





Ichthyoplankton studies as referential for the management and monitoring of fishery resources in the Brazilian Amazon basin

Estudos ictioplanctônicos como referencial para a gestão e o monitoramento dos recursos pesqueiros na bacia Amazônica Brasileira

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Abstract: Studies on ichthyoplankton ecology become essential when one realizes the importance and influence of this component in dynamics, conservation, and maintenance of fishery resources. However, ecological information about this subject is still scarce and has not been properly valued and used by environmental managers and decision-makers. In this study, we present the state of the art of research on ichthyoplankton in the Amazon region. The number of studies has been increasing over time but they are scarce and restricted. We hope this study may encourage research related to ichthyoplankton in the Amazon region.

Keywords: fish eggs and larvae; ecological studies; Amazon; north region of Brazil.

Resumo: Os estudos sobre ecologia do ictioplâncton tornam-se essenciais quando se percebe a importância e influência deste componente na dinâmica, na conservação e na manutenção dos recursos pesqueiros. Porém, informações ecológicas desta natureza ainda são escassas e não têm sido devidamente valorizadas e utilizadas por gestores ambientais e tomadores de decisão. Neste ensaio apresentamos o estado da arte das pesquisas ictioplanctônicas na região Amazônica. O número de estudos vem aumentando com o decorrer do tempo, mas ainda são insuficientes e poucos abrangentes. Espera-se que esse trabalho sirva para valorizar o conhecimento e incentivar os estudos e pesquisas relacionadas ao ictioplâncton na região amazônica.

Palavras-chave: ovos e larvas de peixes; estudos ecológicos; Amazônia; região norte do Brasil.



1. Introduction

In the Amazonian context, the fish are among the main sources of food supply for the human riverside populations (Doria et al., 2012; Lima et al., 2012). They are exploited by artisanal fishing and directed to local consumption or, to a lesser extent, for export. Fishing in the Amazon is still one of the traditional activities of greater social expression, source of employment and income of the sector (Almeida et al., 2009, 2010; Zacardi et al., 2014; Corrêa et al., 2018). Therefore, it is essential to know the species and their stocks in all phases of the life cycle, in order to subsidize appropriate management measures.

A large portion of freshwater fish, mainly migratory species, are widely exploited and account for more than 80% of catches throughout the Amazon (Goulding et al., 2019). Most representatives of this category have eggs and larvae diverting in open waters (Araújo-Lima & Oliveira, 1998; Nakatani et al., 2001; Orsi et al., 2016), which interact with predators and planktonic prey (Nascimento & Araújo-Lima, 2000). These initial forms, known as ichthyoplankton, are sampled with plankton nets or traps specially designed for this purpose, and their presence in the samples is related to the reproductive activity of adults.

Knowledge of the initial phase of the fish life cycle, in addition to clarifying fundamental aspects of life history, also provides important information on reproductive periods, spawning grounds, nurseries, and growth, as well as understanding fluctuations in population dynamics. Furthermore, it allows to estimate migratory routes, the potential for renewal (successful recruitment), to evaluate the conservation status of the species and to assist the maintenance of fishery stocks (Nakatani et al., 2001; Cruz et al., 2016), which can be used to guide management and conservation efforts.

The research was conducted using the three main ecology databases: Aquatic Sciences and Fisheries Abstracts (ASFA), Web of Science (WOS) and Google Scholar. Those included in the search went through May 2019. The search terms used were: (“Ichthyoplankton” OR “fish egg * and larvae” OR “fish * larvae *”) AND (“Amazon” OR “Amazon river” OR “Amazon floodplain”). A few articles that involved studies with eggs and larvae of freshwater environment fish in the Amazon region were selected.

After sorting the articles using the aforementioned criteria, searches performed in locations other than the Amazon region were eliminated. It is also

noteworthy that some of the articles found did not fit the research, so they were excluded. The database searches yielded 86 articles, however, only 20 articles containing information on ichthyoplankton in the Amazon region were selected.

Despite the relevance, existing scientific information about this planktonic community is insufficient, diffuse and very recent, especially in the natural environment in the Amazon (Figure 1).

