Feeding, reproduction and population structure of *Pimelodus maculatus* Lacépéde, 1803 (Teleostei, Siluriformes, Pimelodiae) from Paraná basin: a review.

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Abstract

The aim of this review is to present data regarding the feeding, reproduction, population structure of *Pimelodus maculatus* (Siluriformes, Pimelodidae). Forty two scientific manuscripts from 24 journals and 17 book chapters were analyzed from the years of 1951 to 2009. This species has type locality at the River Plate, Argentina, and have a wide geographical distribution in South America, being one of the most abundant species of the Paraná River basin, and an important constituent of the fish fauna of streams, rivers, and lentic waters (including large reservoirs). *P. maculatus* is characterized as a omnivorous species, with a large plasticity of feeding habits, being able to feed on vegetal matter, invertebrates, insects and fish. Due to this opportunistic behavior, some authors argue that *P. maculatus* is able to explore almost all trophic levels of aquatic freshwater ecosystems. In addition, it is considered a migratory species, able to perform migrations of up to 1,000 km; however, the physiological demands related to reproductive success are much smaller. The period of reproduction varies slightly according to the environment, but is always from October to March, a period corresponding to higher rainfall in the region of the Upper Paraná basin. Based on all information revised, *P. maculatus* has characteristics that allow it to adjust in different manners to environmental conditions, in different locations in natural geographical distributions.

Key-words: Upper Paraná River basin, ecology, feeding, reproduction, growth, mandi-amarelo.

Resumo

O objetivo desta revisão é apresentar dados referentes à alimentação, reprodução e estrutura populacional de *Pimelodus maculatus* (Siluriformes, Pimelodidae). Foram analisados 42 artigos científicos oriundos de 24 periódicos e 17 capítulos de livros entre os anos de 1951 a 2009. Esta espécie tem como localidade tipo o rio da Prata, Argentina, tendo ampla distribuição geográfica na América do Sul. Ainda, é uma das espécies mais abundantes na bacia do rio Paraná e um importante constituinte da ictiofauna de riachos, rios e represas. *P. maculatus* é caracterizada como espécie de hábito alimentar onívoro, com grande plasticidade alimentar, podendo se alimentar de vegetais, invertebrados, insetos e peixes. Devido a este comportamento oportunista, alguns autores relatam que *P. maculatus* pode explorar todos os níveis tróficos dos ecossistemas aquáticos. Também, é considerada uma espécie migratória, podendo realizar migrações de até 1.000 km. Entretanto, suas necessidades fisiológicas para obter sucesso reprodutivo são muito menores. O período de reprodução apresenta pouca variação de acordo com o ambiente, sendo sempre entre os meses de outubro a março, período chuvoso na região da bacia do alto Paraná. Baseado nestas informações, concluí-se que *P. maculatus* possui características que permitem um bom ajuste para diferentes condições ambientais, em diferentes locais de sua distribuição geográfica natural.

Palavras-chaves: bacia do alto rio Paraná, ecologia, alimentação, reprodução, crescimento, mandi-amarelo.

Introduction

The bony fish form the largest class of vertebrates, with about 24,610 known species, distributed in 57 orders, 482 families and approximately 4,258 genera (Nelson, 2006). According to Reis *et al*. (2003), there are approximately 13,000 freshwater species, and about 6,000 of these are found in the Neotropical region. The Siluriformes order constitutes over 2,400 species, distributed in 34 families and 412 genera, and occurs in all continents except the Antarctica (Helfman *et al.*, 2009; Nelson, 2006). Over 40% of species are in the Neotropical region and many of these are in the Amazon (Py-Daniel and Cox-Fernandes, 2005). The Pimelodidae family includes about 50-60 genera and 300 species (Mees, 1974), but some taxonomic doubts still persist regarding this family.

