Specialization of feeding as survival strategy

Chapter Concepts

• Assessment of preference of prey colour by the juveniles of the prioritized fishes with reference to the biocontrol perspective.

• Attempts for assessment of preferred diurnal spatial distribution pattern of the vulnerable stages of the fishes, between environmental structure and light-exposed region.

• Measure the reactive distance of the juveniles and sub-adult stages of the fishes.
Introduction
Shelter from predators and prey availability is another habitat consideration for eggs, larvae and juveniles. Many species of fishes provide protection for eggs until larval dispersal. At the point when juveniles leave parental protection they become susceptible to predation, leading to a need for shelter acquisition. Freshwater fishes living near structure find shelter in vegetation or other submerged objects. Studies on several species of north temperate freshwater and marine fishes have shown a strong tendency for juveniles and developing adults to seek shelter in the presence of a predator. But when predators were absent they distributed themselves much more widely, occupying most of the aquatic habitat. This indicates how important shelter from predators and food availability is to larvae and juveniles.

Colour vision is an important feature for fishes inhabiting bright environments, where they are able to discriminate details in the ambient surroundings that bring advantages on feeding, defense, migration or mating (Levine, 1980; Wheeler, 1982). The ambient light and the visual tasks that fishes experience during their life are selective forces modulating visual systems (McFarland and Munz, 1975) and in some species, spectral sensitivity changes according to ontogenetic development (Douglas, 1989; Alexander et al., 1994) and the season of the year (Whitmore and Bowmaker, 1989). These changes in colour sensitivity arise from the switch of different opsins, density of different cone types in the retina or shifts in the chromophore source (Cheng and Flamarique, 2004; White et al., 2004; Luchiari and Pirhonen, 2008).

Under fish farm conditions different environmental colours may affect the vision of fishes, influencing for example food intake, signals for hierarchical status and reproduction. As the environmental colour can also affect stress or stress responses of fishes (Gilham and Baker, 1985; Papoutsoglou et al., 2000) the optimal species-specific light or tank colour may improve growth and productivity of intensively cultivated species. Food intake and growth can be regarded as valuable variables for estimating general performance and well-being of fishes under culture conditions, but these variables are also the most important ones for economical profitability of an aquaculture operation. Thus, under colour conditions that improve fitness, the fishes may spend more energy on growth than under unsuitable conditions. Despite the possible positive effects of certain ambient wavelengths on feed intake and growth, this area has received surprisingly little attention among fish researchers.

Aposematic coloration has been defined as the exhibition of conspicuous color patterns by prey to advertise noxious properties to potential predators (Guilford, 1990). This definition
implies that conspicuous colorations increase the ability of predators to learn to associate color patterns with distasteful prey. Several authors have shown that conspicuousness does indeed enhance the effectiveness of learning. Gittleman and Harvey (1980) demonstrated that chicks learn aversions to conspicuous prey more readily than to cryptic prey. Gaudy coloration directly affects the strength of initial learning by chicks and the duration of memory for a noxious stimulus (Roper and Redston, 1987).

Research on aposematism in terrestrial animal behavior has been focused mainly on bird-insect interactions (Brower, 1984; Cardoso, 1997). In marine environments, it is generally accepted that many marine molluscs with conspicuous colorations use distasteful chemicals to deter predatory fishes. To conduct research on the visibility of an organism’s color pattern, we must consider not only the inherent properties of the pattern, but also the predator’s vision, hunting tactics, prey behavior, and background color patterns. The effects of these factors are not independent, and may vary with depth and location (Endler, 1978; Giménez-Casalduero et al., 1999).

Light plays an important role in governing the ability of larval fishes to capture prey and to avoid predators. Larval fishes are visual predators, for the most part, and require adequate light to locate and identify suitable prey. The amount of light available and its duration are thus important habitat variables for larvae. Adaptations to take advantage of light in capturing prey are common in the development of larvae. Adaptations to take advantage of light in capturing prey are common in the development of larvae and show the importance of light in the survival of larvae. Sensory development of fish larvae revealed that a pure cone retina is adequate for feeding in fish larvae and this normally develops at about the time of the larvae has absorbed its yolk and begin to feed. More recent work has empirically linked light intensity to feeding and has shown that the visual sensitivity of larvae increases rapidly from first feeding to the end of larval period. Increases of up to three orders of magnitude were developed over period of development along with the increment of tactile sensitivity.

Functional morphology is centered on exploring how structures work and how differences in form influence the mechanical performance of these structures. In ecomorphology, the emphasis is on identifying the relationships between interspecific variation in these structures and ecological differences among species. The study of the trophic ecomorphology of fishes is an active area of research. Functional studies can provide important insights into the biomechanical basis of ecomorphological patterns.
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Human impact on water quality and quantity has affected freshwater fish biodiversity on a global scale (Goudie, 1993). The human impact on fish populations can be divided into 4 categories: i) climatic; ii) physical; iii) chemical; and iv) biological. Depending on the fish diversity, the location, and the physical characteristics of the water, the combination and dominance of the various components of human impact may differ in significance. In this chapter, we present examples of indigenous fishes affected by 3 latter categories. Effects of climatic variations on the large lakes fish fauna have been suggested (Nyberg et al., 2001), but whether or not these climatic variations are brought about by man still needs to be proven. Among the physical impacts addressed in this paper are altered migration routes, e.g. changes resulting from the construction of dams and ship canals. Chemical effects may comprise acidification, eutrophication, and pollution from various toxic compounds (Grimas et al., 1972; Svirdson and Molin, 1981). The biological impact has mainly been from fisheries and fisheries management, i.e. mainly overexploitation and introduction of new species. This paper focuses on the former. The various effects of human impacts on the fish diversity and impacts on early life history traits of some economically threatened fishes will be discussed.

Although few original species have been lost and few new species have been added to the ichthyofaunal diversity of the studied river, the recent human interference has caused major shifts in dominance of the fish community structures, and serious reductions of vulnerable populations of native Chitala chitala, Ompok pabo and Anabas testudineus. These large changes may also involve large, anonymous and genetically irreversible losses. Many of the impacts described above have proven reversible, e.g. the effects of eutrophication in non-salmonid lakes and possibly the effects of overfishing. Clearly, as we write this today we are not looking to the past to learn from the long period of mistakes made by our ancestors. There is no passed history of human impact in fisheries management we are certainly in the midst of repeating as well as achieving new mistakes.
Literature review
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of the distribution of juvenile fish in the littoral area of a shallow lake have been explored by Lewin et al. (2004). The concept of foraging behavior and invasive fishes exhibit higher feeding rates and broader diets than their noninvasive relatives was established by Rehage et al. (2005).

Because of light attenuation down the water column the risk stems not only from the illumination intensity, but also from the prey’s ability to return to the safe habitat rapidly (Lima et al., 1985; Stephens and Krebs, 1986). Increased physical structure in the habitat creates more microhabitat types – a greater total niche space creating spatial heterogeneity, stability and diversity in ecosystems have been analyzed by Smith (1972). Habitat complexity also influences resource use, which is apparently closely tied to the utility or profitability of a particular resource relative to alternatives as studied by Pyke et al. (1977). Habitat structural complexity has a profound effect on the ecological interactions as observed by Crowley (1978). Some species may stay in their littoral shelters both day and night, as do bluegill sunfish (Lepomis macrochirus) in their first year of life was studied by Werner et al. (1983). Food, predation risk and microhabitat selection in a marsh fish assemblage was also studied by McIvor and Odum (1988). Predator avoidance and community structure was analyzed by Turner and Mittelbach (1990). This is related to the distance between the prey foraging site and the prey refuge. The effect of behavioural and morphological plasticity on foraging efficiency in the threespine stickleback (Gasterosteus sp.) was studied by Day and McPhail (1996). Light induced changes in the foraging success of visual fish predators is a potentially important mechanism affecting aquatic food webs as analyzed by Eiane et al. (1997, 1999). Visual feeding of fish in turbid environment was studied by Utne-Palm (2002). Others may only keep to the safety of the littoral during the day, when the high level of underwater illumination ensures that time spent away from plant cover entails greater risk of detection by visually oriented piscivores at greater distance (piscivorous fish) or to a greater depth (piscivorous birds). Integrating spatial and temporal variability into the analysis of fish food web linkages in Tijuana estuary have also been studied by West et al. (2003). Fish behaviour entailing the use of littoral daytime refuges may differ through the ontogenetic stages and from one species to another. Trading safety for food in roach and bleak, captured at different distances offshore from their daytime littoral refuge was also observed by Gliwicz et al. (2006). Bay and Self (1972) observed feeding of guppy, Poecilia reticulata in Culex pipiens fatigans breeding sites. The release of Gambusia affinis and Poecilia reticulata fishes into the
aquatic environment has resulted in the alteration of vector faunal components of the ecosystem as established by Menon (1977). Food and feeding habits of the larvivorous fish *Apl ocheilus lineatus* in its natural habitat have been studied by Jacob and Nair (1982). Therefore, larvivorous fishes such as *Gambusia affinis* and *Poecilia reticulata*, the primary biological control agents of mosquito larvae, have been extensively employed in certain regions in mosquito abatement programmes.