Researches, so far, estimate the distribution, abundance variation, diversity and the structure of this community, being some works of the description of initial ontogeny of native species.

The radical ontogenetic morphological transformations that many fish species undergo during the early stages of development and the high biological diversity of the ichthyofauna are known to make the taxonomic identification of fish larvae a difficult and complex task. One difficulty is the high similarity between different species with overlaps between some diagnostic characters and broad morphological variation, when compared to adult individuals (Bialetzki et al., 1998; Nakatani et al., 2001). For example, *Pachypops fourcroyi* (Lacepède, 1802) larvae present mentonian dewlap in the beginning of the larval stage and lose this structure along their development (Chaves et al., 2019). Due to insufficient morphological diagnostic characters, fish larvae are easily misidentified, which makes taxonomic results from different laboratories often inconsistent (Ko et al., 2013).

Moreover, it is only possible to differentiate fish eggs as belonging to species of the Sciaenidae family, or migratory and non-migratory, since the presence of oil drop and the distance from the perivitelline space are the only diagnostic features available (Nakatani et al., 2001; Orsi et al., 2016).

In this sense, descriptions, identification keys, and illustrations are ways of reaching a specific

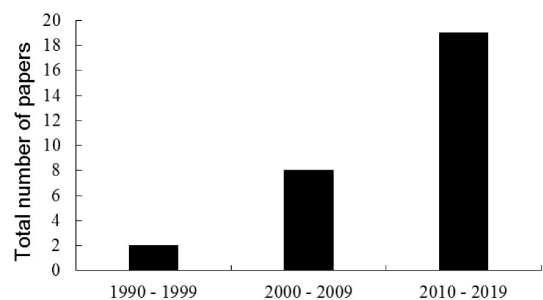


Figure 1. Total number of articles on abundance and space-temporal distribution of ichthyoplankton in the Brazilian Amazon basin, published in the last decades in national and international journals.

level. But specialized literature is often scattered in isolated and/or restricted access publications. In addition, the scattered and incomplete nature of the descriptions has imposed limitations and influenced negatively the development of ichthyoplankton studies (Nakatani et al., 2001; Cruz et al., 2016; Zacardi & Bittencourt, 2017), hampering fisheries management and successful conservation strategies (Maggia et al., 2017).

Due to the great importance of fishery resources for the Amazon and the need to expand the basic knowledge on fish larvae identification, characterization works of the larval development initial phases were developed in the Central Amazon region. However, they were focused only on Characiformes, such as larvae of jaraqui-escamagrossa, *Semaprochilodus insignis*, pacus, *Mylossoma aureum* and *M. duriventre* and branquinhas *Potamorhina latior*, *Psectrogaster amazonica* and *Potamorhina altamazonica*, among others (Araújo-Lima, 1985, 1991, 1994; Araújo-Lima & Donald 1988; Araújo-Lima et al., 1993; Nascimento & Araújo-Lima, 1993). These studies considered morphological characters, pigmentation patterns and a number of myomeres counting, even occurring, in many cases, an overlap of the number of muscular segments, and provided a leap in regional researches.

Additionally, in 2007, 10 species of larvae of migratory catfish from the Amazon basin belonging to the Pimelodidae family (Leite et al., 2007) were described. Subsequently, the larval development stages of two sympatric and congeners species of Siluriformes from Rio Negro (Amazon basin), known regionally by maparás *Hypophthalmus fimbriatus* and *H. marginatus* (Oliveira et al., 2008) were described.

However, studies of this nature may still be considered incipient if we consider the biodiversity of fish species in the region. The Amazon Basin is estimated to contribute significantly to the diversity of world freshwater fish, with about 2,716 valid species, of which 1,089 (45%) are unique to this Basin (Dagosta & Pinna, 2019). However, approximately 3% of these fish species (53) have their initial development described. This precariousness compromises the realization of ecological works since the correct identification of the species is an essential tool for the understanding of the composition, structure, distribution and dynamics of the species in the environment.