This highly diversified family of Neotropical Siluriformes has a wide distribution in the freshwater of Central and South America. Among freshwater Neotropical fish fauna, Pimelodidae is the most diverse group of catfish, with 29 genera and 94 endemic species (Ferraris, 2007; Lundberg and Littmann, 2003), and the genus *Pimelodus* is the most diverse, with 29 species (Ribeiro *et al.*, 2008), including *Pimelodus maculatus*, first described in 1803 by Lacépède, and identified in the River Plate, Argentina (Fowler, 1951).

The aim of this review is to present data regarding to the biology of *Pimelodus maculatus* (Siluriformes, Pimelodidae), including aspects of feeding, reproduction and population structure. Forty two scientific manuscripts from 24 journals and 17 book chapters were analyzed from the years of 1951 to 2009. The majority of the studies published on the biology and ecology of this species, referred to in this review, are based on studies in the Paraná River basin that is part of the Plate River Basin.

External Morphology

According to Britski *et al.* (1999), *Pimelodus maculatus* presents a naked body (without scales), high anterior dorsal profile, and a dorsal head surface covered with a thin, wrinkled skin. It has three duplet (maxillary and mentonian) barbells, and the maxillary barbell extends to beyond the base of the caudal fin in the young fish, but does not reach the base of the caudal fin in specimens of above 15 cm. The adipose fin base is short, and its length is smaller than the distance between the tip of the snout to the back of the orbit. There are three to five sets of large maculae along the body, and a dark maculae is often present at the dorsal, adipose and caudal fins, also occurring sporadically on the pectoral, ventral and

anal fins. The maximum total length of this species registered is 44 cm (Barbosa *et al.*, 1988). The mouth is terminal with numerous small and long teeth on both jaws; the dorsal fin of this species is well evident with anterior spine and five to seven soft rays (Figure 1).

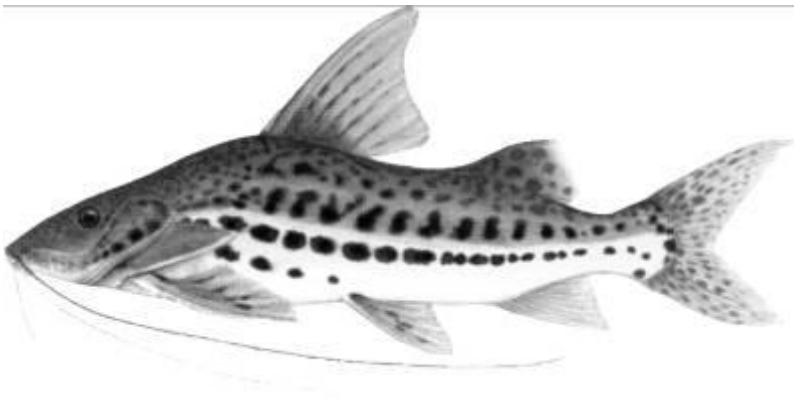

Figure 1. Illustration of *Pimelodus maculatus.* Source: Britski *et al.* (1999).

Geographic distribution

Pimelodus maculatus is a species of wide geographical distribution in South America, found in Paraná and São Francisco river basins (Reis *et al.*, 2003) (Figure 2). It is one of the most abundant species of the Paraná river basin and an important constituent of the fish fauna of streams, rivers (Lima-Junior and Goitein, 2006; Lobón-Cervia and Bennemann, 2000; Lolis and Andrian, 1996) and lentic waters, including large reservoirs (Agostinho *et al.*, 2007; Agostinho *et al.*, 1997a; Agostinho *et al.*, 1997b; Alves *et al.*, 1998; Braga, 2001; Braga and Gomiero, 1997; Suzuki *et al.*, 2005). In northeastern Brazil, *P. maculatus* was introduced into ponds and small reservoirs in 1934, when experimental stock programs were taken by the Technical Committee for Fisheries of the former Federal Inspectorate for Works Against Drought, increasing its area of distribution (IFOCS, 1940, *in* Barbosa *et al.*, 1988).

Figure 2. The geographic distribution of *Pimelodus maculatus* in South America.