Feeding in fishes has become one of the most extensively studied areas of vertebrate functional morphology. Prey capture by fishes offers excellent potential for a unified view of performance across a large slice of vertebrate life because most fish species use the same basic suction feeding mechanism to capture their prey, and yet there is tremendous diversity in size and shape of the feeding apparatus and a complete understanding of the implications of this diversity for suction feeding ability is still lacking. Nyberg (1971) studied prey capture in the
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Tanaka (1973) evaluated the suction feeding by the nurse shark. Lauder (1980) demonstrated the suction feeding mechanism in sunfishes (Lepomis) in an experimental analysis. Experimental and theoretical approaches of aquatic prey capture in fishes were analyzed by Lauder (1983a, 1986). Lauder (1983b) also studied prey capture hydrodynamics in fishes. Optimum sucking techniques for predatory fish was initially studied by Van Leeuwen and Muller (1984). Aquatic feeding in lower vertebrates was observed by Lauder (1985). Prey capture in a flatfish, Pleuronichthys verticalis was observed by Gibb (1995). Whereas prey size and mobility imposes an effect on prey-capture kinematics in leopard sharks, Triakis semifasciata as studied by Ferry-Graham (1998b). Novel feeding mechanism in the osteoglossomorph fish Chitala chitala was established by Frost and Sanford (1999). Prey-capture success of young brook charr in streams was observed by McLaughlin et al. (2000). Ferry-Graham and Lauder (2001) analyzed aquatic prey capture in rayfinned fishes. Sanford (2001) observed kinematics of a novel feeding mechanism in the brook trout Salvelinus fontinalis. Scaling of suction feeding kinematics in the African catfish, Clarias gariepinus was done by Van Wassenbergh et al. (2005).

Identifying the relationships between interspecific variation in the structures and ecological differences among species is emphasized in ecomorphology. Functional morphology is centered on exploring how structures work and how differences in form influence the mechanical performance of these structures. The study of the trophic ecomorphology of fishes
is an active area of research, as functional basis of feeding constraints in Caribbean labrid fishes were studied by Wainwright (1988). Functional design and prey capture dynamics in an ecologically generalized surf perch was documented by Chu (1989). Wainwright and Richards (1995) predicted patterns of prey use from morphology in fishes. Variation in prey-resource utilization between two populations of largemouth bass, *Micropterus salmoides* was done by Huskey and Turingan (2001). Feeding patterns of *Chelus fimbriatus* (Pleurodira: Chelidae) was observed by Lemell *et al.* (2002). A functional morphological approach to the scaling of the feeding system in the African catfish, *Clarias gariepinus* was evaluated by Herrel *et al.* (2005).

These studies have demonstrated that predatory experience may be a primary determinant of prey-capture mode. Effect of light and turbidity on the reaction distance of bluegill (*Lepomis macrochirus*) was also observed by Vineward and O’Brien (1976). Turbidity-induced changes in reactive distance of rainbow trout were depicted by Barrett *et al.* (1992). Bernfield and Minello (1996) depicted the relative effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. Sweka and Hartman (2001) evaluated the influence of turbidity on brook trout reactive distance and foraging success. Sweka and Hartman (2003) also evaluated the reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to elevated turbidity levels. To understand trophic diversity in fishes is largely to understand these three feeding methods, how fish use them, why fish use them, and the basis for differences among species in performance.
Materials and methods
4.1 Evaluation of prey colour preference:

One individual each of different stages of *C. chitala*, *O. pabo* and *A. testudineus* (viz. 3 fry stages, fingerling and developing adult stage), as predator, were kept in large plastic circular containers of 2.5' diameter and 1.5' depth containing 35 L filtered pond water with larvae of *Cx. quinquefasciatus* and *Ch. striatipennis*, as prey items. Small twigs of *V. spiralis* and *J. repens* as environmental structures were kept in the experimental set up for prey and predator refuge. Larvae of *Cx. quinquefasciatus* (I, II, III and IV instars), with dark brown colouration and larval stages (I, II, III and IV instars) of *Ch. striatipennis*, which are red coloured, were designated with prey colour cues. Each larval instar of *Cx. quinquefasciatus* along with other larval instars of *Ch. striatipennis* in equal densities (50: 50) were given as prey population to each predator. These prey population was selected in all possible combinations. The observations were carried out after 24 h of predation. Six such replicates in each case were done. Each observation was carried out with fresh 24 h starved predator and the excreta loaded water was changed everyday.

Using Multivariate analysis of variance technique, which depicts normal distribution for observed variables, and transformation of the count data by square root transformation using $\sqrt{x+0.5}$, the deviation between predation rate on red and dark coloured prey type as predator-induced colour cue selection of the developing stages of *C. chitala*, *O. pabo* and *A. testudineus* were analyzed.

4.2 Determination of food preference during light and dark condition:

Twenty four different prey items, viz. four larval instars each of laboratory reared *Cx. quinquefasciatus* and *Ch. striatipennis*, 5 naiads and adult stage of *An. bouvieri*, two size groups (0.5-1.0 cm and 2.5-3.5 cm) of *Tx. tubifex*, 2nd and 4th instars of *Mac. lamarrei*, juveniles (3-6 mm shell height/shell length) of *Ga. orcula, Lym. luteola, Indo. exustus, Gy. convexiusculus* and *Bel. bengalensis* and early fry stage of *Or. niloticus* (0.8-1.4 cm), were taken in single specific density (30 prey individuals) all together in large circular plastic containers of 2.5' diameter and 1.5' depth containing 35 L filtered pond water and kept under light condition with single predator each, of developing adult, fingerling and 3 fry stages of *C. chitala*, *O. pabo* and *A. testudineus*, all 24 h starved. The predators were acclimated for 12 h light and dark condition, 6 days prior to
the onset of the experiment. Similar experimentation design was performed in dark condition for 12 h where the experimental setup were built within earthen pitcher, containing 35 L of filtered pond water, with its opening closed with aluminum foil creating a perfect dark environment inside. Artificial aeration was provided to maintain adequate level of dissolved oxygen. Experiment was carried out in 6 replicates, each with fresh 24 h starved predator and the water was replenished everyday.

To find change in predation potential of the developing stages of *C. chitala, O. pabo* and *A. testudineus* during light and dark condition, Univariate analysis of variance (ANOVA) technique, with transformation of the count data by square root transformation using $\sqrt{x}+0.5$ was performed.

### 4.3 Assessment of spatial distribution pattern:

In large earthen circular containers with 2.5' diameter and 1.5' depth, containing 35 L filtered pond water, juveniles (3 fry stages) of *C. chitala, O. pabo* and *A. testudineus* were taken in two different densities viz., 100 and 200 individuals each. The containers were superficially separated into four quadrants so that no hindrance takes place in the fish movement. Combinations were made with and without food in open and in structured environments and the distribution of juvenile fishes were observed during day as well as in dark regime. 6 such observations were made. The water was replenished daily to avoid accumulation of unutilized food stuff and metabolic wastes of fishes.

Pattern and difference in distribution of fish larvae during day or night in each quadrant of the container in varied densities, within densities in day and night regime was calculated using Univariate ANOVA. Moreover change in orientation in fish larvae in different quadrants within structured and open systems, food and without food condition and in different densities were also measured using Univariate ANOVA. Transformation of the count data by square root transformation using $\sqrt{x}+0.5$ was done to analyze the deviation between distribution patterns between the quadrants.

### 4.4 Measurement of reactive distance:

Observation methods used to monitor feed intake and feeding behavior involve video recording. The filming chamber used in this study was a glass aquarium (5' X 2.5' X 2.5') with
declorinated ground water maintained at 25°C. One side of the chamber was covered with some aquatic vegetations acting as a refuge. Fishes were allowed to acclimate to the aquaria prior to beginning of the experiment. *Tx. tubifex*, larvae of *Cx. quinquefasciatus* and *Ch. striatipennis* were given as prey in a randomized fashion, and individual items were offered consecutively by placing them on the floor of the filming chamber and allow the fishes to approach and capture the item. Two cameras were used to record the feeding events so that movements could be visualized in three dimensions and the actual angle of the fishes with respect to the cameras could be determined.

Video sequences were digitized using a digitized programme. Several specific strike variables were also quantified. These included reactive distance, the distance between predator and prey at the instant the predator first showed any reaction to the prey (Norton and Brainerd, 1993).
Results
4.1 Preference of prey colour:

Experiments on predatory potential of C. chitala, O. pabo and A. testudineus at the different developmental stages showed positive affinity towards red coloured prey than its non-red relatives of the same guild.

