rest in corners

Sequence-2

Water depth = 50 cm, Pump discharge= 94 m^3/hour, Velocity= 0.6 m/sec

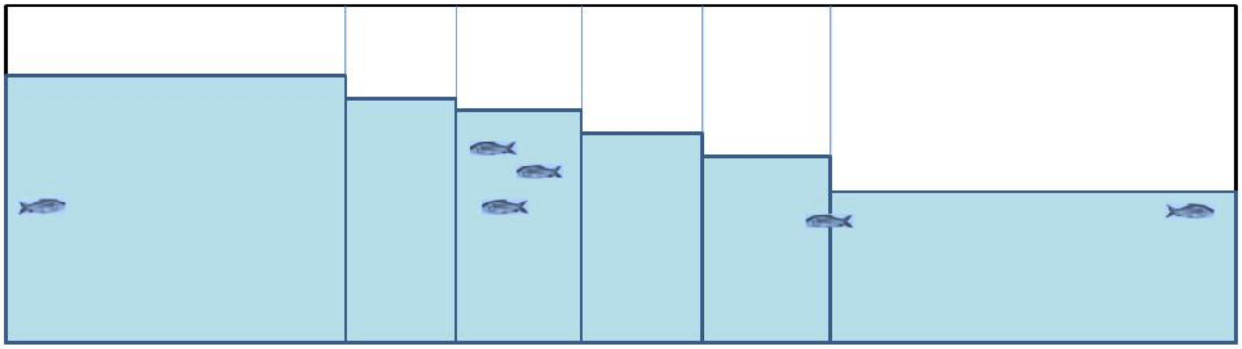


Fig 67. Sequence 2, depth 50 cm, velocity-0.6m/sec, fishes sustained swimming behavior

Fish Behavior Observation: Fishes are released in the upstream position of the fish pass. One Mrigal fish entered into the third chamber within 3 minutes and after another 3 minutes it went toward the end of the fish pass. Other fisheswere swimming in different chambers.ADV was used to detectthe velocity of water. Fishes were seen to be moving around the ADV meter. The overall hydraulic condition wasnormal (without any pressure). Fishes observed moving with the water flow. No fishes have seen moving against the water flow. No school/group were observed to be forming in two hours. It was seen that the fishes were swimming individually to search for food and trying to take shelter where water flow is low or in lower velocity of water. Fishes swim in upstream, not trying to enter fish pass, but high water current enter them into the pools and pass fish pass smoothly in a few second.

Fig 68. Fishes swimming with the water flow

Fig 69. Fish sustained speed in second chamber

Sequence-3

Water depth = 50 cm, Pump discharge= 105 m^3/hour, Velocity= 0.7 m/sec

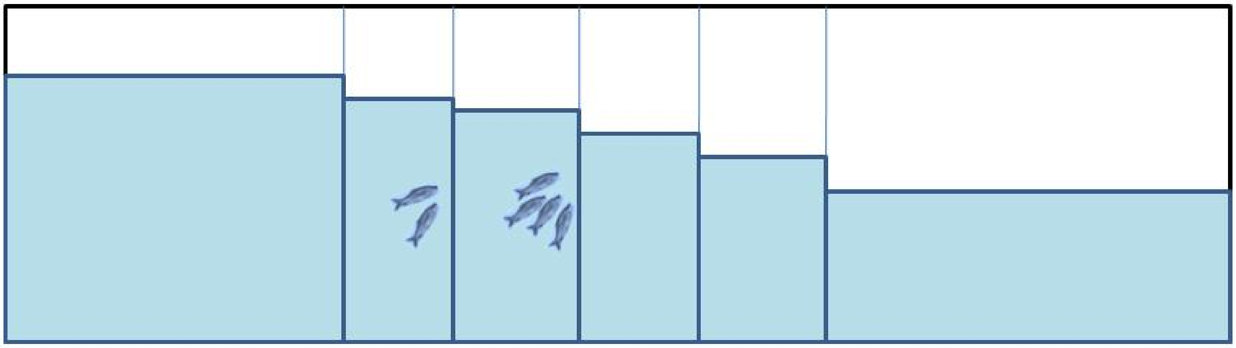


Fig70. Sequence 3, depth 50 cm, velocity- 0.7m/sec, fishes bursting swimming behavior

Fish Behavior Observation: Fisheswere released in pool/chamber 1 position of the fish pass. After an hour all 6 fishes remained in the same chamber. The tide condition was very rough, It was very difficult to move against wave. Fishes were not able to move from one chamber to another chamber.Fishes were observed to be swimming in A and C position in the first and second chamber.Huge weight loss was observed for sample fishes. From the experiment it was seen that in high velocity, fisheswere unable to move. They tried tostay in the Ccorner of chamber 1 and 2, where therewere comparatively less velocity(velocity was measured by using ADV velocity meter).

Fig71. Tide condition was rough Fig72. Fish taking shelter on A/C corners

Sequence-4

Water depth = 50 cm, Water Discharge = 118 m^3/hour, Velocity= 0.8 m/sec

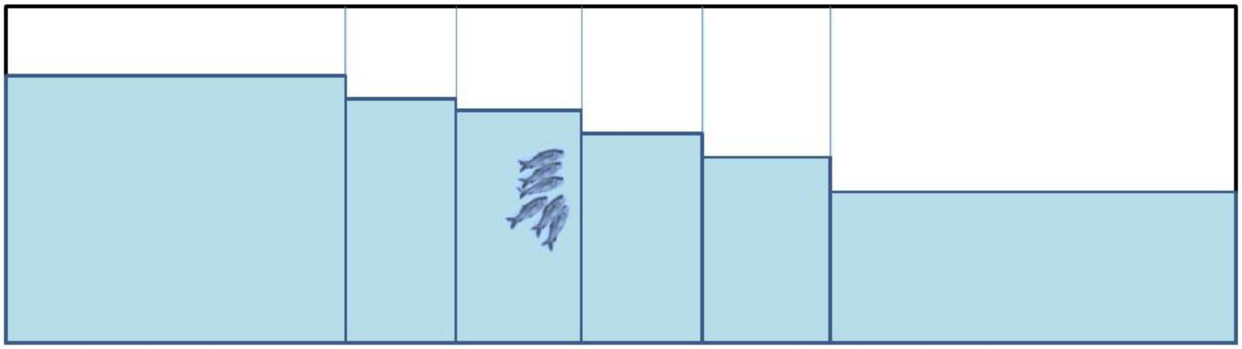


Fig73. Sequence 4, depth 50 cm, velocity- 0.8 m/sec, fishes bursting swimming behavior

Fish Behavior Observation: Fisheswere released in chamber 1 position of the fish pass. After an hour all but 2 fishes remained in chamber 1.Tide condition was much rougher than the previous sequence. Initially fishes were not able to move from one chamber to another chamber. But afterwards bigfishes were observed to be moving toward downstream via the water flow itself alone. In this sequence, due to high velocity two fishes jumped outof the flume. No school/group were observed to be forming. Fishes just passed the chambers with tide, no free swimming or cruising speed seen in this condition.

Fig74. Bursting condition for fishes   Fig 75. Fishes took shelter where velocity is low

Sequence-5

Water depth = 50 cm, Pump discharge= 55 m^3/hour, Velocity= 0.3 m/sec

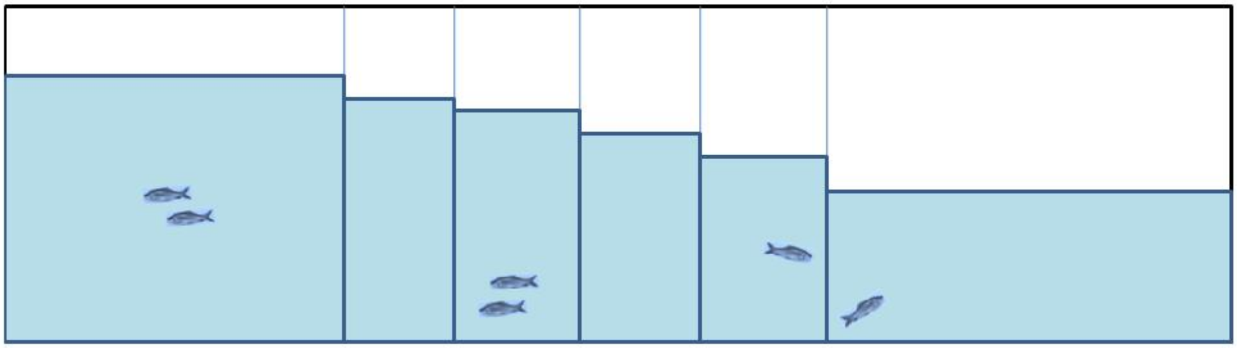


Fig 76. Sequence 5, depth 50 cm, velocity- 0.3 m/sec, fish showsnormal swimming behavior

Fish Behavior Observation: Fishes were released in Pool/Chamber 1 position of the fish pass. The water velocity was very friendly in this sequence. All the fishes moved one chamber to another quite comfortably, not necessarily moving with the tide. Hydraulic condition looks very friendly, can be said that it is one of most favorable condition for cruising speed. Fish moves freely with the water current. Sometime they create school within the same size and sometime they swim alone.