Feeding and digestive system

According to Santos *et al.* (2007), the digestive system of *P. maculatus* presents a bucofaringean cavity, folded lengthwise, and mucosa with stratified squamous epithelium. The esophagus has the same type of epithelium, with a predominance of mucous cells. The stomach is differentiated by a cardial, fundial and pyloric region with the mucosa continuously covered by a simple cylindrical epithelium; the inner layer has tubular glands that branch gradually and contain oxinticopeptic cells, related to the synthesis of chloridric acid and pepsinogen. The intestinal villi are lined by a simple cylindrical epithelium with goblet cells, alternated with this same type of epithelium without goblet cells.

Godinho (1967), Lolis and Andrian (1996) and Menin and Mimura (1992) suggested that the morphological characteristics of this fish species are associated with their feeding tactics, allowing the omnivorous feeding plasticity observed in *P. maculatus*. According to Luz-Agostinho *et al.* (2006), this species displays few morphological restrictions for the

capture of the food, since it eats detritus, animals and plants from a wide range of sizes, shapes and habitats.

P. maculatus is characterized as a generalist omnivorous species, with a large plasticity of feeding habits, and its diet may comprise vegetal matter (seeds, fruits, other parts of higher plants and algae), invertebrates (worms, mollusks and arthropods) and fish (Baiz and Cabrera, 1968; Basile-Martins *et al.*, 1986; Bonetto, 1963; Hahn and Fugi, 2007; Lobón-Cervia and Bennemann, 2000; Lolis and Andrian, 1996; Nomura *et al.*, 1972; Resende, 2000; Silva *et al.*, 2007). Some authors, Callisto *et al.* (2002), Lobón-Cervia and Bennemann (2000), Lolis and Andrian (1996) and Silva *et al.* (2007) argue that *P. maculatus* is able to explore almost all trophic levels of aquatic freshwater ecosystems. Furthermore, around the cage fish farms system of large reservoirs of Brazil, their feeding tactics can adjusted to allow them to feed on artificial food wasted by operation of this cage farms, reaffirming the opportunistic behavior this fish species (Ramos, 2009). Ramos (2009) reported the presence of remains of ration originated from aquaculture in the stomach of specimens caught near the cage fish farm system in the Chavantes Reservoir, Paranapanema River basin, demonstrating once more the opportunistic behavior of this species.

Another important aspect is the ontogenetic diet shift, where the smaller individuals consume mainly Chironomidae (larvae and pupae) and small benthic organisms, whereas larger individuals incorporate larger prey such as fish and crustaceans in their diet (Basile-Martins *et al.*, 1986; Lima-Junior and Goitein, 2003; Silva *et al.*, 2007). According with Lima-Junior and Goitein (2003) ontogenetic change in diet is related to the increase in the size of the mouth, and consequent ingest of larger prey. Lima-Junior and Goitein (2003), argue this diet shift is related to the use of the barbell in the chemical orientation of small fish, while larger fish still use the chemical approach, but present a developed visual orientation.

The feeding activity of *P. maculatus* increases in the morning and before sunset, and decreases in the evening (Lolis and Andrian, 1996). This behavior allows the species to explore organisms that are active during the day and night, with a feeding peak at between 8:00h and 12:00 h PM (Lolis and Andrian, 1996). DE Croux (1996) reported that, during the period of low light, *P.maculatus* presents high movement and feeding activity. *P. maculatus* shows an increased feeding activity before the start of gonadal maturation and during autumn and winter, as observed by Andrade and Braga (2005), Basile-Martins *et al.* (1986), Bennemann *et al.* (2000), Lima-Junior and Goitein (2004) and Lolis and Andrian (1996).

