INTERACTIONS OF FRESHWATER FISH FRY WITH THE PLANKTON COMMUNITY

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ABSTRACT

This paper is a synthesis of the main aspects of the interactions between the young forms of fish (YFF) and the plankton community, describing biological factors and behaviors. The recruitment of fish populations depends on the success of YFF in the natural environment. Thus, the development of mechanisms that allow efficient food capture, as well as reduction of competition or also reduced predation by other organisms, are of fundamental importance for the maintenance of the populations of fish and their natural environments. YFF, which show ecological characteristics different from those of adults, depend on the availability of food organisms in terms of density, size, palatability, attractiveness, biological value and adequate swimming capacity for capture. Among the factors that determine the capture of food organisms by YFF are the fry length/prey length relationship, mobility and capacity of escape of the prey, body protection, palatability and prey abundance. The predation and feeding selectivity on the zooplankton by YFF can cause changes in the plankton community structure in natural environments.

Key-words: natural feeding; young forms of fish; larvae; predator-prey relationship

INTERAÇÕES DE LARVAS DE PEIXES DE ÁGUA DOCE COM A COMUNIDADE PLANCTÔNICA

RESUMO

Neste artigo apresenta-se uma síntese dos principais aspectos das interações entre as formas jovens de peixes (FJP) com a comunidade planctônica, evidenciando fatores biológicos e comportamentais. O recrutamento das populações de peixes depende do sucesso das FJP no ambiente natural. Desta forma, o desenvolvimento de mecanismos que possibilitem eficiência de captura do alimento, assim como redução da competição ou, ainda, menor predação por outros organismos são de fundamental importância para a manutenção das populações de peixes e seus ambientes. As FJP, as quais, em sua maioria, apresentam características ecológicas distintas daquelas de seus adultos, dependem da disponibilidade de organismos-alimento em densidade, tamanho, palatabilidade, atratividade, valor biológico e capacidade natatória adequados para serem capturados. Dentre os fatores que determinam a captura dos organismos-alimento pelas FJP estão a relação tamanho da larva/tamanho da presa, mobilidade e capacidade de escape da presa, proteção do corpo, palatabilidade e disponibilidade da presa. A predação e/ou a seletividade alimentar sobre o zooplâncton por FJP podem causar alterações na estrutura da comunidade planctônica dos ambientes naturais.

Palavras-chave: alimentação natural; formas jovens de peixes; larva; relação predador-presa

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INTRODUCTION

Fish larvae are the smallest vertebrates that feed actively, some of them, like anchovies (*Anchoa mitichilli*), being 2-3 mm in length and weighing 20 mg. In most of teleosts, the reduced size of the larvae is compensated by high fecundity, with the number of eggs laid by a female per year reaching more than one million. An interesting hypothesis to explain this event is that fish larvae, as well as other organisms, act as a form of transfer of energy between plankton organisms and larger fish, due to the size discrepancy that exists between the secondary producers (zooplankton) and the adult fish (OSSE *et al.*, 1997).

Predation and hunger are considered the main agents of larval mortality. Effective systems of swimming capture and food assimilation must develop simultaneously to permit the success of larvae in the environment (GERKING, 1994; PARADIS *et al.*, 1996).

Each species, or even different phases of development of a same species, can present preference for a certain type of food, in agreement with the development of its sensorial and alimentary organs (SIPAÚBA-TAVARES *et al.*, 1994; SOARES, 2003). Most fish feed on plankton, at least during a certain period of their life. Plankton organisms are of fundamental importance in the development of fish, mainly in the initial phases, being indispensable for most species of larvae (HUNG, 1989; NASCIMENTO, 1989; PORTELLA *et al.*, 1997; CUNHA and PLANAS, 1999).

The capture of food organisms by fish, mainly during the early phases of development (larvae, postlarvae and juveniles), depends on a series of environmental factors such as photoperiod, water luminosity and turbidity (SILVA-GARCIA, 1996; FERMIN and SERONAY, 1997; RIEGER and SUMMERFELT, 1997), as well as on factors related to predator-prey interaction, such as size, escape capacity, palatability and availability of the prey, visual and swimming efficiency of the predator, and also on the relationship between larval mouth size and prey size (FREGADOLLI, 1993; CUNHA and PLANAS, 1999; SOARES, 2003). Interactions between two or more of those factors can affect the development, growth, survival and behavior of young forms of fish (FERMIN and SERONAY, 1997; RIEGER and SUMMERFELT, 1997; BEHR *et al.*, 1999), and the effect can vary as a function of the biology of each species, since differences exist in the type of environment necessary for each species, in addition to variations in the different developmental phases.

The abundance, distribution and size of zooplankton organisms can suffer seasonal changes in the ecosystems, directly affecting the populations of fish feeding on plankton, and possibly affecting the development and survival of fish in the early phases of development. Thus, knowledge about these relationships is essential to understand the processes of recruitment of fish populations (WELKER *et al.*, 1994; VRIES, 1998).