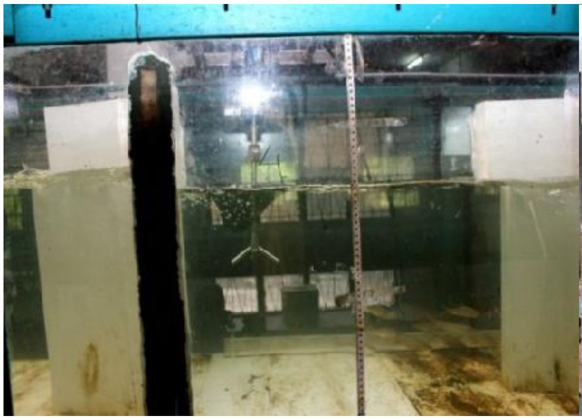


Fig 77.Normal water flow in the flumeFig 78. Fishes movement very normal

Sequence-6

Water depth = 50 cm, Pump discharge= 68 m^3/hour, Velocity= 0.4 m/sec

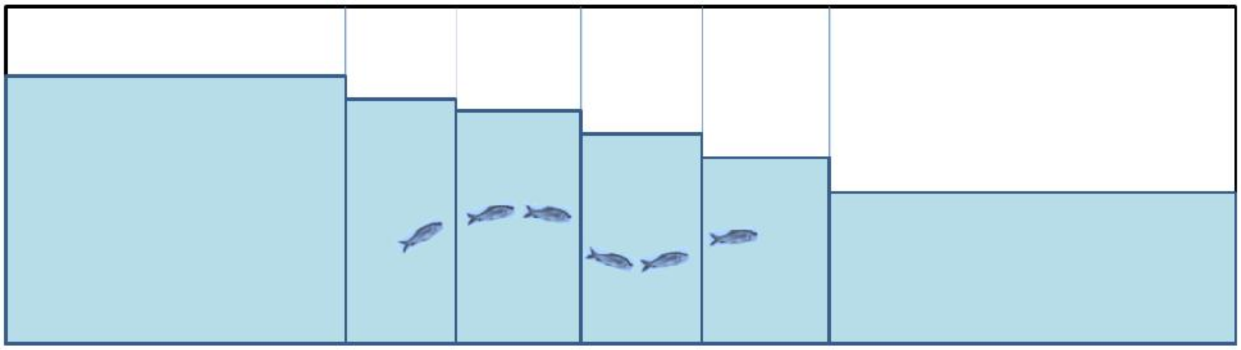


Fig 79. Sequence 6, depth 50 cm, velocity- 0.3 m/sec, fish showsnormal swimming behavior

Fish Behavior Observation: In this sequence, the water velocity was very friendly. The fishes movedabout 15 times from upstream to downstream and then back to upstream very comfortably.No significant weight loss was observed. They were observed to be swimming like playing i.e. competing with one another to cross the pass from one end to other end. They were not moving towards the tide. Within the first hour they individuallysearched for food and comfort zone. But after two/three hours, the fishes formed a school and they passed the fish pass together. They were not facing any suffocation/discomfort. The fishes were observed to be passing without any mortality.

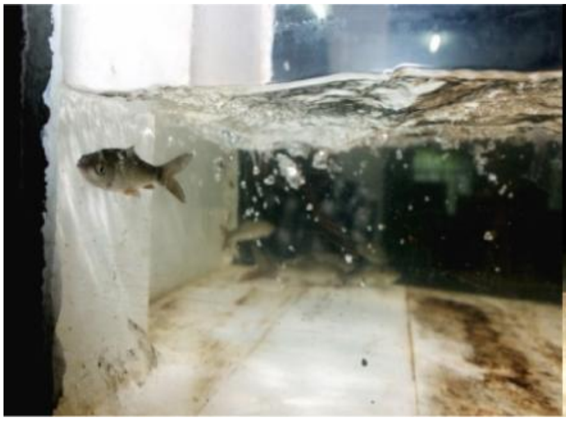


Fig80.Single fish resting behavior in corner

Fig81. Fishes formed school

Sequence-7

Water depth = 40 cm, Pump discharge= 64 m^3/hour, Velocity= 0.5 m/sec

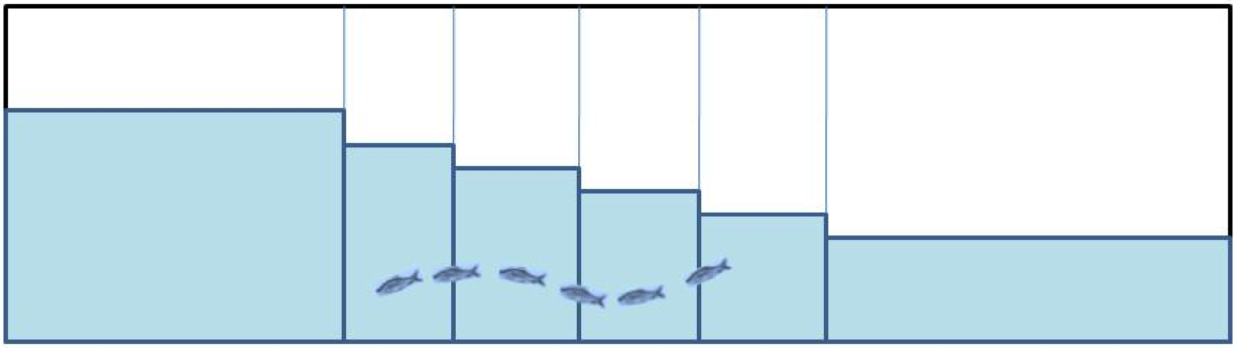


Fig 82. Sequence 7, depth 40 cm, velocity- 0.5 m/sec, fish shows normal swimming behavior

Fish Behavior Observation: The water velocity was very friendly. Fishes movedfrom upstream to downstream by school/groupfrequently. Within the first hour they stayed in individual chambers, but after one hour they formeda school and passed the fish pass together very spontaneously for 5 times. They were not facing any suffocation/discomfort. They movedalong as well as opposite of the water flow.The fishes passed the fish pass without any mortality.Hydraulic condition seems favorable for fishes.

Fig83.Fishes crossing the fish pass

Fig 84. Fishes formed school

Sequence 8:

Velocity : 0.6 m/sec, Water discharge: 75m^3/hour, Water depth: 40cm

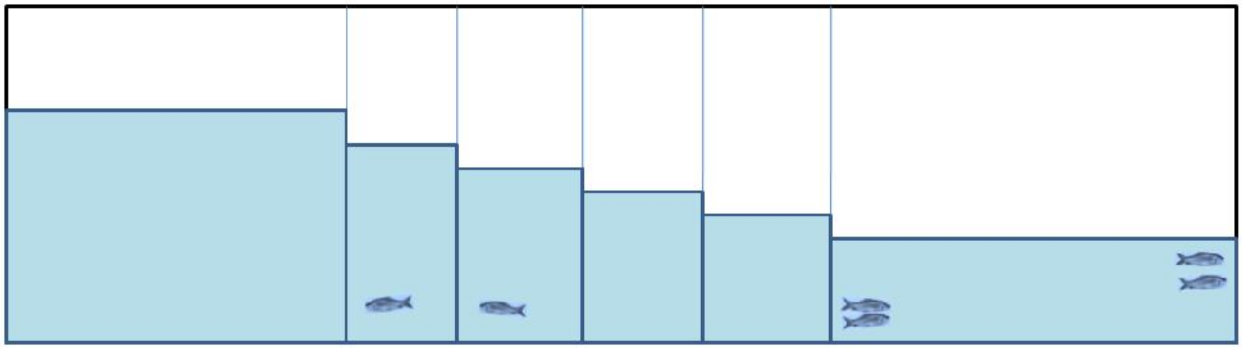


Fig 85. Sequence 8, depth 40 cm, velocity- 0.6 m/sec, fish shows normal swimming behavior

Fish Behavior Observation: Water velocity was not that friendly, fishes weremoving up and down with the water flow. Sometime they move individually and sometime they move ina group/school. For the first 2 hours they stayed separately, but after sometime fishes formed a schooland moved together in whatever the water condition was. All the fishes passed the fish pass for almost 9 times. The way theytravelled through the pass was amazing.They were seen to enter the pass, move all the way to the end of the tunnel and then came back to the opening in under a minute. Sometime they would move with the water current and sometime they would move against the water current. It looks like, fish number is 10, it can be one of the main reason for swimming in a bad hydraulic condition. Very slight weight loss was observed.

Fig 86.Fishes crossing the fish pass

Fig 87. Fishes entering into pass from downstream

Sequence 9:

Velocity : 0.7 m/sec, Water discharge: 87 m^3/hour, Water depth: 40cm

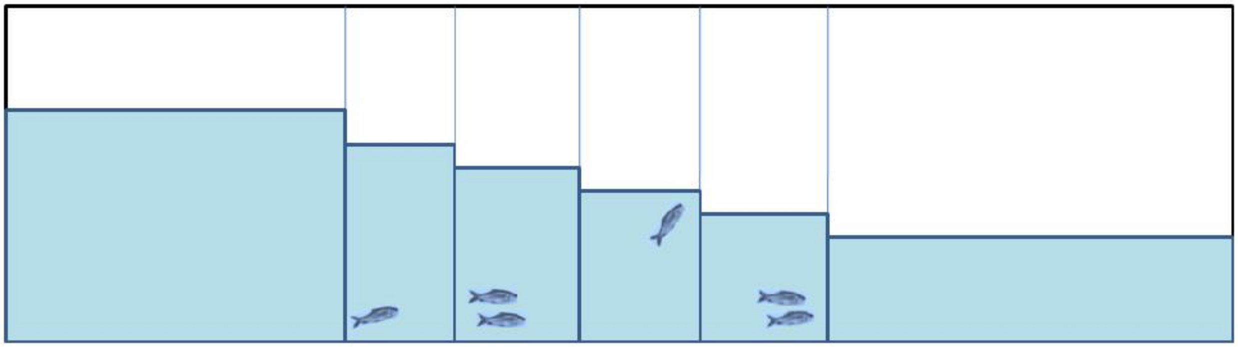
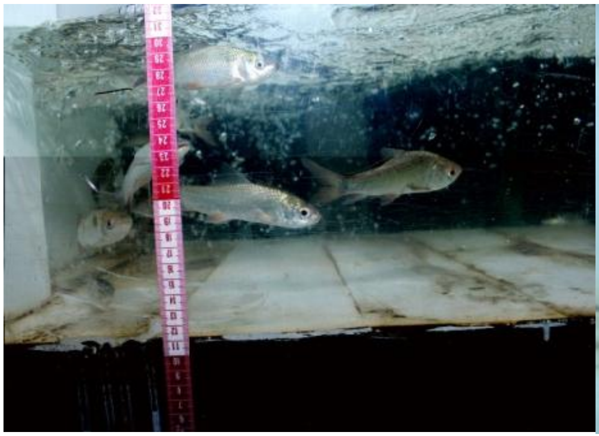


Fig 88. Sequence 9, depth 40 cm, velocity- 0.7 m/sec, fish shows sustained swimming behavior

Fish Behavior Observation: Fishes were released into fish pass model first pool. Some took place in upstream, some wentthrough the pass, and some moved with the water current toward downstream. But fishes stayed at the same place for half an hours where they released. They did not form any school. Even though some tried to move, most of themcould not move. It looks bursting velocity for fishes. Though water depth is small, fishes cannot move without water flow. They just passed the passed with the water current, cannot swim against the water current.