4.1.1 Prey colour preference in C. chitala:

The fry 1 stage of C. chitala mostly preferred feeding on Chironomous striatipennis larvae than that of Culex quinquefasciatus but when combinations of Ch. striatipennis IV instar: Cx. quinquefasciatus I instar, Ch. striatipennis IV instar: Cx. quinquefasciatus II instar and Ch. striatipennis IV instar: Cx. quinquefasciatus III instar were given, significant shift (P<0.05) in prey preference towards Culex larvae was observed. In comparison with IVth instar Chironomous, 37.83 ± 0.7 of Cx. quinquefasciatus I instar, 34.67 ± 0.09 of Cx. quinquefasciatus II instar and 32.17 ± 0.87 of Cx. quinquefasciatus III instar larvae were predated by fry 1 stage.

Fry 2 stage of C. chitala on the other hand always exhibited a steady preference towards chironome feeding, though, while in combinations with Ch. striatipennis I instar: Cx. quinquefasciatus III instar and Ch. striatipennis II instar: Cx. quinquefasciatus III instar, no deviation (P>0.05) was observed in the feeding activity towards red- and non-red coloured prey.

A slightly significant inclination (P<0.05) towards Culex quinquefasciatus (49.33 ± 0.33) as prey item over Chironomous was depicted when combinations of Ch. striatipennis I instar: Cx. quinquefasciatus III instar was catered to fry 3 stages of Chitala. Combinations of Ch. striatipennis II instar: Cx. quinquefasciatus III instar and Ch. striatipennis III instar: Cx. quinquefasciatus III instar on the other hand exhibited insignificant deviation (P>0.05) towards predatory efficiency among them.

Predation of IIIrd (49.83 ± 0.17) and IVth (49.83 ± 0.17) instar Culex larvae was slightly higher than that of Chironomous larvae, whereas combinations with Ch. striatipennis I instar: Cx. quinquefasciatus II instar, Ch. striatipennis I instar: Cx. quinquefasciatus IV instar, Ch. striatipennis II instar: Cx. quinquefasciatus III instar, Ch. striatipennis III instar: Cx. quinquefasciatus II instar, Ch. striatipennis III instar: Cx. quinquefasciatus III instar and Ch. striatipennis IV instar: Cx. quinquefasciatus IV instar exhibited no significant drift (P>0.05) in predatory potency of C. chitala fingerlings. With the other possible combinations, chironomes were mostly predated with respect to Culex larvae.
**Figure 4.1.1:** Preference of prey colour by *C. chitala* at different developmental stages when different larval instars of *Cx. quinquefasciatus* and *Ch. striatipennis* were given as prey items in all possible combinations.
Developing adult stages of C. chitala on the other hand had less preference of small sized prey (lower instars of both Chironomous and Culex), but its predatory bout was more towards Culex sp. (P<0.05) when combinations of Ch. striatipennis I instar: Cx. quinquefasciatus III instar (20.33 ± 1.33), Ch. striatipennis I instar: Cx. quinquefasciatus IV instar (49.0 ± 0.52), Ch. striatipennis II instar: Cx. quinquefasciatus III instar (23.0 ± 0.89), Ch. striatipennis II instar: Cx. quinquefasciatus IV instar (49.33 ± 0.33) and Ch. striatipennis III instar: Cx. quinquefasciatus IV instar (49.33 ± 0.49) were given. No significant (P>0.05) selective predation towards red coloured prey was seen in case of Ch. striatipennis IV instar: Cx. quinquefasciatus III instar (Figure 4.1.1).

4.1.2 Prey colour preference in O. pabo:

Ompok pabo at the fry 1 stage usually preferred Ch. striatipennis but when combinations of large size chironome alongwith smaller instars of Cx. quinquefasciatus like Ch. striatipennis IV instar: Cx. quinquefasciatus I instar (37.83 ± 0.7), Ch. striatipennis IV instar: Cx. quinquefasciatus II instar (34.67 ± 0.49) and Ch. striatipennis IV instar: Cx. quinquefasciatus III instar (32.17 ± 0.87) were given, automatic choice for smaller size prey was evident with significant difference (P<0.05) among the respective predatory potential, where gape size acting as a limiting factor.

All throughout different combinations of larval instars among Ch. striatipennis and Cx. quinquefasciatus, when catered against the fry 2 stage of Ompok, it was noticed that they feed maximally on red coloured Chironomous. But significant (P<0.05) feeding preference among Ch. striatipennis I instar: Cx. quinquefasciatus III instar and Ch. striatipennis II instar: Cx. quinquefasciatus III instar were noticed.

Significant difference (P<0.05) on the feeding of Cx. quinquefasciatus III instar (49.33 ± 0.33) with that of Ch. striatipennis I instar was observed when fry 3 stage of O. pabo predated on all combinations of Culex and Chironomous larval instars. In the rest of the cases, red coloured chironomes were mostly preferred by the predator, though no such significant deviation (P>0.05) was observed between the predation rate of Ch. striatipennis II instar and Cx. quinquefasciatus III instar.

Predatory efficacy of fingerling stages of Ompok depict that besides combinations like Ch. striatipennis I instar: Cx. quinquefasciatus II instar, Ch. striatipennis I instar: Cx. quinquefasciatus III instar, Ch. striatipennis I instar: Cx. quinquefasciatus IV instar, Ch. striatipennis II instar: Cx. quinquefasciatus III instar, Ch. striatipennis II instar: Cx.
Figure 4.1.2: Preference of prey colour by *O. pabo* at different developmental stages when different larval instars of *Cx. quinquefasciatus* and *Ch. striatipennis* were given as prey items in all possible combinations.
quinquefasciatus IV instar, Ch. striatipennis III instar: Cx. quinquefasciatus II instar, Ch. striatipennis IV instar: Cx. quinquefasciatus III instar and Ch. striatipennis IV instar: Cx. quinquefasciatus IV instar, a significant difference lies among the prey preference which inclines towards the red coloured chironomid prey.

Though developing adult too generally preferred chironomes with respect to its ecological equivalent Culex, but when combinations like Ch. striatipennis I instar: Cx. quinquefasciatus III instar, Ch. striatipennis I instar: Cx. quinquefasciatus IV instar, Ch. striatipennis II instar: Cx. quinquefasciatus III instar and Ch. striatipennis II instar: Cx. quinquefasciatus IV instar were given, significant preference towards Culex was noticed, when the predation rate counts to 20.33 ± 1.33, 49.0 ± 0.52, 23.0 ± 0.89 and 49.33 ± 0.33 respectively. Combinations with Ch. striatipennis III instar: Cx. quinquefasciatus IV instar and Ch. striatipennis IV instar: Cx. quinquefasciatus IV instar showed no difference (P>0.05) among prey preference (Figure 4.1.2).

4.1.3 Prey colour preference in A. testudineus:

A. testudineus at its fry 1 stage mostly preferred feeding on Chironomous striatipennis larvae than that of Culex quinquefasciatus but when combinations of Ch. striatipennis IV instar: Cx. quinquefasciatus I instar, Ch. striatipennis IV instar: Cx. quinquefasciatus II instar and Ch. striatipennis IV instar: Cx. quinquefasciatus III instar were catered, significant shift (P<0.05) in prey preference towards Culex larvae was observed. In comparison with IVth instar Chironomous, 37.83 ± 0.7 of Cx. quinquefasciatus I instar, 34.67 ± 0.09 of Cx. quinquefasciatus II instar and 32.17 ± 0.87 of Cx. quinquefasciatus III instar larvae were predated by fry 1 stage.

Anabas at its fry 2 stage always exhibited a feeding preference towards chironome larvae, though, while in combinations with Ch. striatipennis I instar: Cx. quinquefasciatus III instar and Ch. striatipennis II instar: Cx. quinquefasciatus III instar, no significant deviation (P>0.05) between the feeding frenzy towards red- and non-red coloured prey was observed.

Significant difference (P<0.05) on the predation potential of Cx. quinquefasciatus III instar (49.33 ± 0.33) with that of Ch. striatipennis I instar was depicted when fry 3 stage of A. testudineus predated on all possible combinations with Culex and Chironomous larval instars. Red coloured chironomes were mostly preferred by the predator in rest of the cases. No significant deviation (P>0.05) was observed between the predation rate of Ch. striatipennis II instar and Cx. quinquefasciatus III instar.
Figure 4.1.3: Preference of prey colour by *A. testudineus* at different developmental stages when different larval instars of *Cx. quinquefasciatus* and *Ch. striatipennis* were given as prey items in all possible combinations.
Though combinations like *Ch. striatipennis* I instar: *Cx. quinquefasciatus* II instar, *Ch. striatipennis* I instar: *C. quinquefasciatus* III instar, *Ch. striatipennis* I instar: *Cx. quinquefasciatus* IV instar, *Ch. striatipennis* II instar: *C. quinquefasciatus* III instar, *Ch. striatipennis* II instar: *Cx. quinquefasciatus* IV instar, *Ch. striatipennis* III instar: *C. quinquefasciatus* IV instar and *Ch. striatipennis* IV instar: *Cx. quinquefasciatus* IV instar, showed no predatory affinity (*P*>0.05) of the *Anabas* fingerling towards red coloured *Chiromonous*, but the rest of the combinations depicted appositive affinity towards its prey preference on red coloured chironomid prey.