Knowledge of the aspects related to fish feeding during its different development phases and of the possible modifications of these in the different types of environments is also important for the understanding of the ecology of the fish community. Although several studies related to the natural feeding of adult fish are available, few reports have been published about the early phases of development of these vertebrates. However, information about the dietary items and their importance for the different species during the early stages of development and about the interactions of early fish stages with the organisms of the plankton communities would be highly valuable for the determination of priority areas for the development and maintenance of natural populations, as well as for their propagation in programs of repopulation of native sites.

RESULTS

Predator-prey relationships between fish in the early stages of development and plankton organisms

The availability of plankton organisms of adequate size, palatability, mobility and density is of fundamental importance for the survival and growth of fish larvae. The abundance and quality of food lead to the success of larval foraging, which, however, can also depend on the distribution of suitable size (SOARES, 2003).

The detection of a prey organism by a fish larva does not always results in successful capture, but a process of prey selection exists and is strongly affected by the characteristics of the preys available in the environment (COX and PANKHURST, 2000). The interactions between predators and preys can determine the structuring of the fresh-water plankton community (ZARET, 1980; SOARES, 2003). Some factors inherent to the predator, such as age, ontogenetic development, mouth size, swimming capacity, visual capacity, preference, hunger and feeding behavior, affect prey consumption by fish larvae that feed on plankton organisms (ZARET, 1980;

CUNHA and PLANAS, 1999; COX and PANKHURST, 2000). Consumption can also be affected by specific characteristics of the prey, such as escape capacity, size, shape, protection and pigmentation of the body, contrast against the environment, palatability, preferential habitat, and population density.

Studies on predator-prey relationships, mainly on the capture of live food by fish larvae, have shown that a successful predation rate is also related to environmental factors, such as light intensity, wall color and water turbidity (RIEGER and SUMMERFELT, 1997). OSTROWSKI (1989) reported that the use of tanks with dark walls led to greater visual contrast of the food than the use of colorless tanks, thus permitting greater predation efficiency and higher survival rates of *Coryphaena hippurus* larvae.

Studying the diet of larvae of *Iheringichthys labrosus*, *Hipophthalmus edentatus* and *Plagioscion squamosissimus* of the Itaipu reservoir, CAVICCHIOLI (2000) observed that the mouth size of *P. squamosissimus* in relation to body size is larger than in the other two species, and that the species has a different diet, especially preferring Calanoida copepods, while *I. labrosus* and *H. edentatus* selected smaller preys. CAVICCHIOLI (2000) also pointed out that *I. labrosus* and *H. edentatus*, although having a similar mouth size, have different diets, and attributed the fact to differences in the foraging behavior of the species.

As described by GERKING (1994), the feeding behavior of fish larvae during the capture of preys consists of three phases: 1) finding an individual prey, 2) attack, and 3) ingestion before finding another prey. FREGADOLLI (1993), studying the behavior of the larvae of *Piaractus mesopotamicus* and *Colossoma macropomum*, identified four units of behavior in the capture of a prey (Figure 1), i.e., fixation – when the prey enters the field of vision it orients its head towards the prey while its eyes are directed forward, adopting binocular vision; approach - with the prey in the center of binocular vision, the larva takes on an attack posture, flexing its spine to form an "S" with the trunk of its body, with a displacement towards the prey occurring with the use of the pectoral fins; attack - the "S" is undone, causing the larva to project towards the prey while opening its mouth to try to capture it; capture - the prey is captured with the mouth, and, in general, ingested immediately. Manipulation may occur before ingestion, and rejection may occur in the case of less preferred preys.

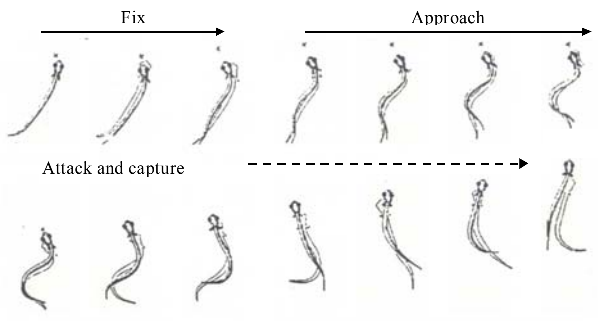


Figure 1. Sequence of behaviors involved in the attempt to capture a prey by *Piaractus mesopotamicus* and *Colossoma macropomum* larvae during the first days of feeding - *Adapted from FREGADOLLI (1993)*

The effectiveness of capture or even the occurrence of prey ingestion by the fish larvae varies as a function of prey species, due to factors such as prey size and shape, and as a function of predator size. The cladoceran *Diaphanosoma birgei*, by having well developed antennas, can be more evasive, turning more difficult the capture by *P. mesopotamicus* and *C. macropomum* larvae, mainly by the smaller larvae. Prey rejection may also occur, with the larvae actively loosening it without a new capture attempt (FREGADOLLI, 1993).