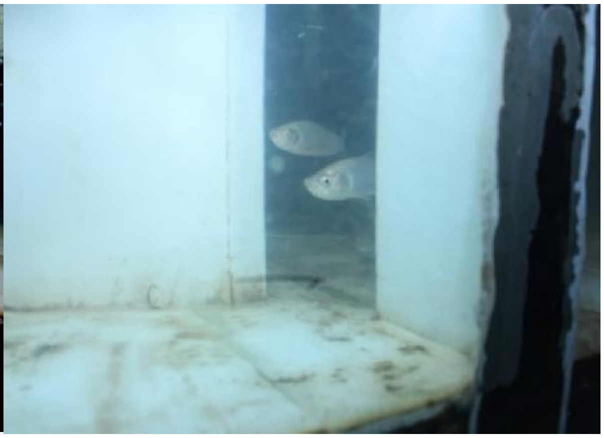


Fig 89.Fishes taking rest in the corner Fig90. Fishes taking place near bottom where velocity low

Sequence10:

Velocity : 0.8 m/sec, Water discharge: 96 m^3/hour, Water depth: 40cm

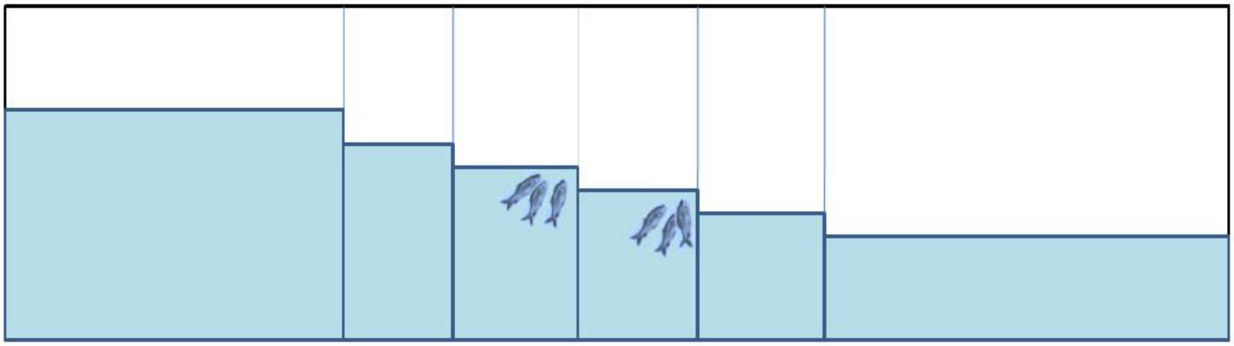


Fig91. Sequence 10, depth 40 cm, velocity- 0.8 m/sec, fish shows bursting swimming behavior

Fish Behavior Observation: Water velocity is very high, in this sequence fishes were not moving at all.They were just staying at a corner and trying to survive. They took the place at corners of A, B, C in the fish pass. They did not try to form any school, as it was not possible for them. Velocity feels more because the water depth is low, only 40 cm. Fishes have no space to get rid from the hydraulic condition.

Fig92.Velocity feels more because the water depth is lowFig93. Fishes taking place near corners

Sequence11 :

Velocity : 0.3 m/sec, Water discharge : 37 m^3/hour , Water depth: 40cm

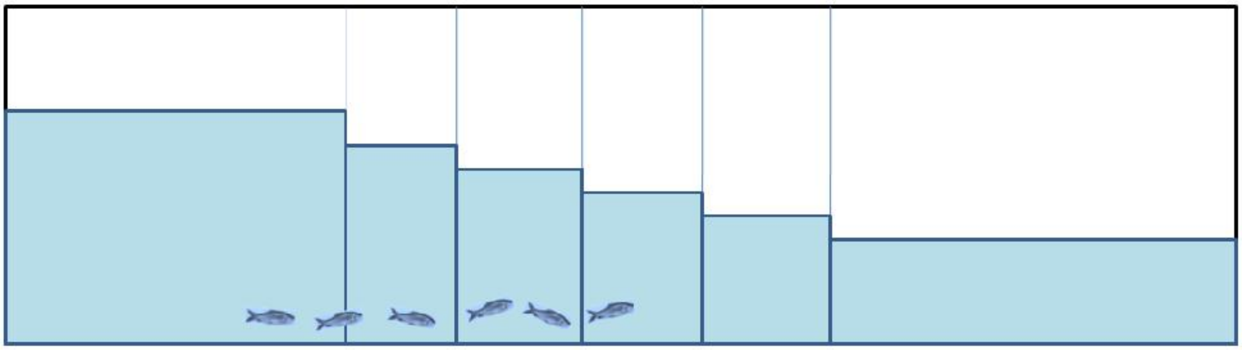


Fig 94. Sequence 11, depth 40 cm, velocity- 0.3 m/sec, fish shows cruising swimming behavior

Fish Behavior Observation: In this sequence water flow condition was like stagnant water, and fishes were moving peacefully. When the fishes were knocked, it began to hide within the pass.Afterwards they startedto create school to pass the passage. It was noticed that they were staying in the corner of the structure, where they got favorable condition. All the fishes came from upstream, passed the fish-pass and went toward downstream and again went back to upstream.They were doing it spontaneously. Sometimes they stayed at M2 place. Depth of water is low, for this fishes swimming near to bottom.

Fig 95.Fishes entering into fish pass

Fig 96. Water depth is low, fishes swim near to bottom

Sequence12

Velocity : 0.4 m/sec, Water discharge: 52m^3/hour , Water depth: 40cm

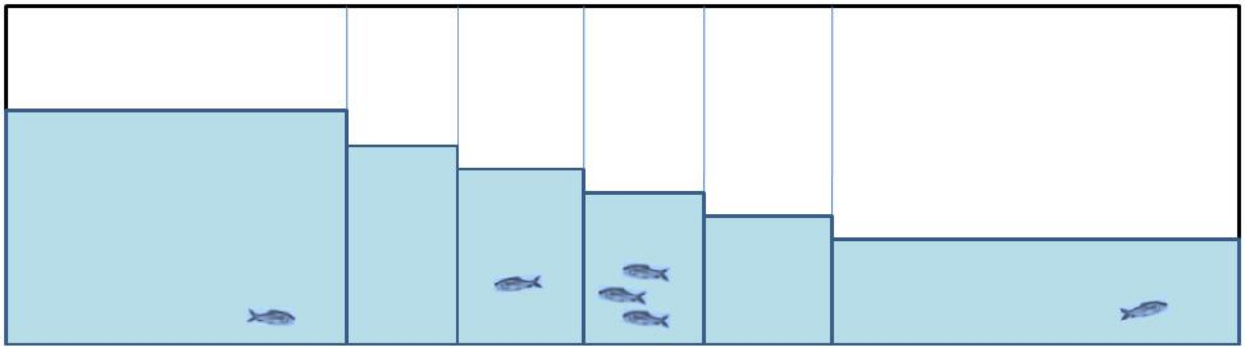


Fig 97. Sequence 12, depth 40 cm, velocity- 0.4 m/sec, fishescruising swimming behavior

Fish Behavior Observation: Fishes are released in upstream position of the fish pass. Water velocity is favorable for fishes. Fishes can move freely one place to another. Oxygen value taken for all possible corner. When the flow is much, oxygen found higher there. But fishes are moving towards the tide. Some fish passing the fish pass individually, some are forming groups. It looks like it is a good condition for cruising speed.

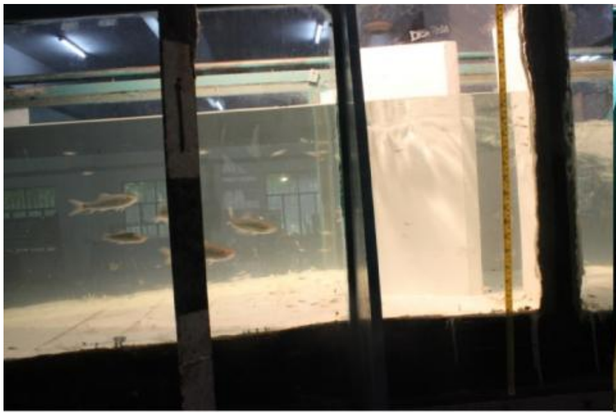


Fig 98.Fishes entering into fish pass from upstream

Fig 99. Fishes passing from pool 2 to pool 1

Sequence13:

Velocity : 0.5 m/sec, Water discharge: 100 m^3/hour, Water depth: 60 cm

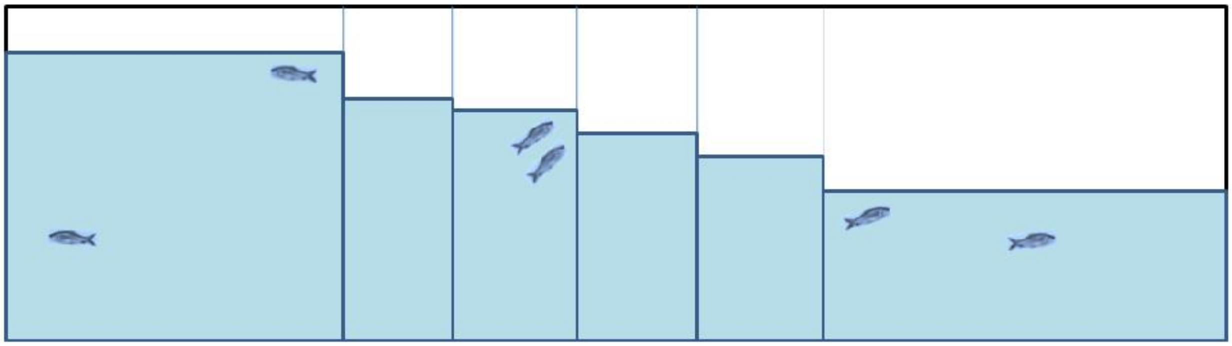
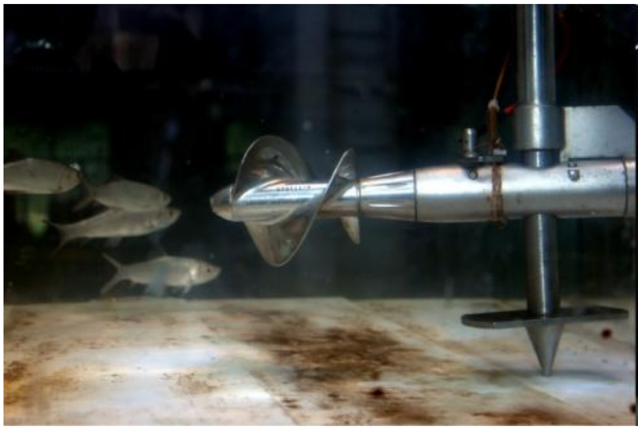


Fig100. Sequence 13, depth 60 cm, velocity- 0.5 m/sec, fishescruising swimming behavior

Fish Behavior Observation: Water velocity is very favorable and there have some rhythm for fishes. This flow is encouraging for fishes, they can move freely but felt obstacle towards the wave current. They have to move with the water current. After 2 hours, they behave like they are playing, doing up-down continuously. Oxygen value taken for all possible corners.Oxygen found higher where water the velocity higher.Water depth is good for fishes to pass.