Developing adult stages of *A. testudineus* on the other hand had lower selectivity towards small sized prey (lower instars of both *Chironomous* and *Culex*) irrespective of colour, but its predatory efficacy was more (*P*<0.05) towards *Culex* sp. when combinations with *Ch. striatipennis* I instar: *C. quinquefasciatus* III instar (20.33 ± 1.33), *Ch. striatipennis* I instar: *C. quinquefasciatus* IV instar (49.0 ± 0.52), *Ch. striatipennis* II instar: *C. quinquefasciatus* III instar (23.0 ± 0.89), *Ch. striatipennis* II instar: *C. quinquefasciatus* IV instar (49.33 ± 0.33) and *Ch. striatipennis* III instar: *C. quinquefasciatus* IV instar (49.33 ± 0.49) were giver. No significant difference (*P*>0.05) in selective predation towards red coloured prey was observed in case of *Ch. striatipennis* IV instar: *C. quinquefasciatus* III instar (Figure 4.1.3).

4.2 Food preference during day and night condition:

4.2.1 Feeding preference in *C. chitala*:

The feeding efficiency as well as food preference of the juvenile fishes was estimated in light and dark condition. When fry 1 stage of *C. chitala* was provided with 9 preferred prey items, the juveniles predated more on *Cx. quinquefasciatus* I instar larvae (24.17 ± 1.04), *Cx. quinquefasciatus* II instar larvae (28.42 ± 1.37), *Ch. striatipennis* II instar larvae (22.08 ± 0.31), and *Tx. tubifex* 1 (3.92 ± 0.31) during night than that during day time. From Univariate ANOVA analysis, it could be depicted that the deviation was significant (*P*<0.05, df=8).

A total of 12 prey items were preferred by fry 2 stage, in which, the juveniles used to prefer *Cx. quinquefasciatus* I instar larvae (25.5 ± 1.29), *Cx. quinquefasciatus* II instar larvae (24.5 ± 0.83), *Cx. quinquefasciatus* III instar larvae (16.33 ± 0.5), *Cx. quinquefasciatus* IV instar larvae (7.25 ± 0.13), *Ch. striatipennis* II instar larvae (21.17 ± 0.77), *Ch. striatipennis* III instar larvae (7.67 ± 0.45), and *Tx. tubifex* 1 (20.56 ± 0.56) during night most significantly (*P*<0.05,
Figure 4.2.1: Food selectivity of *C. chitala* during day and night regime. The prey items catered were *Culex* sp. I instar, *Culex* sp. II instar, *Culex* sp. III instar, *Culex* sp. IV instar, *Chironomous* sp. I instar, *Chironomous* sp. II instar, *Chironomous* sp. III instar, *Chironomous* sp. IV instar, *Tubifex* sp. (0.5-1.0 cm), *Tubifex* sp. (2.5-3.5 cm), *Anisops* sp. I instar, *Anisops* sp. II instar, *Anisops* sp. III instar, *Anisops* sp. IV instar, *Anisops* sp. V instar, *Anisops* sp. adult, *Macrobrachium lamarrei* I instar, *Macrobrachium lamarrei* II instar, *Lymnaea* sp., *Gyraulus* sp., *Gabbia* sp., *Indoplanorbis* sp., *Bellamya* sp., *Oreochromis niloticus* (0.8-1.4 cm).
df=11) than that during the luminous part of the day. The rest of the prey items were consumed more or less in equal proportion ($P>0.05$) during both day and night regime.

The fry 3 stage of *Chitala* used to feed on 17 types of prey items. More inclination towards *Cx. quinquefasciatus* I instar larvae (28.08 ± 0.7), *Cx. quinquefasciatus* IV instar larvae (8.5 ± 0.6), *Ch. striatipennis* III instar larvae (20.33 ± 0.68), *Tx. tubifex* 1 (29.25 ± 0.25), *Tx. tubifex* 2 (29.25 ± 0.25), *An. bouvieri* I instar larvae (2.0 ± 0.37), and *An. bouvieri* III instar larvae (2.5 ± 0.47) during night regime were seen, which deviate significantly ($P<0.05$, df=16) than that during the day. No such variations between day and night were observed on feeding of rest of the prey items.

Prey types such as *Cx. quinquefasciatus* IV instar larvae (12.08 ± 0.74), *Ch. striatipennis* II instar larvae (24.92 ± 0.8), *Ch. striatipennis* III instar larvae (27.58 ± 0.62), *Tx. tubifex* 1 (29.58 ± 0.23), *Tx. tubifex* 2 (27.75 ± 0.76), *An. bouvieri* I instar larvae (3.58 ± 0.58), *An. bouvieri* II instar larvae (2.08 ± 0.42) and *Or. niloticus* (3.92 ± 0.26) used to be fed significantly ($P<0.05$, df=16) during night by the fingerling stage of *Chitala chitala*. No photoperiod dependant deviation ($P>0.05$) was observed on feeding of other 8 prey items.

The developing adult stage of *C. chitala* had a voracious feeding activity on 24 types of prey items. Among them, during night, significant deviation ($P<0.05$, df=23) in predation on *Ch. striatipennis* I instar larvae (10.25 ± 1.15), *Ch. striatipennis* II instar larvae (19.75 ± 0.18), *Ch. striatipennis* III instar larvae (29.92 ± 0.08), *Tx. tubifex* 1 (29.92 ± 0.08), *Tx. tubifex* 2 (29.83 ± 0.11), *An. bouvieri* I instar larvae (29.83 ± 0.11), *An. bouvieri* II instar larvae (28.33 ± 0.93), *An. bouvieri* III instar larvae (26.75 ± 0.66), *An. bouvieri* IV instar larvae (29.75 ± 0.18), *Mac. lamarrei* I instar larvae (30.0 ± 0.0), *Lym. luteola* (17.25 ± 0.71), *Ga. orcula* (7.67 ± 0.77), *In. exustus* (8.83 ± 0.39), *Be. bengalensis* (8.92 ± 0.36) were observed. While, in case of other prey items, photoperiod does not influence the predation potential of *C. chitala* at its developing adult stage (Figure 4.2.1).

From the above experiment, food preference or selectivity of prey items were depicted having prevalence of red-coloured prey. Their prey size was also corroborated with gape width of the predator. From the above results, it can be easily deduced that feeding efficacy of all the juvenile stages of *Chitala* are basically influenced by photoperiod and their strategy for nocturnal feeding may be due to more availability of prey items during night.
4.2.2 Feeding preference of *O. pabo*:

The predatory efficacy of *O. pabo* in the fry 1 stage was more towards, 5 preferred prey items. The juveniles used to prefer more *Cx. quinquefasciatus* I instar larvae (27.0 ± 0.83), *Cx. quinquefasciatus* II instar larvae (27.67 ± 0.74), *Ch. striatipennis* I instar larvae (25.67 ± 0.75) and *Ch. striatipennis* II instar larvae (27.5 ± 0.52) during night than that in the presence of daylight. Analysis from Univariate ANOVA explicitly depicted that the deviation was significant (P<0.05, df=4).

Similar predatory potential was found with fry 2 stage of *O. pabo* which predated on *Cx. quinquefasciatus* I instar larvae (29.83 ± 0.97), *Cx. quinquefasciatus* II instar larvae (28.5 ± 0.79), *Cx. quinquefasciatus* III instar larvae (19.58 ± 0.23), *Ch. striatipennis* I instar larvae (29.33 ± 0.36), *Ch. striatipennis* II instar larvae (28.92 ± 0.08) *Ch. striatipennis* III instar larvae (19.83 ± 0.11) and *Ch. striatipennis* IV instar larvae (19.17 ± 0.3) specifically during dark out of 10 preferred prey items. The difference between dark and light phase was significant (P<0.05, df=9). The rest of the prey items were consumed more or less in equal proportion (P>0.05) irrespective of the photoperiod.

While 11 preferred prey items were taken by the fry 3 stage of *Ompok*, significant (P<0.05, df=10) inclination towards predation of *Cx. quinquefasciatus* I instar larvae (25.92 ± 0.92), *Cx. quinquefasciatus* II instar larvae (27.0 ± 0.86), *Cx. quinquefasciatus* III instar larvae (29.75 ± 0.18), *Cx. quinquefasciatus* IV instar larvae (29.83 ± 0.11), *Ch. striatipennis* I instar larvae (22.67 ± 0.23), *Ch. striatipennis* II instar larvae (21.92 ± 0.08), *Ch. striatipennis* III instar larvae (27.92 ± 0.08), *Ch. striatipennis* IV instar larvae (30.0 ± 0.0), *Tx. tubifex* I (29.58 ± 0.19), *Tx. tubifex* II (29.83 ± 0.11) and *An. bouvieri* I (7.08 ± 0.7) were seen during night. No predatory affinity was observed on feeding of rest of the prey items between day and night.