After the encounter, the visual predation is governed by a combination of factors that include visibility, which is determined by size, contrast, pigmentation, and movement, escape ability, distribution, and abundance of the prey (KEEF *et al.*, 1998). Preys showing an irregular dislocation pattern are more attractive to plankton-eating fish fry (BUSKEY, 1994). Brewer and Coughlin (1996), *apud* KEEF *et al.* (1998), showed that bluegill (*Lepomis macrochirus*) larvae select 70% of the time virtual zooplankton projected on a computer monitor that swim twice as fast as their neighbors.

KEEF *et al.* (1998), in a study on the ingestion of same size clones of *Daphnia* by *Lepomis macrochirus* juveniles, showed a selection of *Daphnia* individuals that swam faster; however, when the preys were anesthetized, they showed no difference in preference. With respect to pigmentation, the fish preferred to consume *Daphnia* individuals of dark color, even in the presence of rapidly swimming individuals of light color (Table 1). Dark individuals were also more consumed when the cladocerans were supplied anesthetized, indicating that the difference in color was more important than the difference in swimming behavior.

Table 1. Choice of *Daphnia* sp clones with different swimming speed and pigmentation by *Lepomis macrochirus* juveniles

Characteristic of *Daphnia* clone	Fish choice (%)			
	normal		anesthetized	
swimming speed				
fast	80	***	55	NS
slow	20		45	
pigmentation				
dark and slow	67	**	73	**
clear and fast	33		27	
dark and slow	69	*	73	*

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$
Adapted from KEEF et al. (1998)

Marked differences in mouth size were observed to *I. labrosus*, *H. edentatus* and *P. squamosissimus* larvae by CAVICCHIOLI (2000), and to initial stage of *Astyanax altiparanae*, *P. mesopotamicus*, *Leporinus obtusidens* and *Prochilodus lineatus* by SOARES (2003). Those differences were less significant in smaller larvae and increased with ontogenetic development (Figure 2).

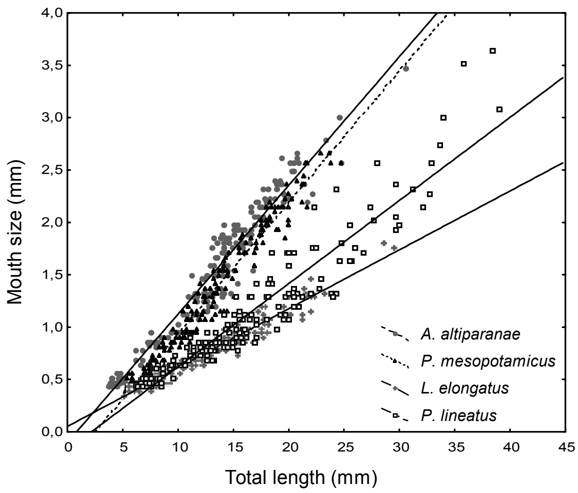


Figure 2. Mouth size by total length of initial stages of *Astyanax altiparanae*, *Piaractus mesopotamicus*, *Leporinus obtusidens* and *Prochilodus lineatus* - *Adapted from SOARES (2003)*

The relationship between the size of the mouth of fish larvae and the size of their preys is considered to be a decisive factor in the capacity of larvae to capture and ingest preys of different sizes. Mouth size determines the maximum and optimum size of the prey to be ingested (CUNHA and PLANAS, 1999, SOARES, 2003). Relating the size of the mouth of the larvae to the size of the consumed zooplankton, CAVICCHIOLI (2000) reported that the size of the consumed zooplankton varied among the studied species, even among larvae with the same mouth size, especially between *I. labrosus* and *P. squamosissimus* (Figure 3), and also that for *P. squamosissimus* there was an increase in the size of the preys consumed with the increase of mouth size in the first three size classes, with stabilization in the subsequent classes, while for *I. labrosus* the length of the consumed zooplankton varied very little with the increase in mouth size. In contrast, for *H. edentatus* the length of the consumed zooplankton increased in the classes of larger mouth size.

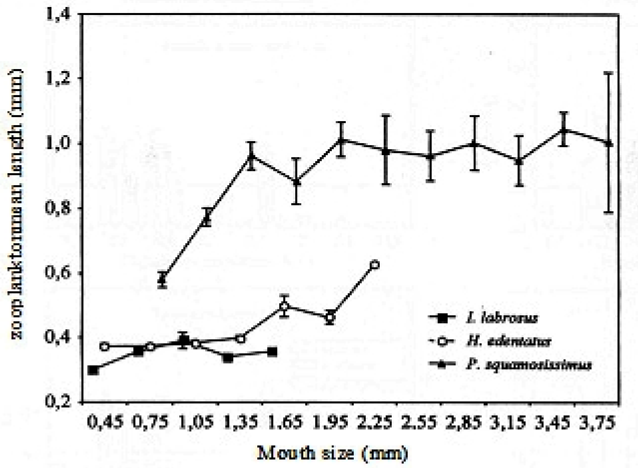


Figure 3. Average length of the zooplankton consumed by larvae of *Iheringichthys labrosus*, *Hipophthalmus edentatus* and *Plagioscion squamosissimus,* according to mouth size class (Vertical bars indicate the standard error.) - *Adapted from CAVICCHIOLI (2000)*

VRIES (1998), studying the relationship between mouth aperture and total length of *Promoxis annularis* and *Dorossoma cepedianum* larvae, observed differences in that characteristic between the two species (Figure 4), which led to variations in the size of the food items consumed by fish of the same size.