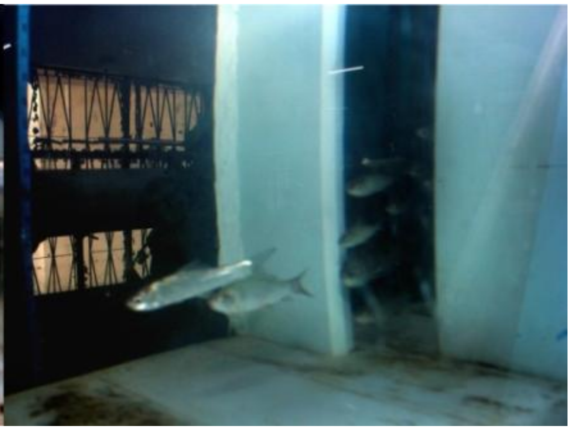


Fig101.Fishes moving around ADV   Fig102. Fishes passing from pool 1 to pool 2

Sequence14:

Velocity: 0.6 m/sec, Water discharge: 110 m^3/hour, Water depth: 60cm

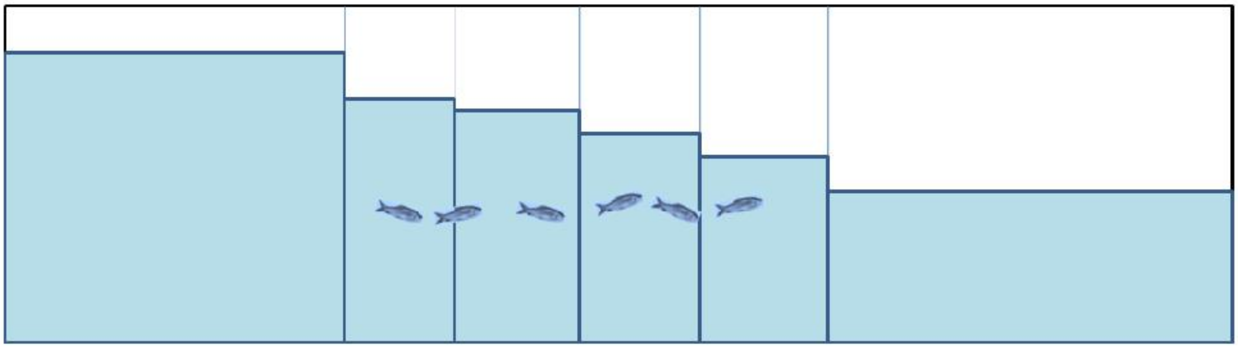


Fig103. Sequence 14, depth 60 cm, velocity- 0.6 m/sec, fishescruising swimming behavior

Fish Behavior Observation: Water velocity is slightly higher for fishes to move. Fishes are moving but not so easily, small one are not moving, big ones are going one place to another. Oxygen value taken for all possible corners, the flow is enough, so oxygen is all around the tunnel and chambers. Water depth is high and tunnel depth is closer to water depth so water velocity could not effect fish movement. Fishes show mid water swimming in the flume and fish pass.

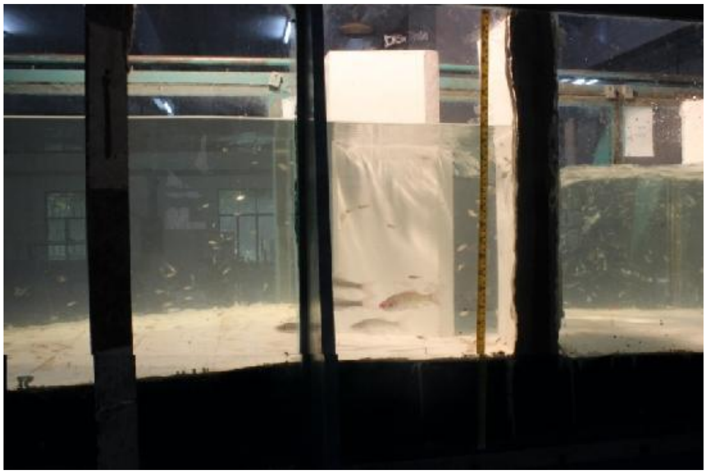


Fig104. Mid water swimming occur in depth 60 cm

Fig 105. 0.6 water velocity in depth 60 cm

Sequence15:

Velocity :0.7 m/sec, Water discharge: 125 m^3/hour, Water depth: 60cm

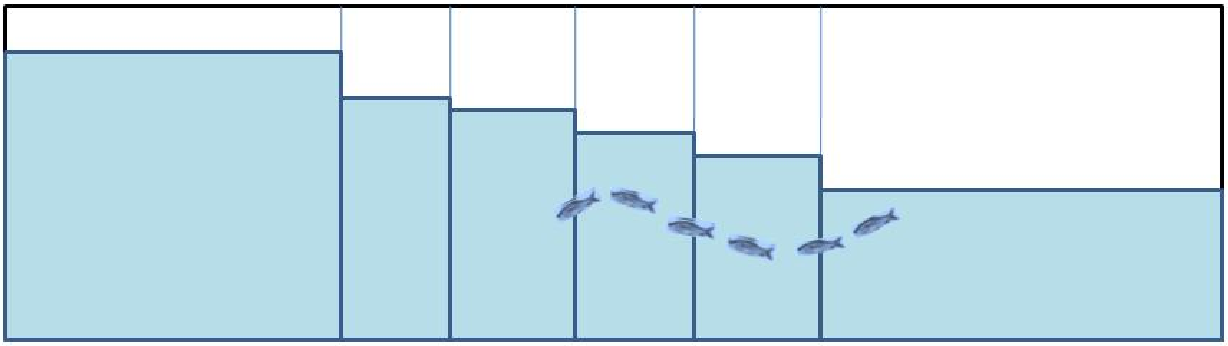


Fig 106. Sequence 15, depth 60 cm, velocity- 0.7 m/sec, fishes swimming behavior

Fish Behavior Observation: Water velocity is high, but water depth is 60 cm, which is supportive for fish. Fishes are moving, water current is not much disturbing for fishes. Fishes crossing the passage, going up-down like it is a game.Special feature, all fishes; small and big doing game.When they came to enter of fish passage, chamber 1, the give the tail in front and passing with the water current. And when they enter from down stream, chamber 4, they give the mouth /face to the chamber, and keep themselves free with the current.

Fig 107.Water flow inside the fish pass

Fig 108. Mid water swimming occur

Sequence16:

Velocity – 0.8 m/sec, Water discharge: 145 m^3/hour, Water depth: 60cm

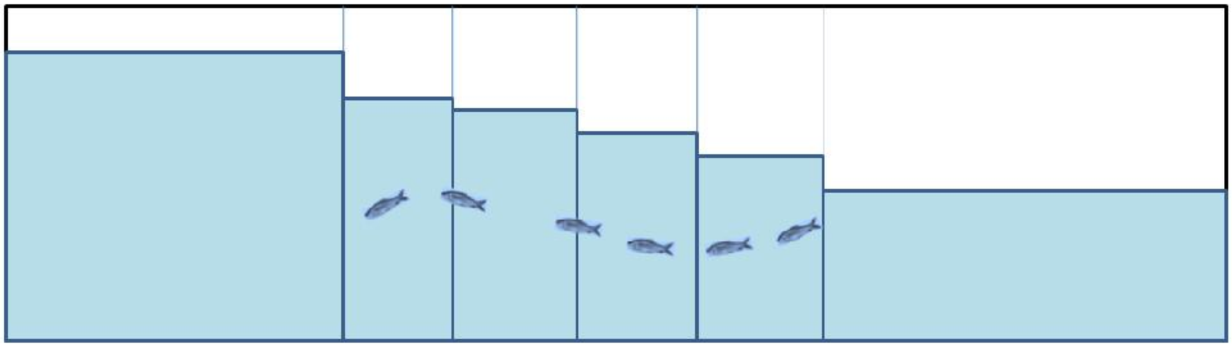


Fig 109. Sequence 16, depth 60 cm, velocity- 0.8 m/sec, fishes swimming behavior

Fish Behavior Observation: Water velocity is highest for fishes, some fishes are moving in the surface. They are trying to enter into the passage, but failed. Water depth is also highest, that’s why fishes are not facing so much problem. Big fishes can pass the passage 4 times with 2 juvenile. Other two juveniles failed to enter. They stayed in the upstream portion. Weight loss occur in those who crossed the passage several time. Mid water swimming also seen in this condition.

Fig 110.Fishes crossing the fish pass

Fig 111. Mid water swimming and school behavior seen

Sequence 17:

Velocity – 0.3 m/sec, Water discharge: 70 m^3/hour, Water depth: 60cm

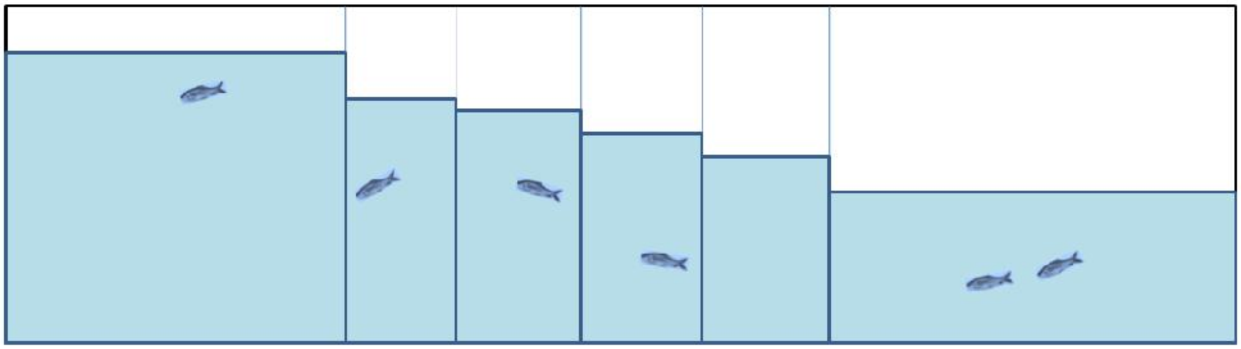


Fig112. Sequence 17, depth 70 cm, velocity- 0.3 m/sec, fishes swimming behavior

Fish Behavior Observation: Fishes are released in upstream position of the fish pass. After sometime fishes are scattered within an hour of the release, two fishes position them in downstream. Two swims at the entry of the fish pass and the rest are in the pools. Water velocity low, favorable condition for fishes. One of the best hydraulic condition for fishes to cruise in water. Weight loss occurred very low.