*Cx. quinquefasciatus* I instar larvae (14.83 ± 1.58), *Cx. quinquefasciatus* II instar larvae (17.67 ± 1.79), *Cx. quinquefasciatus* III instar larvae (23.92 ± 1.65), *Cx. quinquefasciatus* IV instar larvae (29.75 ± 0.18), *Ch. striatipennis* I instar larvae (21.25 ± 1.3), *Ch. striatipennis* II instar larvae (22.83 ± 1.15), *Ch. striatipennis* IV instar larvae (30.0 ± 0.0), *Tx. tubifex* I (29.75 ± 0.18), *Tx. tubifex* II (29.92 ± 0.08), *An. bouvieri* I (17.42 ± 1.06), *An. bouvieri* IV (11.5 ± 0.74), *An. bouvieri* V (12.25 ± 0.84), *An. bouvieri* adult (14.58 ± 0.77), were the prey items which were predated significantly (P<0.05, df=16) by the fingerling stage of *Ompok pabo* during night. No photoperiod dependent deviation (P>0.05) was observed on feeding of rest 4 prey items.
Figure 4.2.2: Food selectivity of *O. pabo* during day and night regime. The prey items catered were *Culex* sp. I instar, *Culex* sp. II instar, *Culex* sp. III instar, *Culex* sp. IV instar, *Chironomous* sp. I instar, *Chironomous* sp. II instar, *Chironomous* sp. III instar, *Chironomous* sp. IV instar, *Tubifex* sp. (0.5-1.0 cm), *Tubifex* sp. (2.5-3.5 cm), *Anisops* sp. I instar, *Anisops* sp. II instar, *Anisops* sp. III instar, *Anisops* sp. IV instar, *Anisops* sp. V instar, *Anisops* sp. adult, *Macrobrachium lamarrei* I instar, *Macrobrachium lamarrei* II instar, *Lymnaea* sp., *Gyraulus* sp., *Gabbia* sp., *Indoplanorbis* sp., *Bellamya* sp., *Oreochromis niloticus* (0.8-1.4 cm).
The developing adult stage of *Ompok* had 18 preferred prey types. Among them, during night, significant predation ($P<0.05$, df=17) on *Cx. quinquefasciatus* II instar larvae (5.58 ± 0.5), *Cx. quinquefasciatus* IV instar larvae (28.67 ± 0.19), *Ch. striatipennis* I instar larvae (11.08 ± 1.15), *Ch. striatipennis* III instar larvae (29.67 ± 0.19), *Ch. striatipennis* IV instar larvae (29.92 ± 0.08), *Tx. tubifex* I (29.67 ± 0.23), *An. bouvieri* I (19.5 ± 0.92), *An. bouvieri* III (23.25 ± 0.63), *An. bouvieri* IV (19.17 ± 0.81), *Mac. lamarrei* I (12.17 ± 0.61) and *Or. niloticus* (14.08 ± 0.89) were observed. Other prey items, however, was not influenced by (Figure 4.2.2).

The food preference or selectivity of prey items based on their size corroborates with gape width of the predator. It can be easily deduced that predatory efficacy of all the juvenile stages of *Ompok* are basically influenced by photoperiod with their strategy for nocturnal feeding based on availability of prey items.

### 4.2.3 Feeding preference of *A. testudineus*:

Feeding efficiency of the juveniles of *A. testudineus* was also estimated in light and dark condition. Significant difference ($P<0.05$, df=9) of feeding strategy between day and light regime was observed, when the fry 1 stage predated more on *Cx. quinquefasciatus* I instar larvae (29.42 ± 0.36), *Cx. quinquefasciatus* II instar larvae (26.92 ± 0.08), *Cx. quinquefasciatus* III instar larvae (12.83 ± 1.04), *Cx. quinquefasciatus* IV instar larvae (3.33 ± 0.62), *Ch. striatipennis* I instar larvae (30.0 ± 0.0), *Ch. striatipennis* II instar larvae (28.56 ± 1.05), *Ch. striatipennis* III instar larvae (11.75 ± 0.89) and *Ch. striatipennis* IV instar larvae (2.58 ± 0.74), during night among 10 prey types.

Among 11 prey species most preferred by fry 2 stage, the juveniles on the other hand significantly ($P<0.05$, df=10) predated maximally on *Cx. quinquefasciatus* II instar larvae (24.34 ± 0.86), *Cx. quinquefasciatus* IV instar larvae (19.25 ± 0.86), *Ch. striatipennis* III instar larvae (29.75 ± 0.18) and *Ch. striatipennis* IV instar larvae (26.25 ± 0.8), *An. bouvieri* I (6.17 ± 0.9) and *An. bouvieri* II (7.75 ± 0.7) during night. The rest of the prey items were consumed more or less in equal proportion ($P>0.05$) irrespective of light and dark condition.

*Anabas* at the fry 3 stage predated on 13 preferred prey items. Predation on *Cx. quinquefasciatus* I instar larvae (19.75 ± 0.81), *Cx. quinquefasciatus* II instar larvae (18.08 ± 0.65), *Cx. quinquefasciatus* IV instar larvae (27.08 ± 0.97), *Ch. striatipennis* III instar larvae (26.33 ± 0.68) and *Ch. striatipennis* IV instar larvae (26.5 ± 0.07), *An. bouvieri* I (14.17 ± 0.9) and *An. bouvieri* II (15.75 ± 0.7) during night regime exhibited significant deviation ($P<0.05$,
Figure 4.2.3: Food selectivity of A. testudineus during day and night regime. The prey items catered were Culex sp. I instar, Culex sp. II instar, Culex sp. III instar, Culex sp. IV instar, Chironomus sp. I instar, Chironomus sp. II instar, Chironomus sp. III instar, Chironomus sp. IV instar, Tubifex sp. (0.5-1.0 cm), Tubifex sp. (2.5-3.5 cm), Anisops sp. I instar, Anisops sp. II instar, Anisops sp. III instar, Anisops sp. IV instar, Anisops sp. V instar, Anisops sp. adult, Macrobrachium lamarrei I instar, Macrobrachium lamarrei II instar, Lymnaea sp., Gyraulus sp., Gabbio sp., Indoplanorbis sp., Bellamya sp., Oreochromis niloticus (0.8-1.4 cm).
df=12) than that during the day. No such food/prey inclinations were observed on the rest of the prey species between day and night.

On *Cx. quinquefasciatus* I instar larvae (12.0 ± 0.99), *Cx. quinquefasciatus* II instar larvae (12.67 ± 0.88), *Cx. quinquefasciatus* III instar larvae (20.83 ± 1.41), *Tx. tubifex* 1 (24.17 ± 0.59), *An. bouvieri* 3 (19.83 ± 0.77), *An. bouvieri* 4 (22.67 ± 0.63) and *Mac. lamarrei* 1 (5.08 ± 1.01) the predatory potential of the fingerling stage of *A. testudineus* was found to be highly significant (P<0.05, df=16) during day than that of during night. On other 10 prey types, photoperiod dependent prey selectivity, exhibited insignificant deviation (P>0.05).

The developing adult stage of *Anabas* predated on 22 types of prey species. Among them, significant deviation (P<0.05, df=21) in predatory efficacy on *Ch. striatipennis* I instar larvae (17.5 ± 2.2), *Ch. striatipennis* II instar larvae (18.0 ± 1.09), *Ch. striatipennis* III instar larvae (24.17 ± 1.48), *An. bouvieri* 1 (18.0 ± 0.56), *An. bouvieri* 2 (12.17 ± 1.29), *An. bouvieri* 3 (12.33 ± 0.79), *An. bouvieri* 4 (15.58 ± 1.15), *An. bouvieri* 5 (21.0 ± 1.04), *An. bouvieri* adult (25.17 ± 0.86), *Lym. luteola* (12.83 ± 0.51), *Ga. orcula* (2.33 ± 0.71), *In. exustus* (2.17 ± 0.76), *Be. bengalensis* (5.17 ± 0.73) and *Or. niloticus* (4.58 ± 1.37) was observed during night in respect to day time predation. While for other prey items, photoperiod does not influence the predation potential of *Anabas* (Figure 4.2.3).

### 4.3 Spatial distribution pattern under multiple resource factor:

When spatial distribution pattern of the fry 1 stage larvae of *C. chitala* were analyzed, it was found that in an environment, devoid of any vegetation structure and food, significant deviation (P<0.05, df=3) in orientation of the larvae among the quadrants were noticed during daytime. Similar significant (P<0.05, df=1) observations were made in parallel experiments with higher densities of larvae. Observations during night, in exposed environments, indicated no significant deviation (P>0.05, df=3) between the individual distribution of the fishes in the four quadrants. With higher densities, fish distribution among the quadrants were also insignificant (P>0.05, df=3). So species distribution pattern was found to be clumped during day, while during night, they were randomly distributed when food and environmental structures are absent.