Since the highest mortality rates during the life cycle of fish occur during the larval phase, several studies focusing on the interactions between young fish forms and the plankton communities have been conducted, many of them in an attempt to understand how the natural plankton populations contribute to the nutritional requirements of larvae. According to GERKING (1994), those studies are directed at the determination of larval requirements, comparing the latter with prey density in the natural environment. For this purpose, the perceptive field of vision and swimming speed of the larvae are determined. Larvae are seen as if swimming in a tube where the limit is the field of vision. This permits to determine the volume of water "researched" by the larvae per unit time.

When the feeding rates of larvae of different ages in the presence of different prey densities are known, the number of preys found and consumed within a given time interval can be calculated. This value, compared with the natural plankton populations, is an indication of whether or not the available natural food can support the larval population.

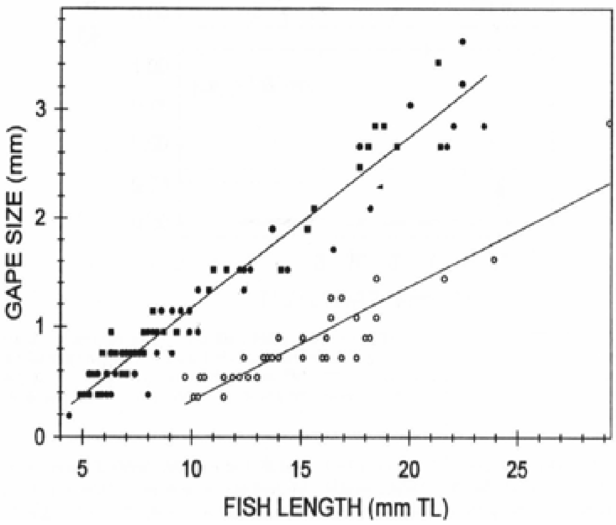


Figure 4. Mouth aperture as a function of the total length of *Promoxis annularis* (full circles) and *Dorossoma cepedianum* (open circles) - *Adapted from VRIES (1998)*

Natural fish feeding during the early phases of development

In terms of feeding, fish larvae are essentially apart species compared to their adults. Larvae and adults are often totally different and can even be considered to be eco-species presenting different peculiarities in terms of type of habitat, feeding and behavior (NAKATANI *et al.*, 1997). Recently emerged larvae are so small and so poorly developed that their feeding ecology greatly differs from that of the same species for the rest of the animals' life (GERKING, 1994). The microhabitat used by the first fish stages and the response of these to environmental oscillations are usually different from those of juveniles and adults of the same species (CHILDS *et al.*, 1998).

The availability of plankton organisms is of fundamental importance for fish development, mainly in the early phases, with the survival of young fish, which depends on environmental conditions and food availability, affecting the size of adult populations (MENG and ORSI, 1991). Inadequate feeding causes high mortality rates and reduction in developmental parameters (NASCIMENTO, 1989; HUNG, 1989, LUIZI *et al.*, 1999). Most fish species depend on the availability of live organisms during the early phases of life to develop properly. This is due to the fact that natural food provides essential nutrients for growth and survival, since the larvae of most fish species have poorly developed digestive and enzymatic systems (HUNG, 1989; DABROSKI, 1991; BAGLOLE *et al.*; 1998; LUIZI *et al.*, 1999; RØNNESTAD *et al.*, 2001). Thus, the availability of food of high biological value, characteristic of plankton organisms, is of great importance to assure successful growth and survival during the early phase of life (FURUYA *et al.*, 1999).

In this respect, GERKING (1994) considers zooplankton as being the main food source for fish larvae, which they locate visually and capture individually. This early carnivorous habit also occurs in those species that, when adults, became herbivorous. Few larvae, usually the very small ones, consume algae.

In a study on the natural feeding of black catfish larvae (*Rhinelepis aspera*) during the first 32 days of life, SOARES *et al.* (1997) observed that rotifers and *Scenedesmus* spp are the most important items in the diet of the species raised in tanks (Figure 5). HAYASHI *et al.* (1999), in a study of the natural feeding of the early stages of *Leporinus macrocephalus*, observed that the organisms most frequently detected in the gut content (87.7%) were *Lecane* sp, protozoa, *Scenedesmus* sp, and diatoms. During the first 24 days of life, *Lecane* sp was the item with the highest dominance rate in the gut contents of the larvae in all tanks. On the other hand, from the 27th to the 40th day, differences in the dominant items were observed in the contents of the larvae in the different tanks, with cladocerans dominating in 60% of the gut contents in tank 1, *Arcella* sp, in 34% in tank 2, and *Coelastrum* sp, in 41% in tank 3, concluding that the food organism *Lecane* sp constitutes the main alimentary item for larvae of *L. macrocephalus* in the first 24 days of life. After this period, the search for food is differentiated, depending on the organisms available in the tanks.