The determining factor for the diet of *P. maculatus* is the availability of resources, since the species is known for its opportunistic behavior (Andrade and Braga, 2005; Callisto

et al., 2002; García and Protogino, 2005; Lolis and Andrian, 1996; Montalto *et al.*, 1999; Silva *et al.*, 2007). Thus, due to all these ecological attributes related to feeding, this species can rapidly take advantage of temporary abundant food resources. Lobón-Cervia and Benneman (2000) argue that *P. maculatus* have seasonal and environmental specific dietary tactics, depending on the availability of food resources. García and Protogino (2005) and Montalto *et al.* (1999) showed a high incidence of exotic mollusks (*Limnoperna fortunei* (Dunker, 1857) and *Corbicula fluminea* (Müller, 1774), respectively) in the diet of specimens from the middle Paraná River and the Plate River.

Reproduction and reproductive system

In regard to reproductive tactics, *P. maculatus* females have a higher average length than males (Barbosa *et al.*, 1988; Basile-Martins *et al.*, 1986; Braga, 2000; Fenerich *et al.*, 1975); the largest recorded length is 44 cm for females and 38 cm for males (Barbosa *et al.*, 1988). The size of first gonadal maturation is variable, depending on the environment (Table 1). Thus, it is evident that the *P. maculatus* life cycle fits into environmental variations, and affects the size of first sexual maturation.

Table 1. Length of first gonadal maturation of *Pimelodus maculatus* in different sites.

	Size at first maturation		***Maximum length***
Location	***Males***	***Females***	***Males + Females***
Jaguari river (Total length)	18,0 cm	19,0 cm	41,5 cm
Bariri reservoir (Total length)	12,5 cm	12,0 cm	45,0 cm
Volta Grande reservoir (Total length)	25,5 cm	27,8 cm	43,4 cm
Corumbá reservoir (Standart length)	15,6 cm	17,8 cm	37,5 cm

Jaguari river ➔ Fenerich *et al*. (1975); Bariri reservoir ➔ Barbosa *et al*. (1988); Volta Grande reservoir ➔ Braga (2000); Corumbá reservoir ➔ Deitos *et al*. (2002).

This species is a dioecious, with pairs of testes or ovaries located in the dorsal portion of the abdominal cavity, just below the kidney and swim bladder (Cruz and Santos, 2004; Godinho *et al.*, 1974). Testicles are fringed, with 73 to 132 fringes, being more abundant in mature testes than during other stages of maturation (Cruz and Santos, 2004). Spermatogenic activity takes place in the cranial region of the testes, while the caudal portion has secretory function (Cruz and Santos, 2004). For females, Godinho *et al.* (1974) reported that the color

of the ovaries varies from slightly pink (at recovery and/or immature), to yellowish (in maturation or mature), and slightly brown (after spawning). Mature oocytes have an average diameter of 290.99 μ and the amplitude varies from 109 to 984 μ being eliminated with 700 a 800 μm of diameter (Godinho *et al.* 1974). Their relative fecundity (number of oocytes in relation to total length) increases gradually with the length of the individual and is approximately 200 x 10^3 oocytes for females of near 36 cm total length (Godinho *et al.* 1974).

P. maculatus is considered a migratory species (Deitos *et al.*, 2002), and can perform migrations of up to 1,000 km (Bonetto, 1963; Godoy, 1967), however, according to Agostinho *et al.* (2003) and Doria and Andrian (1997), the physiological demands related to migration for reproductive success are smaller. The period of reproduction varies slightly according to the environment, but is always from October to March, a period corresponding to higher rainfall in the region of the Upper Paraná River basin (Table 2).

Table 2. Reproductive period of *Pimelodus maculatus* in different environments.