When such experiments were performed in open system in presence of food during daytime, significant difference (P<0.05, df=3) in distribution of larvae among the quadrants were noticed. When density was altered to higher densities, significant orientation pattern
(\(P<0.05, \text{df}=1\)) was also observed. When both larval density and orientation among quadrants in open system was considered, significant deviation (\(P<0.05, \text{df}=3\)) was also observed. It revealed that although food was available, larval stages of the fishes like to remain in aggregated mode during daytime. However, during night, the larvae seems to be equally distributed among the quadrants, though significant deviation was observed (\(P<0.05, \text{df}=3\)) in larval orientation. In case of larger larval population (\(P<0.05, \text{df}=1\)) and in combination with population density (\(P<0.05, \text{df}=3\)), significant difference was also noticed. Though the larval population was randomly scattered throughout the quadrants during night, but presence of food at the centre created patchiness in the population (Figure 4.3.1).

Again, when the larvae of *C. chitala* were kept in absence of food in structured environment, during daytime, aggregation of larval population structure was observed, and the population took refuge under the vegetation structure. Significant deviation (\(P<0.05, \text{df}=3\)) in population distribution among the quadrants was observed alongwith significant results with population density (\(P<0.05, \text{df}=1\)) and combination of density and population structure (\(P<0.05, \text{df}=3\)). Simultaneously, when the same condition arrived during night, the population distribution of the *Chitala* larvae among quadrants became insignificant (\(P>0.05, \text{df}=3\)), i.e. they were randomly distributed inspite of the vegetation structure. Other
factors like population density ($P<0.05$, df=1) and combination with population density and distribution ($P<0.05$, df=3) reveals significant deviations.

Clumped distribution of the larval population was noticed ($P<0.05$, df=3) where the distribution of the larvae were seen under vegetation structure in presence of food, during daytime. When both density and distribution among quadrants were considered, significant deviation was also noticed ($P<0.05$, df=3). No significant deviation ($P>0.05$, df=3) was found in cases, where, the random distribution pattern of populations was found among the quadrants. Combination of population density and its orientation revealed deviation ($P>0.05$, df=3) which was insignificant.

Similar pattern of population distribution of the fishes at different densities were observed with larvae and early juveniles (viz. fry 1, fry 2 and fry 3 stages) of *C. chitala*, *O. pabo* and *A. testudineus*. Moreover, structured environment and presence of food also depicted similar pattern of population distribution orientation.

So, from the above experimental findings it can be concluded that these fishes at their larval and early juvenile stages prefer patchy distribution pattern in both open and vegetated environments during daytime. In a structured environment (here vegetation structure), during daytime, the fishes were mostly found to take refuge under the vegetation structure due to predator avoidance and energy restoration for other physiological activities. At night they are more or less randomly distributed, found in vicinity of their food resource. They were also found to be randomly distributed in absence of food. Under environmental structure very few juveniles were found to take refuge during darker period.

### 4.4 Reactive distance of *C. chitala*, *O. pabo* and *A. testudineus*:

A total of 12 replicated of maximum reactive distance measurements at each stage of development were included in the analysis. Significant differences were found in the reactive distance results obtained from different life history stages of *Chitala chitala*, *Ompok pabo* and *Anabas testudineus* (Figure 4.4.1). When *C. chitala* was considered, at the fry stages (3.02 ± 0.07 cm) the reactive distance was 42.31 ± 0.19 mm, whereas at subsequent fingerling (6.35 ± 0.15 cm) and developing adult stages (16.26 ± 0.22 cm), the reactive distance was measured to be 87.93 ± 1.37 mm and 116.57 ± 0.99 mm respectively. When total lengths of the juvenile fishes of *Chitala*, representing different growth phases, were regressed against the reactive distance, it shows a positive correlation and the equation becomes $y = 24.896x + 0.582$, with $R^2 = 0.886$. 

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86.16 ± 2.31 mm, 139.03 ± 0.81 mm and 174.7 ± 1.15 mm depicted as the reactive distances measured for fry (2.89 ± 0.11 cm), fingerling (6.35 ± 0.15 cm) and developing adult stages (14.79 ± 0.19 cm) of *O. pabo* respectively. When the same characters were regressed at different developmental stages of *Ompok*, a positive reactive distance with the increase in growth, \( y = 59.646x + 0.412 \), with \( R^2 = 0.932 \) were observed. A steady gradual increase in reactive distance measurements at fry (1.7 ± 0.08 cm), fingerling (3.35 ± 0.12 cm) and developing adult stages (5.94 ± 0.08 cm) were observed when *Anabas* was considered as the predator species. It ranged from 33.92 ± 0.25 mm at the fry stages and 54.82 ± 0.23 mm at the developing adult stages, with an intermediate of 40.33 ± 1.19 mm at the fingerling stages. A positive steady increase in reactive distance with the increment in reactive distance at different growth phases of (A) *C. chitala*, (B) *O. pabo* and (C) *A. testudineus*.

\[ y = 28.103x + 0.361, \text{ with } R^2 = 0.939. \]
Discussion
From the results, it can be easily depicted that, the general tendency of the fishes in their early life history stages was towards red-coloured *Chironomus striatipennis* (as provided in the experimental protocol), when both dark-coloured *Culex quinquefasciatus* and *Chironomus* were provided as prey items together. At different combinations of larval instars of *Cx. quinquefasciatus* and *Ch. striatipennis*, it was found that the fry 1 stage of *C. chitala* preferred mainly the 1st, 2nd and 3rd instars of *Chironomus* with respect to 1st, 2nd and 3rd instars of *Culex*, though 4th instars of both *Cx. quinquefasciatus* and *Ch. striatipennis* were avoided by the fry 1 stage. The rest of the developmental stages of *Chitala* (viz. fry 2, fry 3, fingerling and developing adult stages) mainly predated on red-coloured *Chironomus* in all their stages, and less predation was noticed with 2nd, 3rd and 4th instars of *Culex* and on 1st instar *Cx. quinquefasciatus*. The developing adult stage on the other hand predated mainly on 3rd and 4th instar larvae of *Chironomus* and least predation efficacy was observed on 3rd and 4th instars of *Culex*. More or less similar pattern of predation efficacy of different developmental stages of *O. pabo* and *A. testudineus* was depicted, when predatory preference between red-coloured *Chironomus* and dark-coloured *Culex* in their different larval instars was assessed in combinations.

In the present study, although red-coloured dipteran larvae (*Ch. striatipennis*) are found to be a preferred item of the diet than that of the mosquito larval (*Cx. quinquefasciatus*) component, as also noticed by Hora and Nair (1938) and John (1940), probably owing to their relative preference towards red-coloured prey items. Confirmation of the feeding preferences of *Aplocheilus lineatus* is supplied by John (1940) who enumerated a menu almost identical to that revealed in this investigation. Moreover, the preference towards smaller and larger instars of *Ch. striatipennis* and *Cx. quinquefasciatus* was also influenced by the gape limitation and predation efficacy of the juvenile, fingerling and developing adult stages of *Chitala, Ompok* and *Anabas*.

A dietary survey of the *Chitala chitala, Ompok pabo* and *Anabas testudineus* under natural conditions is an essential prerequisite for a proper assessment of its biocontrol potential, as recommended by Prashad and Hora (1936), Hora and Mukerji (1937), Hora and Nair (1938), Job (1940) and Bay (1967), since the diet of a fish in captivity is never a reliable criterion of its natural taste. Again, such baseline data is necessary to avoid a repetition of the deleterious effects on other components of the ecosystem as was the case when exotic larvivores, principally *Gambusia affinis*, were introduced (Myers, 1965; Bay, 1972, 1973;
Menon, 1977). After assessing the feeding niche and dietary components of the three fishes in their developmental stages, it was found that the dipteran larvae of mosquito and *Chironomous* were most common. Moreover, a special predation affinity towards the red coloured *Chironomous* was also observed. Although a number of works by Hyatt (1979) supply information on the dietary habits of fishes in general, in the Indian indigenous larvivorous fishes no such attempt has hitherto been made.

Although the range of food consumed by the fish is wide, as in *C. chitala*, *O. pabo* and *A. testudineus* species like that of *Aplocheilus* (Job, 1941), an analysis of the feeding patterns reveals that as in other fishes (Qasim, 1972), food association is generally ecological and seldom taxonomic. Thus, like *Aplocheilus lineatus*, these three fishes at their early developmental stages can be principally considered as a surface feeding carnivore, preying mainly on the adult and larval stages of aquatic insects. No special selectivity is exercised within this range, and the composition of the diet is probably a reflection of the availability of food in the habitat. A survey of literature on the food consumed by *Aplocheilus lineatus* and other related species reveals that the mosquito and chironomid larval aspect of the diet of the fish in Indian waters is well documented, though no such research work on feeding efficacy of different developmental stages of *Chitala*, *Ompok* and *Anabas* has been done.