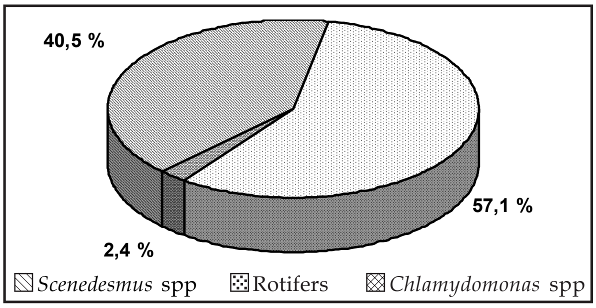


Figure 5. Dominance of food items in the gut of *Rhinelepis aspera* larvae during the first 32 days of life - *Adapted from SOARES et al. (1997)*

According to SIPAÚBA-TAVARES (1993), "tambaqui" (*Colossoma macropomum*) and "tambacu" (*C. macropomum* ♀x *Piaractus mesopotamicus* ♂) larvae present similar feeding behavior, with preference for smaller organisms, mainly rotifers, during early development, and then start to consume larger organisms (cladocerans and copepods) as a function of growth. Cladocerans constituted the item most frequently consumed by the larvae with 12 and 26 days of life, while on the 19th day there was high consumption of copepod nauplii due to the high availability of these. The data demonstrate the plasticity of the diet of the larvae of those fish.

BREMIGAN and STEIN (1999) observed larger numbers of larvae in the weekly cohort of larvae of *Dorossoma cepedianum* during periods when the biomass of small zooplankton (< 0.40 mm) was more abundant both upstream and downstream of four reservoirs in Ohio (Figure 6). High survival rates and a larger occurrence of juveniles of that species were also verified in environments with larger densities of small-sized zooplankton (Figure 7). Those results demonstrate dependence of the juvenile forms of the species on an appropriate amount of food for their development and maintenance. Larger densities of larvae of white crappies (*P. annularis*) in years with high densities of zooplankton were reported by SAMMONS *et al.* (2001) for the Normandy Reservoir.

According to GERKING (1994), in contrast to marine species, fresh-water fish larvae depend more on small cladocerans than on copepods, with rotifers being also common as the first type of food. The larvae of tropical fish in general use rotifers as first food, later consuming cladocerans and nauplii and adult copepods and they seem to present greater plasticity in the diet as they develop (FREGADOLLI, 1993, SOARES *et al.*, 1997; HAYASHI *et al.*, 1999; SOARES, 2003).

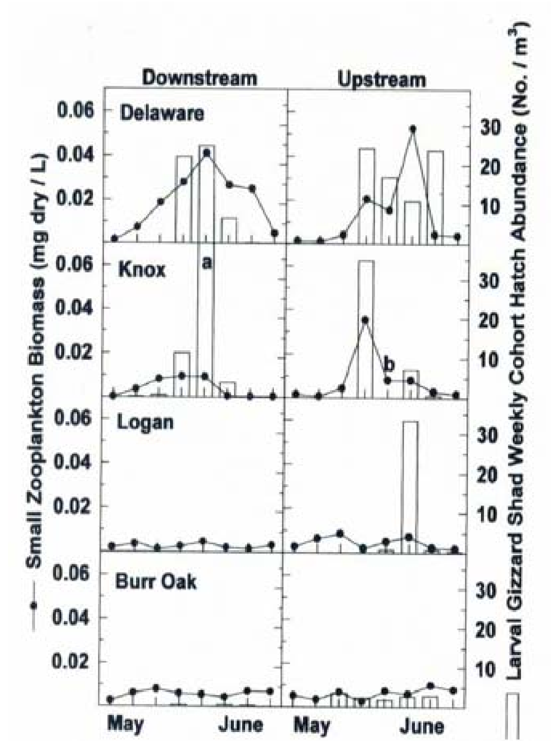


Figure 6. Biomass of small zooplankton (< 0.40 mm) and abundance of weekly cohorts of larvae of *D. cepedianum* upstream and downstream in four Ohio reservoirs - *Adapted from BREMIGAN and STEIN (1999)*