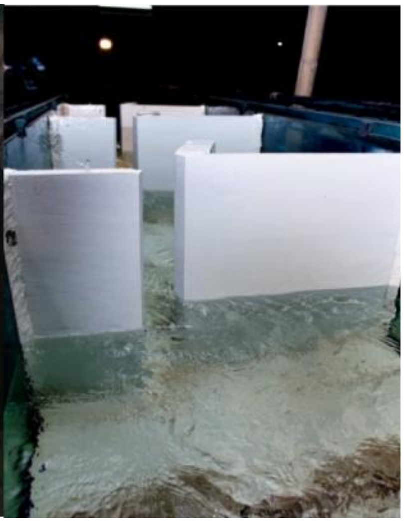


Fig 113.Mid water swimming behavior   Fig 114. Water flow calm and normal

Sequence18:

Velocity – 0.4 m/sec, Water discharge: 84m^3/hour, Water depth: 60cm

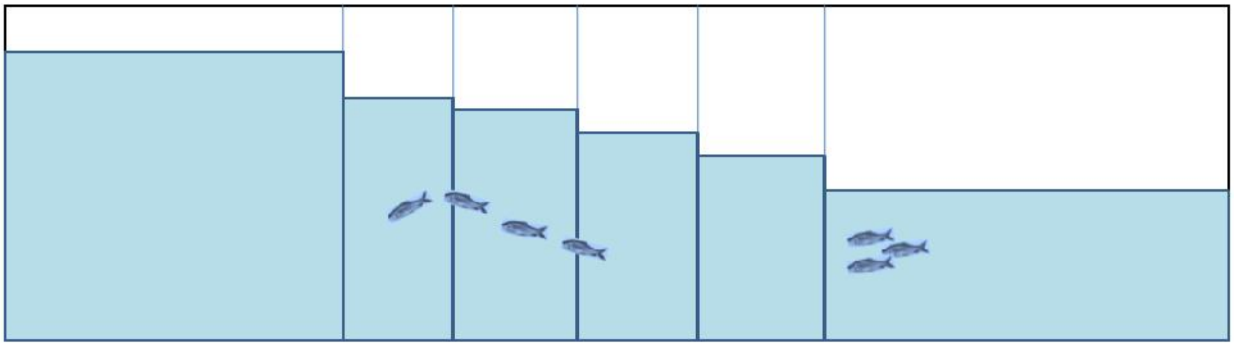


Fig 115. Sequence 18, depth 60 cm, velocity- 0.4m/sec, fishes swimming behavior

Fish Behavior Observation: It is observed that this condition is one of the best hydraulic condition for fishes. Water velocity low, fishes showing free movement, no water current and pressure. Fishes pass to the passage up and down. Weight loss occurred very low. Fishes form school to pass the fishpass. Fishes show mid water swimming and some are taking rest into the corners of the pools.

Fig116. Fish passing one pool to other

Fig 117. Fishes swimming towards fish pass

Carp Swimming Behavior: Test found by observing the results of the Table that Sub-adult and juvenile fishes performed better swimming speed and their swimming performance is better than small fishes. Whenever there is different size combination of fishes it will perform better and create school.Behavior of fish consisted almost exclusively of mid-water free-swimming. Tests were non-injurious to fish. All survived and behaved normally for a minimum of 6 hours following tests and most were alive and healthy weeks and months later.

Run	**Velocity**	**Water Depth**	**Fish size**	**Mortality/ Injury**	**Swimming Behavior/ speed**	**School Formation**
1	0.5	50	S, J, F	no	Cruising	School
2	0.6		Jb, Jsm	no	Sustained	School
3	0.7		J, F	no	Prolonged	School
4	0.8		J, F	no	Bursting	No School
5	0.3		J, F	no	Cruising	School
6	0.4		J, F	no	Cruising	School
7	0.5	40	J, F	no	Sustained	School
8	0.6		J, F	no	Prolonged	School
9	0.7		F	no	Bursting	No School
10	0.8		F	no	Bursting and Exaution	No School
11	0.3		F	no	Cruising	No School
12	0.4		F	no	Cruising	No School
13	0.5	60	F	no	Cruising	No School
14	0.6		Jb, Jsm	no	Sustained	School
15	0.7		S, J	no	Sustained	School
16	0.8		J,F	no	Prolonged	School
17	0.3		J,F	no	Cruising	School
18	0.4		J,F	no	Cruising	School

S= Sub-adult, J= juvenile, F= Fingerling, b=big, sm= small

Table 3.Major Carps; Sub-adult, juvenile,fingerling group swimming behavior.

Individual Swimming Behavior: In experimental runs, fishes were exposed in three different height 40, 50 and 60 cm and six different water velocities viz. 0.3 m/sec, 0.4 m/sec, 0.5 m/sec, 0.6 m/sec, 0.7 m/sec and 0.8 m/sec. Fishes play an interesting role in different velocity condition. Locomotor behaviors observed in fishes: free swimmimg, skimming, hunkering, creeping (on horizontal substrate), wedging, oral-grasping and tail bracing have seen in changing velocity condition.

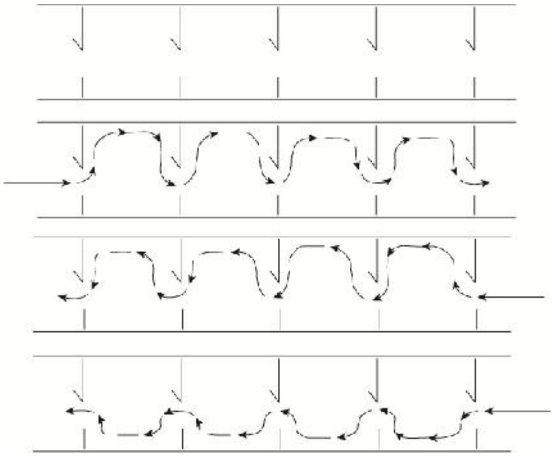


Fig 118. Path of fishes in individual movement to cross the fish pass.

Group Swimmimg: Migration of Carps typically occurs by mass movements. In experiment, the number of Major Carps migrating together tended to increase water velocity, forming schools. Survival of Carps increased with the size of the school of migrating fishes.

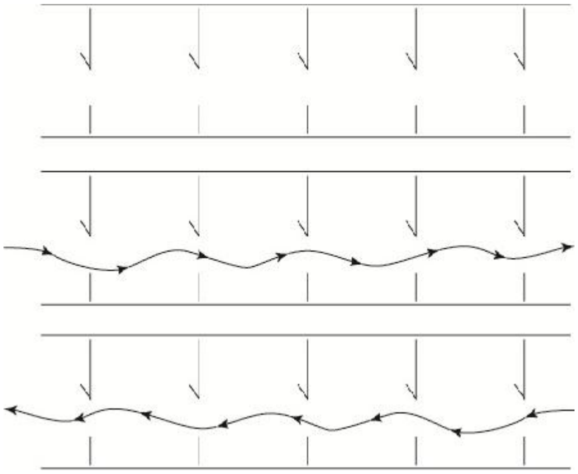


Fig 119. Path of fishes in school movement to cross the fish pass.

4.2.1cSwimming Behavior of Carp and Catfish :

Swimming performance of Carps and Catfishesevaluated using fish pass with test chambers. Fish Experiment are maintained in large static holding flumes that permit unimpeded natural movement and behavior (Including schooling). Each individual fish is tested only once in freshly drawn water. Swimming behavior trials covered four sizes of RuiCatla and Mrigel (adults, juveniles, fingerling and sub-adults) and two sizes for Catfishes (fingerlingand sub-adults). Tests are conducted 20-27^{0}C, associated with greatest activity of the fish. Fish lengths were recorded as fork lengths for Carps and Catfishes for total length.

Fish species:

- Major Carps (Rui, Catla And Mrigel)
- Cat Fishes (Shingi, Magur).

Mixed Group Movement of Carp Fishes

Velocity : 0.3-0.8 m/sec, water depth: 40- 60cm

Fish Behavior Observation: Mixed fish samples shows special feature, all fishes; Adult, Sub-adult, Juvenile and Fingerling (small, medium and big) passing the fish pass that it was a game. When they came to enter of fish passage, chamber 1, the give the tail in front and passing with the water current. And when they enter from downstream (Chamber 4) they give the mouth or face to the chamber, and keep themselves free with the current. Water velocity was high, low and medium but it was not create any barrier for fishes. Mixed fishes moved with the water current and also moved against the water current. It can be said that fish size can be a barrier when fishes are alone, but when they are in school they can pass any barrier. Their speed were cruising and sustained.

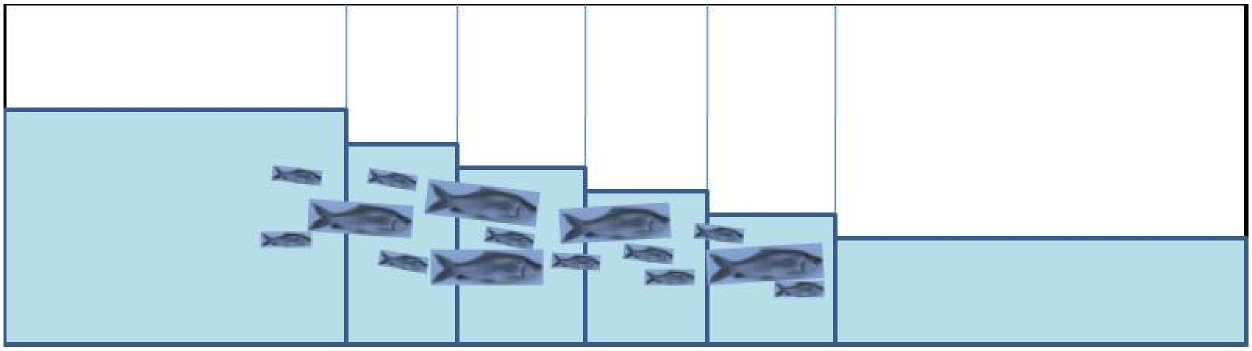


Fig 120.All sizes fishes swimming behavior

Fig 121.Can tolerate high velocity

Fig 122. Can pass the fish pass quickly

Catfish Movement Observation

Velocity :0.3-0.8 m/sec, water depth: 40 -60cm

Fish Behavior Observation:Fishes were released in upstream of the fish pass. After an hour they are scattered in the flume. They are swimming in the lower part of the flume, it looks like they are scrawling in the ground. Some are staying in the same chamber for long and some are moving with the water current. They form school in 0.5 m/sec and 0.6 m/sec in 60 cm depth. When the tide condition was very rough, they take shelters in A, B, C corners of the pools. Shows similar behavior like the Carps.Fishes moves with the water current and against the water current in the fish pass.Fishes were observed the bottom part of the flume, where light is low. They preferably stay at corners, in insufficient light condition, mostly behave like bottom dwellers.