Due to insufficient morphological diagnostic characters, fish larvae are easily misidentified, which

makes taxonomic results from different laboratories often inconsistent (Ko et al., 2013). However, molecular techniques (DNA barcodes) have emerged as an alternative approach and a highly accurate tool for species identification, using high throughput batch larval sequencing. This method allows the acquisition of large data sets, paving the way for a better understanding of the reproductive dynamics and recruitment patterns of tropical fish species, with important implications for fisheries management and conservation (Maggia et al., 2017), but DNA barcoding can be time-consuming and costly.

In recent years, studies are emerging with protocols that represent a considerable advance in studies on ichthyoplankton, allowing for a fast, cost-effective qualitative and quantitative approach that improves identification accuracy (Ko et al., 2013; Becker et al., 2015; García-Dávila et al., 2015; Maggia et al., 2017; Almeida et al., 2018; Nobile et al., 2019). Nevertheless, different studies considering identification with morphological approaches alone have been able to reveal interesting patterns.

2. Ichthyoplankton Distribution and Its Relationship with Migratory Dynamics

The first ecological research with fish larvae in the Amazon basin was performed by Araújo-Lima (1984) who studied the spatial and temporal distribution of Characiformes larvae near Manaus (AM). This author and others such as Araújo-Lima & Oliveira (1998), Oliveira & Araújo-Lima (1998), Lima & Araújo-Lima (2004), Ponte et al. (2016, 2017, 2019), Zacardi et al. (2017a, b, 2018), Cajado et al. (2018) and Carvalho et al. (2018), recorded higher occurrences and distribution of eggs and larvae of migratory Characiformes deriving in several sectors of the Solimões/Amazonas river and other tributaries (Oliveira & Ferreira, 2008; Zacardi & Ponte, 2016) during the first months of the year, coinciding with the beginning of the annual flood and with the spawning period of several species of this group.

In most cases, the adults spawn in white water rivers and the larvae reach the marginal zones and areas of floodplain (canals, holes, multichannel and lakes), by means of passive transport (chains) or active swimming (Oliveira & Araújo-Lima, 1998; Oliveira, 2000; Mounic-Silva & Leite, 2013; Zacardi et al., 2017a, c; Ponte et al., 2019). Although white water rivers are considered favorable to the development of fish larvae (due to their high

concentration of nutrients), in their main channel there is not enough biological production to keep the larvae (Forsberg, 1985; Leite & Araújo-Lima, 2000, 2002).

For this reason, Characiformes larvae depend on entering floodplain areas which are adjacent to the main river, because these environments, during the flood period, offer greater expansion of refuge and foraging places, which enables better larval development conditions (Leite & Araújo-Lima, 2002; Leite, 2004; Leite et al., 2006; Soares & Leite, 2013). These factors characterize these environments as the main natural breeding sites for migratory fish species and for sedentary and small species (Ponte, 2017). These studies also evidenced the importance of connectivity between the nutrient-rich and poor rivers with the floodplains, which occupy a region of approximately 2 million km², about one-third of the Amazon Basin (Goulding et al., 2019), reinforcing the relevance of the floodplain for the conservation and maintenance of these fishery resources (Zacardi et al., 2018; Ponte et al., 2019).

Among the Siluriformes group, migrations of catfish species of the genus *Brachyplatystoma* define a large-scale longitudinal link that unites the breeding and spawning areas (on the slopes of the Andes), the pre-adult feeding areas (the Amazon river channel) and the nursery and growth areas (Amazon estuary region), surpassing state and international borders (Barthem & Goulding, 1997; Leite et al., 2007; Barthem et al., 2017).

The transport and dispersion of this catfish genus' larvae occur in the deep layers of the river Solimões/Amazonas main channel (Leite et al., 2007), and that ensures a higher probability for these individuals to reach feeding and growth areas in the estuary, as proposed by Barthem (1984) and Barthem & Goulding (1997). Unfortunately, there is little information about the downward migration processes of these eggs and larvae in the river channel.

According to Leite et al. (2007), the zones between 400 and 800 meters of altitude, that have high turbulence, seem to present appropriate conditions for the spawning and development of larvae of this *Brachyplatystoma*. The eggs remain and develop in the channel while they are carried downstream, going through all the larval phases before arriving in the estuary, with no need for the environments in the alluvial plain.