On the other hand, the virulence and prevalence of the mosquito and chironome-borne diseases (WHO, 1973) indicate that existing control methods (chiefly chemical) of the vector are inadequate; this has led to a revival of interest in other control techniques, including biological control. Although larvivorous fishes such as *Gambusia affinis* and *Poecilia reticulata*, the primary biological control agents of mosquito larvae, have been extensively employed in certain regions in mosquito abatement programmes (Sasa *et al.*, 1964; Mallars and Fowler, 1970; Bay and Self, 1972), the indiscriminate release of these exotic fishes into the aquatic environment has resulted in the alteration of valuable faunal components of the ecosystem (Myers, 1965; Bay, 1973; Menon, 1977). This in turn has been responsible for the renewed interest in India in the biocontrol potentialities of indigenous larvivorous fishes, such as *Chitala chitala*, *Ompok pabo* and *Anabas testudineus*.

Prey selectivity in juvenile and developing fishes, specially during the juvenile stages, is of particular interest because of gape limitation (Lazzaro, 1987; Schael *et al.*, 1991; Mookerji and Rao, 1993). It is also of considerable relevance in fisheries where the survival and growth of
juvenile and developing adults of many marine and freshwater fishes are known to be influenced by the availability of live food of the right type and size in appropriate concentrations in the water bodies (Pillay, 1990).

Chitala chitala, Ompok pabo and Anabas testudineus are economically important threatened fishes of India. As adults as well as in the juvenile stages, they have more or less similar food niches, though during initial larval stages, they are planktivorous and go through a short initial period of partial dependence on live zooplankton for their food requirements before they are ready to accept other larger prey species (Mookerji and Rao, 1991). Despite the awareness that the nutritional factors largely account for heavy mortalities experienced during larval rearing (Jhingran, 1991), not much information is available on the basic feeding ecology of the juveniles of these species and their capability of feeding in darkness.

Considering the juveniles of C. chitala, the fry 1 stage exhibited better effectiveness towards the consumption of Cx. quinquefasciatus I instar larvae, Cx. quinquefasciatus II instar larvae, Ch. striatipennis I instar larvae and Ch. striatipennis II instar larvae during dark. The different stages viz. fry 2, fry 3, fingerling and developing adult also exhibited similar pattern of results for prey consumption during night. The developing adults consumed significantly on Ch. striatipennis II instar larvae, Ch. striatipennis III instar larvae, Tubifex tubifex (2.5-3.5 cm), Anisops bouvieri I instar, An. bouvieri II instar, An. bouvieri IV instar, An. bouvieri V instar, Macrobrachium lamarrei I instar, Indoplanorbis exustus and Bellamya bengalensis in the dark. Fry 1 stages of Ompok pabo on other hand consumed Cx. quinquefasciatus II instar larvae and Ch. striatipennis II instar larvae more in dark, while Cx. quinquefasciatus I instar larvae, Cx. quinquefasciatus II instar larvae, Cx. quinquefasciatus III instar larvae, Ch. striatipennis II instar larvae, Ch. striatipennis III instar larvae, Ch. striatipennis IV instar larvae, and Tx. tubifex (0.5-1.0 cm) were also consumed more in dark. Except a few prey items, fry 3, fingerling and developing adult stages also was seen to prefer predation during night. Though, in case of Anabas, a very slight preference towards predatory efficiency in darker regime was observed because all the juvenile and developing adult stages predated almost equally in day as well as at night.

The present study demonstrated that the juveniles of C. chitala, O. pabo and A. testudineus showed food selectivity when offered a choice of different prey items and that similar prey selectivity persists even while foraging in total darkness. This is because of predator avoidance during the luminous part of the day. Predators like large aquatic insects, carnivorous fishes, amphibians, piscivorous snakes and fish-eating birds are found to be mostly
active during day, and the predation risk reduces during night. Like *Ompok* which uses tactile sensation while searching prey during night, the juveniles of *Chitala* and *Anabas* exhibit similar mode of feeding despite being visual predators.

All the three fishes in their different developmental stages were not only able to feed in light, but also showed similar prey selectivity as in total darkness. The feeding pattern of these fishes in nature at night was comparable to those observed in the laboratory tests. Their feeding intensity, however, was considerably lower presumably because of relatively lower prey densities and consequent lower prey encounter rates for the larvae. The efficacy to feed in darkness has also been documented for the larvae and juveniles of many fishes (Unger *et al.*, 1984; Hoekstra and Janssen, 1985; Batty, 1987). The juveniles and developing adult stages of *Chitala, Ompok* and *Anabas* must be endowed with other sensory modes of prey perception such as mechanoreception and chemoreception, both of which have been implicated in the foraging behaviour of many juvenile fishes (Blaxter, 1986; Luczkovich, 1988). In most of the cases there is significant increase in total food intake in darkness, a trend observed in other fishes feeding in darkness and considered as probable consequence of higher activity level and increased prey capture success in darkness (Blaxter and Batty, 1987, 1990).

Habitat can be recognized on at least two different scales. Habitat at a macro-scale such as, a major estuary or along stretch of river creates the general parameter for micro-scale habitats. A long stretch of river will have many characteristics such as temperature regime, tidal range, and seasonal duration of production that will be relatively similar among other tropical rivers. Each stretch of river, however, will possess a multitude of microhabitats that differ from each other on the basis of water depth, plant species composition, current, and a variety of other site-specific characteristics. Since micro-scale habitats are not uniform across their entire area, and since the limited mortality of eggs and larvae does not permit them to experience the range of smaller habitats, the most relevant habitat is the contingent habitat - the immediate habitat surrounding the individual fish (Figure 4.3.2).

The adaptive value of juvenile fishes seems to be related in finding more food or avoiding predators. Since predator and prey densities vary between habitats, juvenile fishes must balance their distribution pattern to take into account available food and threats from predator. From the experimental results it was evident that, generally, the juvenile fishes of *Chitala chitala, Ompok pabo* and *Anabas testudineus* prefers to be distributed randomly in the

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environment during night, and during daytime, they appear to remain in a clumped fashion. In presence of a habitat structure in the form of aquatic vegetation, the juveniles again prefer to be under cover for predator avoidance. In presence of food, some juveniles risk themselves to come out from the structured environment in the open to procure some food and again take refuge under the structure during daytime. But during the darker regime of the day, a random distribution of the juveniles confirms that though these stages are basically dependant on visual mode for procuring prey, but the presence of predators like piscivorous birds, snakes and other larger carnivorous fishes, aquatic insects and amphibians and restoration of metabolic energy for other physiological activities shifts their feeding regime during night when the predation risk lowers down. It can be concluded that at larval and early juvenile stages of C. chitala, O. pabo and A. testudineus, preference is towards patchiness in distribution pattern in both
open and vegetated environments during daytime. At night they are more or less randomly distributed throughout, preferably found in vicinity of food resource. Even in the absence of food, they were also found to be randomly distributed.

Shelter from predator is another habitat consideration for egg and larval stages. At the point where larvae leave the nest/or parental protection they become susceptible to predation, leading to a need for shelter. Freshwater fishes living near structure find shelter in vegetation (Figure 4.3.3). Studies on several species of fishes of north temperate freshwater fishes have shown a strong tendency for larvae and juveniles to seek shelter in the presence of predators. But when predators were absent, they distributed themselves much more widely, occupying most of the available habitats. This indicates how important shelter from predators is to larvae and juveniles.

The importance of scaling relationships for the ecology, behaviour, performance and evolution of animals (Walter and Carrier, 2002; Hutchinson and Garcia, 2002; Davenport, 2003) has been highlighted, based on which, theoretical models have been proposed (Richard and Wainwright, 1995). These models provide quantitative predictions of scaling of kinematics in geometrically similar animals. Although most scaling studies have addressed animal locomotion, several experimental studies have focussed on scaling of prey capture kinematics in aquatic feeding of vertebrates (Cook, 1996; Hernandez, 2000; Wainwright and Shaw, 1999; Robinson and Motta, 2002).

The importance of predatory experience to the development of feeding behaviors has been investigated for many teleost fishes like Atlantic salmon, *Salmo salar* (Coughlin, 1991), largemouth bass, *Micropterus salmoides* (Colgan et al., 1986), and anchovy, *Engraulis mordax* (Hunter, 1972). These studies have demonstrated that predatory experience may be a primary determinant of prey-capture mode (Coughlin, 1991, 1994) and feeding success (Hunter, 1972;
Colgan, et al., 1986; Coughlin, 1991; Wanzenbock, 1992). The majority of these studies, however, have addressed changes in behavior over major ontogenetic transitions, mainly the morphological transition from larva to juvenile (Cook 1996). Thus, it is difficult to discount alternative hypotheses that may explain changes in feeding behavior, such as a change in maneuverability with size (Blaxter and Staines, 1971), or a change in mouth size or structure with age (Liem, 1990).