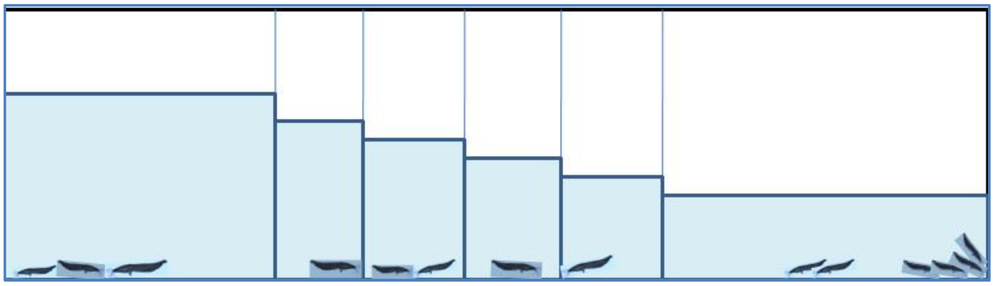


Fig 123. Catfishes were scattered in fish pass when they released in flume

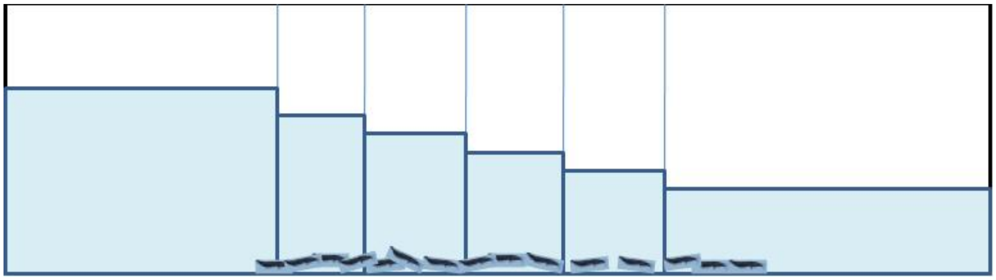


Fig 124. Catfish passed fish pass and formed school in favorable velocity in 0.5 and 0.6 m/sec

Fig 125. Catfishes are swimming in the upstreamFig 126. Fishes are swimming inside pools

Social Facilitation of Carp and Catfish: Carps and Catfishes are the two main migratory fishes of our river and floodplain. Carp and Catfish were experimented individually and to create group to facilitate socially inside the fish pass.

Carps : Behavior of fish consisted almost exclusively of mid water free swimming

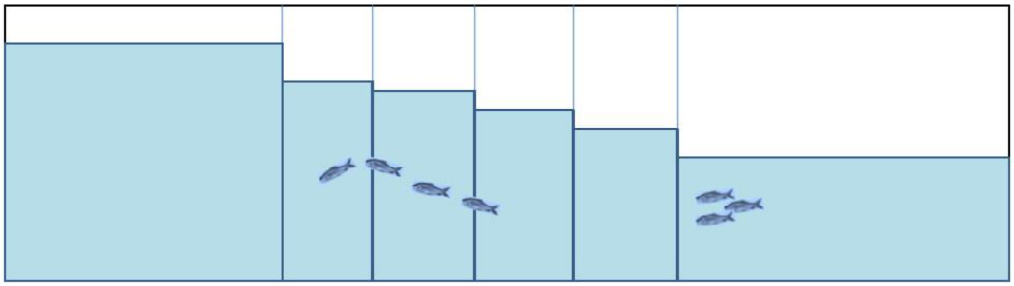


Fig 127. Carps mid water free swimming

Catfishes: Behavior of fish consisted almost sluggish movement and exclusively of down-water swimming (Figure).

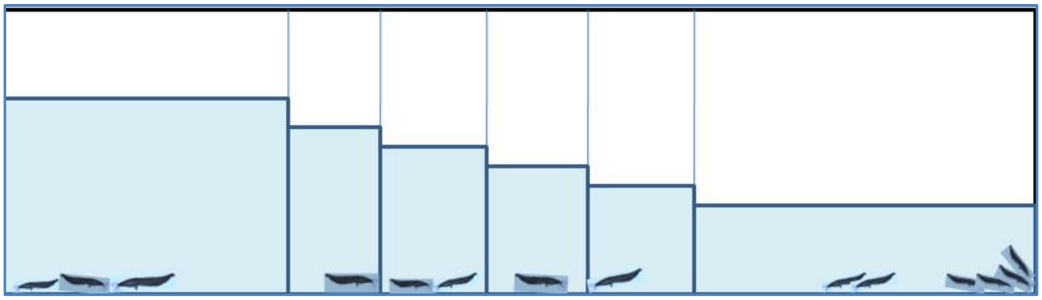


Fig 128.Catfishes sluggish movement

Inter species Behavior: In the experimental runs Catfishesnever create school or group with Carps.

Swimming Speed of School :

Carp Fish School Movement : Carps movement observed in school condition and time is also measured. It is found that total fish school passed the fish pass; upstream , pools and downstream in 2 minute 23 second. The water velocity was 0.5 m/sec . Fishes took 6/7 sec for resting in downstream.

Catfish SchoolMovement : Catfish movement observed in school condition and time is also measured. It is found that total fish school passed the fish pass : upstream , pools and downstream in 4 min 55 second. The water velocity was 0.5 m/sec . Fishes took 1 minute 13 second rest in downstream.

Innate Rhythm

- Adult, Sub-adult and juvenile Carp fishes performed better swimming speed and their swimming performance is better than small fishes.
- Whenever there is different combination of fish sizes in Carp, it will perform better and create school. Tests were non-injurious to fish.
- Carp fishes play an interesting role in different velocity condition. Locomotor behaviors observed in fishes; free swimming, skimming, hunkering, creeping (on horizontal substrate), wedging, oral-grasping and tail bracing have seen in changing velocity condition.
- Fry fishes also survived 100% and can enter into fish pass with water flow.
- All four sizes of Carps were strongly rheotactic and moderately strong swimmers, performance metrics for large fishes were greater than smaller fish.

- More than 90% of fish tested were reotactic, 100% survival of fish was observed in all experimental runs and migrating individuals could stimulate other species in their vicinity to migrate.
- Behavior of Carp fishes consisted almost exclusively of mid-water free-swimming
- Endurance swimming ability generally showed an increase with increasing fish length, a trend which was particularly noticeable in Carps
- There is a strong tendency for grouping animals such as schooling fish to synchronize their activity.
- Experiments showed that Carps are 3/5months old, migrated more quickly and completely out of an experimental stream, when released in large groups rather than in small ones.
- Individual Carp were more influenced by abiotic conditions than were schools, which suggests that social interaction may override environmental stimuli.
- Mass movements could result from a common response to some stimulus such as a threshold photoperiod, temperature or lunar phase.

Therefore, social facilitation may induce migration of fish possibly at slightly different physiological states.

DISCUSSIONS

In situ experiment in Sariakandi shows fish fry, hatching, juvenile and adult movement from Jamuna to Bangali river. After construction of the fish pass, the water volume and fish species of the Bengali River is increased and increased fish diversity and fish biomass, study found 15 migratory species in the fish pass which indicates species diversity exchange by fish pass. Water parameters, depth, velocity and flow also favorable for fishes. In Kashimpur fish pass study show only small species can pass the fish because of low water depth of water. Water parameters, depth, velocity and flow were not favorable for fishes. Water velocity found in Sariakandi fish pass is 1-1.49 m/sec and in Kashimpur fish pass is 0.4 m/sec. Water velocity trigger a fish to migrate which is present in Sariakandi but absent in Kashimpur fish pass.

*Ex situ*onset of migration is associated with a number of factors are thought to be involved in regulating onset of migration. These factors may act at two levels, abiotic and biotic factors. Their relative importance seems to be species, place, and time dependent (Baggerman 1960).The seasonal occurrence and geographic distribution of carps suggests that migration occurs only within a specific range of temperatures. Both too high and too low temperatures seem to inhibit migratory behavior. In both experiment, *in situ* and *ex situ*condition temperature was good for migration of fish. As the suitable temperature for tropical carps are 26-30^{0}C(Jhingran 1991)

Other water parameters were favorable for fish migration study. Fishes were scattered around since the dissolved oxygen levels were similar through the fish pass. Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water (Boyd 1990). A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality. Dissolved oxygen is necessary to life of fish and an important factor for migratory fish. *In situ* and *ex situ*, both experiments, dissolve oxygen level was 6.5- 12.5 mg/l which indicate the presence of oxygen in water. Oxygen level received higher when velocity of water increases and lower when velocity decreases. And it is observed that fishes receive a good level of oxygen inside the flume in running water condition throughout the experiment. Surface water found little higher than ground water because of surface water receive oxygen from the air.

pH indicates the acidity or alkalinity of a solution at a given temperature. A pH of 7 describes a neutral solution because the activities of hydrogen and hydroxide ions are equal (Boyd 1990). When the pH is below 7, the solution is described as acidic - the hydrogen ion activity increases and the pH value decreases. When the pH is above 7, the solution is described as basic or alkaline - the activity of hydroxide ion is greater than that of hydrogen ion.In experiment pH range found high in high velocity of water and found low in low velocity of water.

The main use of TDS measurement isto detect the water condition in that area or place, waste water monitoring is the main purpose. TDS level found low where water flow is high and received high level where water flow is low. Experiment time also a factor for *ex situ* condition, where TDS level were low in the beginning of the experiment and get slight higher at the end of the experiment. As stated by Woodhead (1975) " successful migration depends not only upon the appropriate behavioral responses to environmental stimuli, but equally upon closely regulated metabolic changes which enable the fish to mobilize sufficient energy reserves to sustain a movement which may be both prolonged and extensive migration is as much a matter of metabolism as of behavior". The outcome of this study also match the theory of migration.