However, unlike the group mentioned above, *Pseudoplatystoma* species perform shorter reproductive migrations in tributaries of clear, black

and white Amazonian rivers (Leite et al., 2007; Pareja-Carmona et al., 2014a, b; Chaves et al., 2017). Unfortunately, there is still little information to explain these processes and migration patterns of these species.

According to Cañas & Waylen (2012) the survival of catfish species (Pimelodidae) depends on two important displacements during different stages of their life history, both strongly related to flooding time and connectivity of the entire Amazonian water system, or that is, any changes in the flow rate of interruption of the main river connection will not only endanger the populations of these catfish but will also influence the survival of other fish species, which depend on the lateral connection between the river channel and the flooding plains areas.

However, these long-distance migrations in the life cycle are threatened by human activities such as predatory fishing and the construction of hydroelectric dams, which severely limit larval recruitment and renewal of fishery resources (Maggia et al., 2017), as already observed in several rivers in Africa, Asia and Latin America (McCully, 2001; Poulsen et al., 2002; Dugan et al., 2010) and in other Brazilian basins (Merona et al., 2010; Schork et al., 2012; Santana et al., 2014; Nogueira & Magalhães, 2016), with significant effects on migratory fish fauna and fishing productivity.

3. Determinant Factors of Ichthyoplankton Abundance and Their Relation to Fishery Production

Studying the interannual variation in the recruitment of pacu larvae (*Mylossoma*) in the lower Amazon, Zacardi et al. (2018) indicated a high relation of the landed production with the abundance of larvae in the river. Thus, the intense fishing effort undertaken on the adults and the failure in the process of managing the sustainable use of fishery resources in the region can lead to depletion of the spawning stocks. Consequently compromising the annual recruitment of species, the commercial viability of fisheries and culminating in social and economic losses for the entire lower Amazon.

Variations in the distribution of larval abundance within nursery areas, including seasonal distributions, differ between groups of species and, the synergistic effect of extreme environmental events and fishing may increase the likelihood of fish populations collapse. Ponte et al. (2019) recorded a higher abundance of Characiformes larvae during the flooding period, of Acanthuriformes in the

ebb period and of Clupeiformes at the end of the dry period and during the dry season. Thus, each order presented different behavior and their occurrence was linked to the seasonality of the local hydrological cycle.

The flooding time and the dry season are the main periods for the reproductive activity of most fish species in floodplain systems in the Amazon (Röpke et al., 2016, 2017). They should continue to be the essential moments of protection for adults, which due to the interannual variations of hydrological conditions, especially events of strong droughts and weak and short floods may result in a lower reproductive investment by females.

Therefore, future measures of management, conservation, and planning of these fishery resources should consider: i) the moments of the hydrological cycle; ii) the oscillation of the river quotas; iii) their relations with the abundance of larvae; iv) the biological recruitment of several fish species; and v) the maintenance of the riverside and floodplain environments integrity. These initiatives can contribute to strengthening the sustainability of ecosystem services and to ensure that Amazonian environmental assets (e.g. reproduction, establishment and growth of numerous fisheries stocks) are available in the future.

4. Final Considerations

Despite the low number of studies and the lack of information on ichthyoplankton of various species and regions of the Amazon, the volume of produced data is already of great value and indicates the need to develop more robust management and conservation plans. Especially for large migratory catfish, both interstate and transnational levels should be included in the plans because their life strategy is connected to the wide Andes-Amazonian estuary migratory movement. These plans are vital to maintaining the sustainable exploitation of these resources.

On the other hand, for other groups of fish, such as migratory Characiformes and groups of catfish with a life strategy linked to lowland rivers and lakes (exploited by multispecific commercial fishing aimed at supplying regional urban centers), management proposals should include the local responsibility for the resources ordering, co-management.

Finally, we conclude that the research on ichthyoplankton in the Amazon basin is important and relevant for the human riverside populations. Besides, Amazon presents the world's greatest ichthyodiversity and it has been suffering great

anthropic pressure. Therefore, the studies should aim to support decision-making, helping to promote environmental sustainability with management plans and policies aimed at the maintenance and planning of fisheries. Hence, ensuring food security and the reduction of possibly irreversible damage to these natural resources.

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