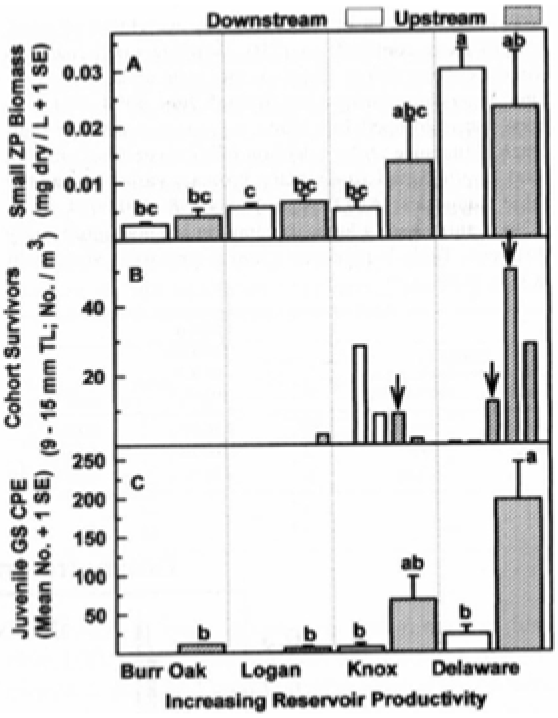


Figure 7. (A) Biomass of small zooplankton (< 0.40 mm) during the reproductive season of *D. cepedianum*; (B) Abundance of larvae; (c) Number of juveniles captured within five minutes of electric fishing upstream and downstream from the reservoirs - *Adapted from BREMIGAN and STEIN (1999)*

Selectivity of plankton organisms by fish in the early phases of development

Fish larvae search for food particles by visual orientation. The success in the capture of food depends on factors such as brightness, temperature, escape capacity of the prey, larval mouth size, and previous experience of the larvae with prey, among others. The preferential food item varies as a function of fish species (CAVICCHIOLI, 2000; SOARES, 2003), with changes for individuals of the same species occurring as they grow (SOARES *et al.*, 1997; HAYASHI *et al.*, 1999; SOARES, 2003). In addition, changes also occur in the frequency of occurrence of food items and in the dominance of the latter in the gut content of juvenile fish forms, which start to consume larger organisms as they grow, a fact observed for *Rhinelepis aspera* by SOARES *et al.* (1997) and for *Leporinus macrocephalus* by HAYASHI *et al.* (1999). However *Prochilodus lineatus* consumes zooplankton in first day and periphytic algae after the 23th day of age (SOARES, 2003).

Studies carried out in the laboratory to determine food selection by "pacu" (*Piaractus mesopotamicus*) and "tambaqui" (*Colossoma macropomum*) larvae were conducted by FREGADOLLI (1993), and studies on "tambaqui" and "tambacu" (*C. macropomum* ♀ x *P. mesopotamicus* ♂) larvae were conducted by SIPAÚBA-TAVARES (1993). The results of those studies indicate that fish larvae select the food organisms available either in a positive or negative manner and that some factors determine the consumption of a certain prey: **a)** ***larval size/prey size* ratio** – according to larval size, there is an ideal size of the food organism to be captured and as the larvae grow they prefer larger prey; **b)** ***mobility and capacity of escape of the prey*** – organisms, such as adult cladocerans and mainly adult copepodites and copepods, are agile, hindering capture; **c)** ***protection of the body and palatability*** - some cladocerans, like *Bosmina deitersi*, are seldom selected compared to *Moina micrura* due to the fact that they have a rigid carapace and consequent little palatability; **d)** ***prey availability*** - the high abundance of a prey of appropriate size leads to a higher frequency of capture.

A study on food selectivity by fish larvae of the Itaipu reservoir carried out by CAVICCHIOLI (2000) showed that larvae of *Iheringichthys labrosus* preferentially select smaller preys, between 0 and 0.6 mm, and mainly 0.2 to 0.4 mm. The larvae of *Hipophthalmus edentatus* selected also preys measuring 0.2 to 0.6 mm, while the larvae of *Plagiocion squamosissimus* preferentially selected larger ones ranging in size from 0.8 to 1.2 mm, and less frequently classes of preys larger than 1.4 mm and between 0.2 and 0.8 mm.

Differences in swimming behavior can be an important attraction mechanism for visual predators. Striped bass (*Morene saxatilis*) individuals in the early phase of development, in the Sacramento-San Joaquim estuary preferentially consume native copepods of the genera *Cyclops* and *Eurytemora* rather than introduced species, a fact attributed to differences in type of swimming and escape behavior of the various copepod species (MENG and ORSI, 1991). Bluegill juveniles (*Lepomis macrochirus*) collected from lake Wingra selected individuals that swam faster between two *Daphnia* clones of the same size and visual contrast in laboratory assays (KEEF *et al.*, 1998).

Thus, the conclusion is that changes in food items in the diet of the early phases of fish development are related to the availability of organisms to the species of the fish and to the course of the ontogenetic development of each species.