Water Flow and waterdepth seems to have an acute and long-term effects on migration. *Ex situ* condition depth was 40-60 cm a good depth for experimental fishes. Height of water level in the flume also a factor for fish migration in fish pass. In 50 and 60 cm fish passes the fish pass and create schoolmore than 40 cm water depth of the flume. Laboratory tests were conducted in 0.3-0.8 m/sec, associated with greatest activity of the fish.Water velocity trigger a fish to migrate which is present in *Ex Situ* experiments, 0.5-0.8 m/sec shows attracting velocity for fishes to migrate if water depth is favorable.

In three sets of experiments fishes were exposed to six types of water velocity viz. 0.3 m/sec, 0.4 m/sec, 0.5 m/sec, 0.6 m/sec, 0.7 m/sec and 0.8 m/sec in each experiment. From fish length and weight relationship, it was evident that juvenile and sub-adult fishes are better performer than small fishes. However, the impacts are different for fish size. Collectively the average weight loss shows some effects with water current and fish size. In all experimental runs viz, 1, 2 and 3, the average weight loss is prominent as the speed is gradually increased. Where small fishes get maximum weight loss than big fishes and average weight loss were evident in lower cruising speed. Fish swim as much as they can in low cruising speed and get weight loss. And in high velocity, water current condition was so rough fishes cannot swim, they try to escape themselves from the wave, get less weight loss. So, the relative weight loss (% weight) in the three experimental also show the similar trends in these experimental runs.

The condition factor (K) is an estimation of the well-being or weight-length relation of the fish. The condition factor of a fish reflects physical and biological circumstances and fluctuations by interaction among feeding conditions, parasitic infections and physiological factors (Le Cren, 1951). Analyzing the experimental fishes, their condition factor is in between 0.3 - 1.0. Condition factor 0.3 -1.0 indicates acceptable and good condition for fishes. The condition factors were changed after the experimental run. Result shows that the condition factors improved for all fishes. This is due to the weight loss and exercise in the experimental run. During migration, an acute and temporary decrease in condition factor occurs around the time of migration, which corresponds to decreased weight (Boeuf, 1993; Young *et al*. 1995). From an evolutionary point of view, it seems appropriate that such a drastic physiological change as sudden growth in length and weight is closely associated with the fish ability to reach feeding habitats, in order to replenish the suddenly depleted energy stores.

Migration of Carps typically occurs by mass movements. Groups of fish traveling together reduce metabolic costs by using turbulence (Weihs, 1984). Moreover, schooling increases the chances of finding food, supplies some protection against predation, and decreases the error in orientation direction (Smith, 1985). In experiment, the number of

Major Carps migrating together tended to increase during the migration time, forming schools. Survival of Carps increased with the size of the school of migrating. Test found by observing the results that adult, sub-adult and juvenile fishes performed better swimming speed and their swimming performance is better than small fishes. Whenever there is different combination of fish size, it will perform better. Tests were non-injurious to fish. Locomotor behaviors observed in fishes: free swimming, skimming, hunkering, creeping (on horizontal substrate), wedging, oral-grasping and tail bracing have seen in changing velocity condition. All four sizes of Carps were strongly moderately strong swimmers; performance metrics for large fishes were greater than smaller fish.100% survival of fish was observed in all experimental runs and migrating individuals could stimulate other species in their vicinity to migrate. Behavior of Carp fishes consisted almost exclusively of mid-water free-swimming. There is a strong tendency for grouping animals such as schooling fish to synchronize their activity. Therefore, social facilitation may induce migration of fish possibly at slightly different physiological states. There was a high degree of individual variation in fish performance both within and between tests.

Bioenergetics study revealed that minimum requirement of oxygen in migratory fishes. According to Jobling (1994), the rate of oxygen consumption of an actively swimming fish is typically 3-7 times higher than oxygen consumption at rest and can reach 10-15 times the resting level of fish swimming at high speed. Which properly measured in the experiment by fish stress test and gulping. Bioenergetics modeling has the potential to provide insight into the mechanisms underlying patterns of habitat utilization and fish production. However, bioenergetics will stay primarily a research tool or will successfully be applied as a management tool for habitat conservation and restoration management (Fausch, 1984). Cost of swimming results that biochemical composition loss occurs very little in migratory fishes.So it is evident that experimented migratory fishes have a small deficiency of biochemical composition than non-migratory fishes.

A vertical slot fish pass allows for variations in discharge and permits fish to ascend the fish pass at any depth they choose. In addition, the path of a fish ascending the fish pass is not tortuous and the fish pass provides resting locations for fish (Clay, 1995). The outcomes of this research work match with the theory of vertical slot fish pass. The vertical velocity profiles that have been presented show that the pool openings are the places of maximum velocities where attractive velocity of fishes can be observed.The velocity profiles at the resting places of fish at the recirculation region just before the partition wall represents lower magnitude of velocities which matches with the theory. The magnitude and distribution of velocity inside the pool of the fish pass is the governing factor for smooth passage of fishes. The resting places were mainly identified at the recirculation regions created at the side of the long baffles just before the partition walls which also agrees with the theory. And the cruising velocities at these places for the fish species were also observed.

CONCLUSIONS AND RECOMMENDATIONS

By conducting detail and rigorous experimental investigations, data analysis and observations offish behavior presented at the previous chapters, the synopsis of the study can be represented as follows:

- The result are showing the behaviour of a particular fish groups varied with different hydraulic condition.
- Water flow change the behaviours of test fishes and initiate the onset of migration
- The hydrological status of the ‘fish channel’ varies with the position and structure of the slots/ chambers
- Swimming capacity of Carps are superior then to the sedentary species like catfishes
- Fish fry, fingerlings, juvenile and sub-adult can survive 100 % and swim through the channel of less than a meter water flow
- Prominent weight loss occur in migratory fishes within high velocity field.
- In attracting velocity (0.5-0.8 m/sec) fish create school to pass the way.
- No fish mortality occur with in experimented run design and velocity profile.
- No significant loss in protein, fat, energy and amino acid in experimented fishes.
- Fish migration velocity are between 0.4-0.6 m/sec for experimented structure .

- Vertical Slot fish passes are suitable for fish migration.

Recommendations for Further Study

Based on the knowledge and experience gathered form the present research work some recommendations for further study can be suggested as follows:

1. Further laboratory studies based on other designs of vertical slot fish pass can be tested with different Bangladeshi fish species.
2. Detailed research works can be performed to understand the biological characteristics of different fish species under migratory regime.
3. Further study related to the water quality parameters can also be performed to find the fish response to the water quality parameters and water quality criterion.

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Table A1: Experiment Set 1 (Water Depth 50 cm)

	Water Velocity	Fish	Fish Species	Fish Size	Length		Weight (gram)		Weight Loss (grams)
Experiment	**M/S**	**#**			**Centimeter**	**Inch**	**Before Experiment**	**After Experiment**	
1	0.5	1	Mrigel	Subadult	20.32	8	58.44	56.84	1.6
		2	Mrigel	Juvenile	17.78	7	40.98	39.88	1.1
		3	Catla	Juvenile	17.272	6.8	39	38.92	0.08
		4	Mrigel	Juvenile	15.24	6	36.87	34.23	2.64
		5	Rui	Juvenile	14.478	5.7	33.86	31.84	2.02
		6	Catla	Juvenile	13.97	5.5	33.34	31.41	1.93
		7	Catla	Fingerling	7.62	3	10.24	8.84	1.4
		8	Rui	Fingerling	7.366	2.9	9.8	8.58	1.22
Experiment									
2	0.6	1	Rui	Juvenile	16.51	6.5	31.33	30.66	0.67
		2	Mrigel	Subadult	17.78	7	35.44	34.11	1.33
		3	Mrigel	Juvenile	15.24	6	26.36	26.11	0.25
		4	Rui	Juvenile	12.7	5	19.5	19.12	0.38
		5	Catla	Juvenile	12.7	5	20.02	18.66	1.36
		6	Rui	Juvenile	11.43	4.5	18.52	18.38	0.14
Experiment									
3	0.7	1	Rui	Juvenile	15.24	6	25.86	22.98	2.88
		2	Rui	Fingerling	8.89	3.5	7.14	6.83	0.31
		3	Rui	Juvenile	12.7	5	23.91	22.12	1.79
		4	Mrigel	Juvenile	10.16	4	15.62	15.23	0.39
		5	Catla	Fingerling	9.398	3.7	13.09	12.66	0.43
		6	Mrigel	Juvenile	11.43	4.5	20.39	18.25	2.14
Experiment									
4	0.8	1	Rui	Juvenile	16.51	6.5	35.38	32.3	3.08
		2	Catla	Juvenile	17.78	7	38.12	33.15	4.97
		3	Rui	Fingerling	7.112	2.8	7.79	7.24	0.55
		4	Catla	Fingerling	7.62	3	9.5	8.25	1.25
Experiment									
5	0.3	1	Mrigel	Juvenile	15.24	6	34.13	32.3	1.83
		2	Rui	Juvenile	12.7	5	18.95	16.39	2.56
		3	Rui	Juvenile	10.16	4	17.43	15.72	1.71
		4	Catla	Fingerling	8.89	3.5	11.25	9.26	1.99
Experiment									
6	0.4	1	Rui	Juvenile	15.24	6	18.86	18.38	0.48
		2	Rui	Juvenile	12.7	5	17.21	16.74	0.47
		3	Mrigel	Juvenile	16.51	6.5	24.18	23.92	0.26
		4	Catla	Juvenile	13.97	5.5	21.12	19.04	2.08
		5	Catla	Fingerling	8.128	3.2	11.48	10.22	1.26
		6	Mrigel	Fingerling	10.16	4	16.39	14.79	1.6

TableA2 : Experiment Set 2 (Water Depth 40 cm)