Predatory fish have been divided into two broad categories, based on their strategy for searching and capturing prey. Ambush predators move infrequently, searching for prey at their periphery of their strike range and attack as prey cross into it. In contrast, cruise predators moves relatively continuously and scan for prey at the outer periphery of their search space (O’Brien et al., 1990; Browman and O’Brien, 1992a, b; Dowling et al., 2000). Identifying foraging strategies is important when constructing energy budgets or exploring possible energetic explanations for changes in behaviour. Energy budgets require data on foraging efficiency, which depends on prey encounter rate (density), search time and volume scanned. The manner in which each of these variables is calculated will vary according to the foraging strategy employed. Specifically, search time and volume have been approximated previously assuming a cruise strategy throughout the larval period, resulting in an underestimation of foraging efficiency (Browman and O’Brien, 1992a, b; Dowling et al., 2000).
Chapter 4: Specialization of feeding as survival strategy

Foraging strategies result from a trade-off between the cost of searching and vigilance for predators and benefits for increased prey encounters and capture rates. During development, a cost/benefit balance may alter due to morphometric changes such as increased streamlining, body length and eye diameter, and be reflected by a change in foraging mode. Previous investigations of foraging behaviour in larval and juvenile fish have concentrated on describing changes in the kinematics of foraging in response to manipulations of environmental factors such as light and water turbidity (Vinyard and O'Brien, 1976; Barret et al., 1992), turbulence (Mackenzie and Kiorboe, 1995), or prey distribution (Ryer and Olla, 1995) and density (Munk, 1995). No detailed studies of ontogenic changes in reactive distance as feeding kinematics have been undertaken.

The reactive distance of the different developmental stages of *C. chitala*, *O. pabo* and *A. testudineus* increased nonlinearly with increase in total length of the fishes. The reactive distance calculated in the fingerling stages were minimum while attaining a sudden hike at the fingerling stages. No such significant difference (*P* > 0.05) was found between the reactive distance measured at fingerling and developing adult stages (Figure 4.4.2). In general, the smaller juvenile fishes prefer ambush predation because the risk of being predated by other predators was found to be maximum during the fry and the fingerling stages. But with the attaining of adulthood, the
fishes become cruise predators, scanning the environment and foraging maximum, contributing to be considered as voracious carnivorous predators. The foraging efficacy of *Ompok* as small-sized predators at fry and fingerling stages reveal its foraging efficiency depends upon tactile sensation as a silurid fish (Figure 4.4.3). The other fishes (e.g. *Chitala* and *Anabas*) used visual acuity for voracious feeding (Figure 4.4.4). Comparison on reactive distance across fish species are different due to differences in experimental procedure, prey type and size used, and the size of fish tested in respective studies (Sweka and Hartman, 2001).

Though the experiments in the laboratory conditions have been carried out in clear water, precisely, in nature, turbidity becomes the guiding factor for fish feeding. It is noted that a non-linear relationship exists between the reactive distance between fish and turbidity (Vinyard and O'Brien, 1976; Gregory and Northcote, 1993; Miner and Stien, 1996; Sweka and Hartman, 2001, 2003). Benfield and Minello (1996) suggest that the relationship between reactive distance and turbidity is smaller for all species. Reduction in reactive distance with increasing turbidity has been linked to decreased prey consumption and subsequent growth (Sigler *et al.*, 1984; Berg and Northcote, 1985; Reynolds *et al.*, 1989). Similar observations on developmental stages eliciting lower reactive
distances for largemouth bass and brook trout (Sweka and Hartman, 2001) and for rainbow trout (Barret et al., 1992) also support this belief.

To understand trophic diversity in fishes is largely to understand these three feeding methods, how fish use them, why fish use them, and the basis for differences among species in performance. While the basic mechanics of each of these mechanisms are known, recent years have brought a new realization of the surprising diversity, both mechanical and ecological, contained within each category (Alfaro and Westneat, 1999; Wainwright et al., 2004; Collar et al., 2005; Konow and Bellwood, 2005; Van Wassenbergh et al., 2006a, b). These new studies have challenged our understanding of the basis of feeding performance and the result is an urgent need to identify the morphological basis of feeding performance in fishes as a means of interpreting diversity.

Moreover, increased search volume would increase the profitability of a prey item eliciting a reaction. A competitive experimental design may have allowed to better estimate reactive distance, but brings into question the generality of measure of profitability of reacting to prey. The influence of different developmental stages on prey consumption may also be dependent on fish density. A full understanding of the mechanisms by which it influences long term prey consumption and growth are more complex than simply not seeing potential prey.
Significance
Significance:

After analyzing all the above-told life-history traits and characteristics, it is essential to discuss anthropogenic changes to aquatic environments and how they affect fish populations through impacts on their eggs, larvae and juveniles. The aquatic ecosystems in which fishes live are specially impacted by urbanization and developments. The majority of fishes live in the narrow band of water along the margin of land masses. All together, 755 of the world's fish species and 227 Indian freshwater fishes (BCPP CAMP, 1998) are listed as endangered or threatened according to IUCN Red List (2000), but freshwater fishes are the most heavily impacted. Freshwater habitats are extremely vulnerable and species occurrence in them is likely to face a much higher risk of extinction than those in marine environments.

The early stages of fishes are especially vulnerable to habitat loss, water quality changes, and pollutants. The unique contribution of early life stages to fish population dynamics amplifies these impacts since changes in hatching success, growth and mortality determine whether a population grows or declines. Human impacts like increased green house gases from fossil fuel combustion and deforestation contribute to global warming and increase the rate of climatic change (Chapin et al., 2000; Holt, 2002) act on early life stages by reducing survival rates either through direct mortality or through changes in behaviour, development, or distribution that lead to increased mortality. Such changes result from habitat degradation, introduced species, over-fishing, or from chemical pollution. Floodplains and freshwater marsh were vitally important nursery grounds for many freshwater fishes. The associated development removes shallow habitats, changes hydrology and interferes with along-shore movement of fishes. Water diversions for flood control, irrigation, and drainage change the hydrology of the environments and thereby alter larval fish transport, retention, and quality of nursery habitats. The cleaning of terrestrial vegetation in water shades increases runoff, river flow, and sedimentation in a water body, consequently changing habitat characteristics important to eggs, larvae and juveniles. Upstream development and channelisation also increases water flow to the lower part of the river. The increased water flow removes vegetation, washes eggs from the substrates, and inundates marshes and backwater areas that are important to feeding of many larvae and juveniles. The increased sediment load and sedimentation rate reduces survival of fish embryos.

Heavy fishing pressure on species, as is generally the case, dramatically alters community structure and food webs. Targeting of predatory fish like *Chitala*, *Ompok* and *Anabas*
releases pressure on its prey, allowing the forage species to increase in abundance. On the other hand excessive fishing on small prey fishes removes food important for the predator and releases predation pressure on small invertebrates. This could result on increased grazing pressure on phytoplankton and ultimately a shift in primary production to other aquatic plants. The indirect effect on the ecosystem has rarely been investigated, but key changes in trophic and competitive interactions are likely to have serious consequences for fishes and their eggs, larvae and juveniles. Expanding human population growth, industrialization and urbanization have increased the amount of pollution entering lakes and rivers. Included among these pollutants are excess essential nutrients (phosphorous, nitrogen and ammonia) and toxic chemicals (pesticides, herbicides and heavy metals). These pollutants can reduce egg population, increases egg, larvae and juvenile mortality; alter the physiology and behaviour of larvae to reduce viability, and alter trophic structure.

Loss of nursery habitats and accessibility to remaining habitat has limited the number of recruits and seriously affected many fish populations. Alternations to aquatic habitats may interfere with transport and dispersal patterns and prevalent larval fishes from reaching critical nursery habitat. In general, loss or modifications of wetland habitats means that suitable habitats for larvae may not be available. The tributary streams of large free-flowing rivers, with their dense concentration of plankton, were important feeding and nursery areas for freshwater species. These habitats have been greatly reduced or eliminated through the modification of all the major rivers of India. While these changes can be tolerated individually, they are often devastation when combined. Multistressors can lead to a cascade of changes throughout the ecosystems that make it difficult to decipher the important pathways that lead to high egg and larval mortality and the collapse of a fishery.

Human impacts that changes life history characteristics of adult populations can directly influences early life stages. Permanent reduction in juvenile and spawning biomass has resulted from habitat loss and over-fishing. The quality of spawning grounds for fishes that spawn on or among the aquatic vegetation (e.g. *Chitala* spawns on the large macrophytes acting as a substrate, while *Ompok* and *Anabas* spawns around the vegetation structures) is reduced by habitat degradation that degrades benthic habitat too. Such anthropogenic activity alters important spawning and nursery habitats and reduces the preferred prey of adults that can cause poor reproductive success, hatching success as well as larval survival.