Impact of fish larval feeding on plankton communities

As is the case for adult fish, the juvenile forms have an impact on the plankton communities in natural environments, reducing the population density of some organisms and consequently permitting an increase in the population of others (GERKING, 1994). Selective visual predation by fish is important in the structuring of the zooplankton community (KEEF *et al.*, 1998) and can promote differences in zooplankton composition, both in terms of the species and size of the organisms present (BÖING *et al.*, 1998; SOARES, 2003). The consumption of larger zooplankton organisms reduces the impact of herbivorous feeding on the phytoplankton, permitting an increase in biomass as well as changes in the organisms of this community (MILSTEIN *et al.*, 1988; BÖING *et al.*, 1998; ESTEVES, 1998; MATHEUS and BARBIERI, 1999; PEGANO *et al.*, 1999), and increasing the total chlorophyll levels (BEKLIOGLU and MOSS, 1995; SOARES, 2003). On the other hand, it also promotes an increase in the density of smaller-sized zooplankton organisms (BEKLIOGLU and MOSS, 1995; SOARES, 2003). Thus, the effects of predation by fish on the zooplankton community appear in different ways in lake ecosystems, possibly causing alterations in the diversity and density of the species that constitute the zooplankton, in the composition and biomass of the phytoplankton and in the physical and chemical conditions of the water.

In lakes with high densities of fish feeding on zooplankton there is a lower density of large-sized zooplankton organisms such as cladocerans and a dominance of small-sized organisms such as rotifers. On the other hand, in lakes with low densities of those fish, the opposite phenomenon is observed (JOHANNSSON and O'GORMAN, 1991; ESTEVES, 1998). The feeding strategy used by a given fish species usually leads to greater effectiveness in capturing individuals of a specific zooplankton group. This, in turn, favors the groups that are not captured, which will be able to proliferate due to the reduction of predators and competitors and/or greater food availability.

In a study on yellow perch larvae (*Perca flavescens*) in Oneida Lake, MELLS and FORNEY (1983) observed that, in open waters, the perch larvae consume large amounts of dafinids, with *Daphnia pulex* being the main prey, which is practically exterminated in years with higher densities of the larvae of this fish. The consumption can reach 33% of the population of this cladoceran in a day, exceeding its daily production rate. Thus, drastic reductions in the population density of *D. pulex* occur in years with high densities of perch larvae (Table 2).

Table 2. Abundance of yellow perch larvae (*Perca flavescens*, Percidae) in Oneida lake, New York

year	yellow perch larvae		*Daphnia* (ind./L)		Reduce (%)
	ind./ha	(kg/ha)	May - June	August - October	
1968	36000	48	4.90	0.40	92
1969	7200	9	1.20	1.20	0
1970	14000	24	13.60	9.10	33
1971	37700	26	7.90	0.00	100
1976	6500	9	9.70	8.80	9
1977	14700	31	6.10	0.10	99
1979	13400	17	7.20	3.30	54

Adapted from MILLS and FORNEY (1983)

Studying the relationships of larvae and juveniles of gizzard shad (*Dorossoma cepedianum*) with the zooplankton and recruitment of sporting fish in four reservoirs, BREMIGAN and STEIN (1999) observed that the high abundance of young forms of this fish promotes reduction in the densities of total zooplankton in mesotrophic environments, and when assessing the density and biomass of zooplankton organisms during the period of recruitment of *D. cepedianum* larvae and during the period when juveniles of this species are present in four Ohio reservoirs, the authors observed a greater reduction of the density and an increase in the biomass of the total zooplankton in the reservoirs where the densities of juvenile of *D. cepedianum* were higher, a fact related to the consumption of small-sized zooplankton organisms by the fish.

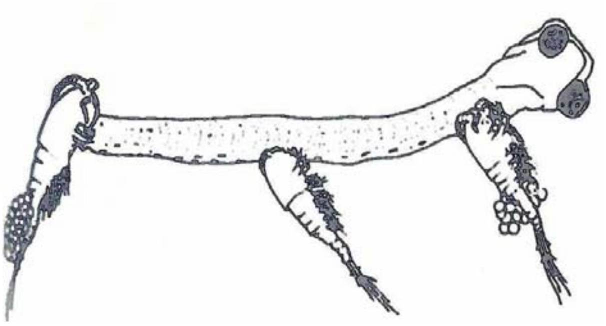
URABE (1990) observed reduced phytoplankton biomasses in environments with high biomasses of the cladoceran *Daphnia galeata*, whereas BÖING *et al.* (1998) reported a smaller phytoplankton biovolume with the increase rate of *D. galeata* clearance, and they also observed an increase in the mean size of cells and colonies of phytoplankton organisms and related these events to the grazing pressure promoted by the cladoceran.

Predation of fresh-water fish larvae by plankton copepods

The food availability in an aquatic ecosystem is considered to be one of the most important factors in the survival rate of fish larvae (FARIA *et al.* 2001), and predation is one of the main causes of mortality, strongly affecting the recruitment of the populations of young fish (LAFONTAINE and LEGGETT, 1987). Cyclopoid copepods, which can act as a biological factor, affect the recruitment of some populations of fresh-water fish (FABIAN, 1960), and are among the major predators of fish larvae, a fact that makes them extremely undesirable during the early rearing phase of young fish forms, causing significant losses during this stage (BEHR *et al.*, 1997).