	Water Velocity	Fish	Fish Species	Fish Size	Length		Weight (gram)		Weight Loss (grams)
Experiment	M/S	#			Centimeter	Inch	Before Experiment	After Experiment	
7	0.5	1	Catla	Juvenile	10.16	4	17.2	16.19	1.01
		2	Rui	Juvenile	10.922	4.3	18.1	17.55	0.55
		3	Catla	Fingerling	7.62	3	12.91	11.86	1.05
		4	Rui	Fingerling	7.62	3	10.66	10.06	0.6
Experiment									
8	0.6	1	Rui	Juvenile	10.668	4.2	14.74	14.51	0.23
		2	Catla	Juvenile	10.922	4.3	17.2	15.97	1.23
		3	Rui	Fingerling	7.62	3	8.96	8.17	0.79
		4	Catla	Fingerling	6.35	2.5	5.21	4.14	1.07
		5	Rui	Fingerling	6.35	2.5	5.4	5.25	0.15
		6	Mrigal	Fingerling	6.35	2.5	5.68	5.35	0.33
Experiment									
9	0.7	1	Rui	Fingerling	7.62	3	8.03	7.91	0.12
		2	Mrigal	Fingerling	7.62	3	7.79	7.48	0.31
		3	Catla	Fingerling	6.35	2.5	4.76	3.97	0.79
		4	Rui	Fingerling	6.35	2.5	3.38	2.87	0.51
Experiment									
10	0.8	1	Rui	Fingerling	8.382	3.3	11.82	10.59	1.23
		2	Rui	Fingerling	6.35	2.5	7.79	7.41	0.38
		3	Catla	Fingerling	6.35	2.5	6.3	5.9	0.4
		4	Mrigal	Fingerling	5.588	2.2	5.79	4.3	1.49
		5	Catla	Fingerling	5.842	2.3	6.13	5.84	0.29
Experiment									
11	0.3	1	Rui	Fingerling	7.62	3	10.85	9.62	1.23
		2	Catla	Fingerling	6.35	2.5	7.86	7.3	0.56
		3	Rui	Fingerling	6.35	2.5	6.92	6.16	0.76
		4	Catla	Fingerling	6.35	2.5	6.97	6.38	0.59
Experiment									
12	0.4	1	Rui	Fingerling	7.62	3	7.68	7.12	0.56
		2	Mrigal	Fingerling	7.62	3	6.25	5.98	0.27
		3	Rui	Fingerling	7.62	3	7.44	7.18	0.26
		4	Catla	Fingerling	7.62	3	6.93	6.25	0.68

TableA3: Experiment Set 3 (Water Depth 60 cm)

	Water Velocity		**Fish Species**	**Fish Size**	**Length**		**Weight (g)**		**Weight Loss (g)**
Experiment	**m/sec**				**Centimeter**	**Inch**	**Before Experiment**	**After Experiment**	
13	0.5	1	Rui	Fingerling	8.89	3.5	7.81	7.16	0.65
		2	Catla	Fingerling	8.89	3.5	7.29	7.06	0.23
		3	Rui	Fingerling	7.62	3	6.38	6.12	0.26
		4	Catla	Fingerling	7.62	3	6.46	6.22	0.24
		5	Catla	Fingerling	7.112	2.8	5.78	5.32	0.46
		6	Rui	Fingerling	7.366	2.9	5.98	5.55	0.43
Experiment									
14	0.6	1	Catla	Subadult	13.97	5.5	30.07	29.06	1.01
		2	Catla	Subadult	15.24	6	34.27	32.98	1.29
		3	Rui	Subadult	14.478	5.7	33.29	32.38	0.91
		4	Rui	Juvenile	11.938	4.7	22.88	21.68	1.2
		5	Mrigal	Juvenile	12.446	4.9	25.68	24.98	0.7
		6	Mrigal	Juvenile	12.7	5	26.28	25.66	0.62
Experiment									
15	0.7	1	Catla	Adult	28.448	11.2	76.28	74.27	2.01
		2	Mrigal	Adult	27.432	10.8	70.68	69.35	1.33
		3	Rui	Adult	27.686	10.9	71.55	70.11	1.44
		4	Catla	Subadult	15.24	6	40.76	39.99	0.77
		5	Mrigal	Subadult	14.986	5.9	37.58	36.38	1.2
		6	Rui	Subadult	14.986	5.9	38.22	36.15	2.07
Experiment									
16	0.8	1	Catla	Juvenile	11.938	4.7	20.44	18.65	1.79
		2	Rui	Juvenile	11.43	4.5	16.87	15.01	1.86
		3	Rui	Fingerling	8.89	3.5	10.2	8.57	1.63
		4	Mrigal	Fingerling	7.62	3	6.66	5.9	0.76
Experiment									
17	0.3	1	Rui	Juvenile	12.7	5	20.5	19.89	0.61
		2	Rui	Juvenile	12.192	4.8	18.33	16.87	1.46
		3	Catla	Juvenile	11.43	4.5	16.9	14.75	2.15
		4	Mrigal	Fingerling	8.128	3.2	9.14	4.64	4.5
		5	Rui	Fingerling	9.906	3.9	12.96	11.1	1.86
Experiment									
18	0.4	1	Rui	Juvenile	13.462	5.3	24.28	23.77	0.51
		2	Catla	Fingerling	10.668	4.2	14.55	14.19	0.36
		3	Catla	Fingerling	9.398	3.7	13.84	13.56	0.28
		4	Rui	Fingerling	9.144	3.6	11.36	11.02	0.34
		5	Mrigal	Fingerling	7.62	3	8.86	8.58	0.28

Hydrodynamic data collected from (Rahman M.Sc . Thesis, 2015)Table A4-A18

TableA4. Specifications of the Experiment Runs

Experiment RunNo.	U/s Water Level (cm)	Discharge, Q (m3/hr)	Total Head Loss, Ah (cm)
1	50	81	6
2	50	94	8.6
3	50	104	12.1
4	50	118	19.5
5	50	55	1.75
6	50	68	3,35
7	40	65	6
8	40	75	10.75
9	40	87	16.67
10	40	96	29.17
11	40	37	1
12	40	52	3.5
13	60	100	5.75
14	60	110	7.4
15	60	125	10.75
16	60	145	15.75
17	60	70	2
18	60	84	3.33

Table A5: Behaviour of Rui *(Labeo rohitd)* of fry size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity at D/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0.8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	0,3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A6: Behaviour of Rui *(Labeo rohita)* of fingerling size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0.8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A7: Behaviour of Rui *(Labeo rohitd)* of juvenile size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	Yes	Yes	F
2	50	94	0.6	Yes	Yes	F
3	50	104	0.7	Yes	Yes	F
4	50	118	0,8	No	No	U.F
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	Yes	Yes	F
8	40	75	0.6	Yes	Yes	F
9	40	87	0.7	No	No	U.F
10	40	96	0.8	No	No	U.F
11	40	37	0.3	Yes	Yes	F
12	40	52	0.4	Yes	Yes	F
13	60	100	0.5	Yes	Yes	F
14	60	110	0.6	Yes	Yes	F
15	60	125	0.7	Yes	Yes	F
16	60	145	0.8	No	No	U.F
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A8 : Behaviour of Catla *(Catla catla)* of fry size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0,8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	.0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A9: Behaviour of Catla *(Catla catla)* of fingerling size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0.8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A10: Behaviour of Catla *(Catla catla)* of juvenile size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0,5	Yes	Yes	F
2	50	94	0.6	Yes	Yes	F
3	50	104	0.7	Yes	Yes	F
4	50	118	0.8	No	No	U.F
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	Yes	Yes	F
8	40	75	0.6	Yes	Yes	F
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	Yes	Yes	F
12	40	52	0.4	Yes	Yes	F
13	60	100	0.5	Yes	Yes	F
14	60	110	0.6	Yes	Yes	F
15	60	125	0.7	Yes	Yes	F
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A11: Behaviour of Mrigel *(Cirrhinus mrigala)* of fry size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (nvVhr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0,8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
1	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

A12: Behaviour of Mrigel *(Cirrhimts mrigala)* of fingerling size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	No	No	U.F.
2	50	94	0.6	No	No	U.F.
3	50	104	0.7	No	No	U.F.
4	50	118	0.8	No	No	U.F.
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	No	No	U.F.
8	40	75	0.6	No	No	U.F.
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	No	No	U.F.
12	40	52	0.4	No	No	U.F.
13	60	100	0.5	No	No	U.F.
14	60	110	0.6	No	No	U.F.
15	60	125	0.7	No	No	U.F.
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

Table A16: Behaviour of Mrigel *(Cirrhinus mrigala)* of juvenile size under different experimental runs

Experiment Run No.	U/S Water Level (cm)	Discharge, Q (m^3/hr)	Approx. Velocity atD/s Opening of Pool 4, m/s	Passing U/S Slot	Passing D/S Slot	Resting Behaviour
1	50	81	0.5	Yes	Yes	F
2	50	94	0.6	Yes	Yes	F
3	50	104	0.7	Yes	Yes	F
4	50	118	0.8	No	No	U.F,
5	50	55	0.3	Yes	Yes	F
6	50	68	0.4	Yes	Yes	F
7	40	65	0.5	Yes	Yes	F
8	40	75	0.6	Yes	Yes	F
9	40	87	0.7	No	No	U.F.
10	40	96	0.8	No	No	U.F.
11	40	37	0.3	Yes	Yes	F
12	40	52	0.4	Yes	Yes	F
13	60	100	0.5	Yes	Yes	F
14	60	110	0.6	Yes	Yes	F
15	60	125	0.7	Yes	Yes	F
16	60	145	0.8	No	No	U.F.
17	60	70	0.3	Yes	Yes	F
18	60	84	0.4	Yes	Yes	F

Note: U.F. = Unfavorable F. = Favourable

5.5 Velocity of Fish Species

Velocity of fish species have been measured while they were passing from upstream to downstream. Cruising velocities of fish species can be measured by deducting the water velocity from velocity offish species.

Table A17 : Observed velocity offish for fingerling species *of Labeo rohita*

Experiment Run No.	U/s Water Level (cm)	Pump Discharge (m^3/hr)	Approx. Velocity at D/s Opening of Pool 4 (m/s)	Velocity of water in Pool without Strc. (m/s)	Velocity of Fish (m/s)
1	50	81	0.5	0.042	0.38
4	50	118	0.8	0.096	0.31
5	50	55	0.3	0.0	0.44
7	40	65	0.5	0.0	0.67
10	40	96	0.8	0.095	0.64
11	40	37	0.3	0.0	0.38
13	60	100	0.5	0.055	0.43
16	60	145	0.8	0.06	0.29
17	60	70	0.3	0.0	0.43

Table A 18: Observed velocity offish for juvenile species *of Labeo rohita*

Experiment Run No.	U/s Water Level (cm)	Pump Discharge (m^3/hr)	Approx. Velocity at D/s Opening of Pool 4 (m/s)	Velocity of water in Pool without Strc. (m/s)	Velocity of Fish (m/s)
1	50	81	0.5	0.042	0.6
4	50	118-	0.8	0.096	0.32
5	50	55	0.3	0.0	0.49
7	40	65	0.5	0.0	0.69
10	40	96	0.8	0.095	0.38
11	40	37	0.3	0.0	0.31
13	60	100	0.5	0.055	0.67
16	60	145	0.8	0.06	0.38
17	60	70	0.3	0.0	0.53

Furthermore, an attempt has been made to represent the response offish behavior of selected species with the flow pattern and hydrodynamic conditions inside the fish pass.