Authors	**Location**	**Reproductive period**
Basile-Martins *et al.* (1975)	Jaguari River	October - December
Godinho *et al.* (1977)	Jaguari River	December - February
Vazzoler *et al.* (1997)	Paraná River Basin	October - March
Braga (2000)	Volta Grande Reservoir	October - February
Deitos *et al.* (2002)	Corumbá Reservoir	November - January
Lima-Junior and Goitein (2006)	Piracicaba River	Spring - Summer
Bazzoli *et al.* (1997)	Marimbondo Reservoir	Whole year

Braga (2001), Deitos *et al.* (2002), Maia *et al.* (2007) and Ramos (2009) reported that *P. maculatus* do not spawn in lentic areas, moving to lotic places during the reproductive period. Thus, these authors inferred that the species probably uses the lentic areas of reservoirs for feeding and growth while lotic areas are used for reproduction. *P. maculatus* females are partial spawners, displaying the maturation of different groups of oocytes during the reproductive period (Basile-Martins *et al.*, 1975; Bazzoli *et al.*, 1997; Godinho *et al.*, 1974, 1977; Hirt *et al.*, 2005) and not providing parental care (Agostinho *et al.*, 2003). According to Basile-Martins *et al.* (1975), oocyte maturation starts at temperatures of around 22 ºC, and spawning occurs at temperatures of near 25 ºC, when the river level ascends in about one meter. Additionally, this species prefers slightly acid waters for reproduction, with

high concentrations of dissolved oxygen. These conditions are normally found only in the downstream or lotic portions of the reservoirs (Deitos *et al.*, 2002).

Thus, the fact that the species does not reproduce in the main body of the reservoirs may be related to the absence of appropriate environmental conditions; furthermore, the reproductive success of *P. maculatus* must be related to the presence of appropriate sites in the upper portions of the reservoirs, where favorable lotic conditions are found, even in smaller tributaries.

Population structure

Populations of *P. maculatus* present sex ratios (female/male) of 1:1 in the Jaguari, Tietê, and São Franscisco rivers (Barbosa *et al.*, 1988; Basile-Martins *et al.*, 1986; Brasil-Sato and Pavanelli, 2004, respectively) to 1.5:1 and 2.23:1 in the Paraná and Piracicaba rivers, respectively (Lima-Junior and Goitein, 2006; Brasil-Sato and Pavanelli, 2004). Thus, the species also displays spatial variations in sex ratios, in response to local environmental conditions, as observed previously for the onset gonadal maturation.

According to Basile-Martins *et al.* (1986) and Deitos *et al.* (2002), *P. maculatus* presents spatial stratification of the population in relation to age and length. In lentic waters (floodplains and reservoirs), there is a higher frequency of young individuals, while in lotic sites, adults and larger individuals are more abundant. Data on the growth rate of *P. maculatus* are scarce in the literature, where only two reports exist. Fenerich *et al.* (1975) showed a slightly higher growth rates for males (0.21) than females (0.19) in the Jaguari and Piracicaba rivers. However, Braga (2000) reported that females have a higher growth rate (0.43) than males (0.35), in the Grande River. These authors also present data on the age structure of *P. maculatus*. Fenerich *et al.* (1975) observed that males can reach a maximum of four years and females, six years old, while Braga (2000) observed males with a maximum age of three and a half years and females of five years. These results infer that males have a shorter lifespan than females.

Concluding remarks

Based on all the revised information, *P. maculatus* has characteristics that allow it to adjust in different ways to environmental conditions, in different locations in natural geographical distributions. Thus, this species is able to achieve a good fit to environments

with anthropogenic disturbances, increasing its abundance and distribution, as observed by Agostinho *et al.* (1999), after the formation of reservoirs for hydroelectric generation, such as Rosana, Três Irmãos and Corumbá. In addition, Zanatta (2007) and Ramos (2009) reported that this species is one of the most abundant in the area around cage fish farms of the upper and medium Paranapanema river basin, where, according to Ramos *et al.* (2009), these fish survive on the remains of artificial feed from the cage aquaculture. Thus, the biological and ecological characteristics of *P. maculatus* populations must be regarded as key elements to understanding the impact of human activities, such as cage fish farming and rivers damming, on the Neotropical ichthyofauna of the main South American fresh water ecosystems.

Acknowledgment

The authors thank the Universidade Estadual Paulista for support and CNPq for the scholarship granted for the first author.

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