Among the copepods there is a group of cyclopoid fish parasites, but most of them are filterers, although some are carnivores (VARELLA, 1994; ESTEVES, 1998) which attack other zooplankton organisms such as copepodites and cladocerans (HUTCHINSON, 1967) or even fish larvae (FARIA *et al.*, 2000; SANTEIRO and PINTO-COELHO, 2000). Few cyclopoids are sufficient to kill hundreds of larvae and post-larvae within a short period of time (WOYNAROVICH and HORVÁTH, 1983). These authors stated that a density of 100 copepods of the genus *Cyclops* L^{-1} can kill quickly 90 to 95% of the post-larvae stocked in nurseries. However, those organisms, even if they do not consume their prey instantaneously due to the differences in size of the latter, attach themselves to the larvae injuring their skin and fins and consequently causing their death (BEHR *et al.*, 1997). *Acanthocyclops vernalis* copepods have been reported to prey on *Alosa pseudoharengus* larvae (Figure 8) by HARTIG *et al.* (1982)

Figure 8. Three specimens of *Acanthocyclops vernalis* attacking a larva of *Alosa pseudoharengus - Adapted from HARTIG et al. (1982)*



According to SUKHANOVA (1965), predation by *Acanthocyclops vernalis* significantly affects the survival rate of silver carp larvae (*Hypophthalmichthys* sp) reared in Asia, while DAVIS (1959) mentions the predation of rockbass (*Ambloplites rupestris*) larvae. NIKOLSKI (1963) reported that shad larvae (*Alosa* sp) were attacked by *Mesocyclops* sp and *Acanthocyclops* sp.

BEHR *et al.* (1997) studied the predation of larvae of the Brazilian catfish *Pseudoplatystoma corruscans* by *Mesocyclops longisetus* at different densities (0, 10, 20, 30 and 40 ind. L^{-1}), observing the occurrence of predation of the larvae after 4 and 7 hours in the treatments with densities of 30 and 40 ind. L^{-1}, respectively, and after 25 hours all treatments involving copepods presented lower survival rates compared to control.

HARTIG *et al.* (1982) described the predation of alewife larvae (*Alosa pseudoharengus*) and spottail shiner (*Notropis hudsonus*) by cyclopoid copepods in Lake Michigan. The attack by the copepods *Diacyclops thomasi* and *Acanthocyclops vernalis* on larvae of six fish species in Lake Michigan and on larvae of five fish species in Lake Pigeon were studied by HARTIG *et al.* (1984). The highest predation rate (83%) was observed for *D. thomasi* attacking larvae of *Perca flavescens*. Also, according to HARTIG *et al.* (1984), the lower predation of other species is due to spatial and temporal synchronization of prey and predator, low probability that they will encounter each other, robust size of certain species of fish larvae, as well as their swimming capacity and ability to escape.

Some studies have suggested the hypothesis that the predation of fish larvae by copepods is related to larval size. According to SANTOS and GODINHO (1994), the susceptibility of *P. corruscans* larvae to the attack of cyclopoid copepods is related to the small size of the larvae that are born with 3.30 mm of total length and measure, on average, 5.50 mm by the forth day of life.

In an experiment evaluating the predation of pacu (*Piaractus mesopotamicus*) larvae by cyclopoid copepods (*Mesocyclops longisetus*) at different densities in environments with different visual contrasts (transparent or black walls), FARIA *et al.* (2001) observed lower survival rates of larvae in aquaria with transparent walls, indicating that *M. longisetus* kill more larvae in brighter environments, a fact related to prey visualization by the copepods. With respect to copepod density, FARIA *et al.* (2001) also observed a linear increase in predation rates with increasing densities starting three hours after the beginning of the experiment, with predation being more intense in aquaria with 30 copepods L^{-1}, although no mortality occurred in the aquaria without copepods.

Concerning the predation behavior, FARIA *et al.* (2001) observed that copepods attacked the larvae of *P. mesopotamicus*, catching and loosening after wounding them; however, very seldom the larvae were able to flee. On some occasions, the permanence of the copepod attached to the larva was longer after the attacks and the almost dead larvae were attacked by various copepods.

FINAL CONSIDERATIONS

The availability of plankton organisms of adequate size, density and quality is a relevant factor in the determination of the recruitment of young fish forms.

Fish in the early phases of development select the food organisms available in a positive or negative manner as a function of larval size/prey size ratio, pigmentation, mobility and escape capacity, body protection and palatability of the prey as well as its availability.

Fishes in the early life phases of development have a significant impact on the zooplankton population and can drastically alter the density of the organisms of that community in natural environments and causes changes in the phytoplankton community and indirectly on the abiotic factors, determining the structuring of the plankton community, which varies according to the ontogenetic development of the fish.

The predation of *Plagioscion* fish larvae by cyclopoid copepods in certain environments can be an important parameter with impact on the recruitment of freshwater fish populations.

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