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An overview of freshwater fish aging in South America: the science, biases and future directions

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ABSTRACT. South America harbors the largest freshwater diversity in the world (about 4,475 valid species). Aging studies of 153 species published in 92 papers were reviewed for this publication. They were categorized according to the journal where they were published, decade, number of researches per river basin, methods and structures most used to estimate age, validation methods, period and causes of the formation of the age ring and age of the fish in South America. Our results showed an increase in the studies of age and growth, especially in the Paraná river basin. Scales were the structure most used in the studies of aging. Most of the researchers did not validate age. On a continental level, there was no specific period for growth ring formation, but in general, it was related to reproductive activity and flooding period. South American freshwater fishes did not present high longevity (maximum of 15 years). The ongoing governmental support to the fishery in South America, such as in Brazil with the creation of the Ministry of Fishing and Aquaculture, will certainly enlarge the fishing industry. Thus, it is necessary to know and to evaluate the fishery stocks correctly in order to guarantee sustainable use.

Key words: age and growth of fishes, South American freshwater fishes.

RESUMO. **Uma visão sobre idade de peixes de água doce na América do Sul: a ciência, tendências e o futuro.** A América do Sul possui a maior diversidade de peixes de água doce do mundo (cerca de 4.475 espécies válidas). Para esta publicação, foi revisada a idade de 153 espécies de 92 artigos. Eles foram categorizados de acordo com o periódico, década, número de pesquisas por bacia hidrográfica, métodos e estruturas mais usadas para estimar a idade, métodos de validação, época e causas da formação do anel etário e idade dos peixes da América do Sul. Os resultados mostraram aumento de estudos de idade e crescimento, especialmente na bacia do rio Paraná. As escamas foram as estruturas mais usadas nos estudos considerados. A maioria dos pesquisadores não fez a validação da idade. Em nível continental não foi verificado um período específico para a formação dos anéis de crescimento, mas em geral, as marcas estiveram relacionadas com a atividade reprodutiva e ao período de cheias. Os peixes de água doce da América do Sul não têm elevada longevidade (máximo 15 anos). Na América do Sul, é esperado que a indústria pesqueira expandirá, pela criação de programas de incentivo, como a criação o Ministério da Pesca e Aquicultura no Brasil, e assim, será necessário conhecer e avaliar os estoques corretamente com o propósito de uso sustentável.

Palavras-chave: idade e crescimento de peixes, peixes de água doce da América do Sul.

Introduction

First efforts in establishing the aging and growth of freshwater fish in South America was carried out for *Salminus braziliensis* (Junior Synonym *S. maxillosus*) by Morais Filho and Schubart (1955). They comment that the scales were the easiest structures to study, in spite of the deformity problems and formation of false rings. In this pioneering work, they found 11-years old individuals in the Mogi Guassu river. The value of this historical registration was important because in other South American rivers, populations with ages varying between 5 and 8 years were found (BARBIERI et al., 2001; CASTAGNOLLI, 1971; DEI TOS et al., 2009; FEITOSA et al., 2004; SVERLIJ; ESPINACH-ROS, 1986). In that period, there was a concern in Brazil about using aging and growth studies to evaluate fishing stocks. There was a perception that decreases in the average size of the stock indicated overfishing and this is sign of the unsustainability of a greatly exploited fishery.

The ability to determine age of fish without bias is critical to effective management and research. Besides being used to estimate growth, age data are regularly used to assess fish population dynamics (growth, mortality and recruitment) and stock (ISELY; GRABOWSKI, 2007). The Neotropical region contains approximately 16% of all freshwater species (about 4,475 valid species; REIS et al., 2003) from a total species richness of about 27,977 valid species in the world (NELSON, 2006). A review of aging in South America was already made by Lizama and Vazzoler (1993), but they considered only 32 freshwater species, along with 27 marine ones. Only 0.7% of freshwater fish from South America had aging and growth reported before 1993.

This review purposed to answer the following questions related to the growth of fish in South America: I) Which are the structures used to estimate age? II) What are the methods used to determine age? III) What are the validation or corroboration methods used to estimate age? IV) What are the methods used to determine the formation period of the growth rings? V) Is there regularity in the formation period for growth rings in fish of South America? VI) What are the causes of the formation of growth marks? VII) What is the age variation by sex? The answers to these questions will identify gaps and will improve the state of knowledge on aging fish in South America, which certainly will contribute to the development of fishing management studies.

Material and methods

The review

To achieve our objectives, we included a large number of publications; however, we recognize that some papers were not considered. This review includes 92 publications (from 1971 to 2008), which emcompassed 153 species from the following river basins: Approuague, Sinnamary, Iracoubo, Cayenne, Kouron and Mana, Orinoco, Paraguay, Paraná, Plata, Uruguay and São Francisco (Amazonian, East, Northeast and Southeast basins).

The publications considered were: Castagnolli (1971), Cordiviola de Yuan (1971), Dourado et al. (1971), Nomura et al. (1972), Fenerich et al. (1975), Nomura (1975), Nomura and Chacon (1976), Nomura et al. (1978), Rodrigues et al. (1978), Nomura and Barbosa (1980), Nomura and Hayashi (1980), Nomura and Mueller (1980), Barbieri et al. (1981), Barbieri and Barbieri (1983), Barbieri and Barbieri (1984), Antoniutti et al. (1985), Lecomte et al. (1986), Sverlij and Espinach-Ros (1986), Barbieri and Santos (1987), Barbieri and Barbieri (1988a and b), Barbieri and Santos (1988), Barla et al. (1988), Nomura (1988), Barbieri (1989), Barbieri and Barbieri (1989), Barbieri and Cruz-Barbieri (1989), Barbieri and Afonso Marins (1990), Agostinho et al. (1991), Boujard et al. (1991), Carozza and Cordiviola de Yuan (1991), Gurgel and Barbieri (1991), Santos et al. (1991a and b), Santos and Barbieri (1991), Barbieri (1992), Giamas et al. (1992), Goulart and Verani (1992), Hartz and Barbieri (1993), Sverlij et al. (1993), Agostinho and Marques (1994), Gurgel and Barbieri (1994), Meunier et al. (1994), Barbieri (1995a and b), Giamas et al. (1995), Hartz and Barbieri (1995), Reina et al. (1995), Isaac and Ruffino (1996), Ambrósio and Hayashi (1997), Bruschi Junior et al. (1997), Braga (1998), Castro (1998), Hartz et al. (1998), Amaral et al. (1999), Araya (1999), Araya and Sverlij (1999), Braga (1999), Jepsen et al. (1999), Orsi and Shibatta (1999), Ruffino and Isaac (1999), Barbieri et al. (2000a, 2000b), Braga (2000), Lizama (2000), Loubens and Panfili (2000), Miranda et al. (2000), Ruffino and Isaac (2000), Arenzon et al. (2001), Barbieri et al. (2001), Braga (2001), Fernades et al. (2002), Loubens (2003), Ambrósio et al. (2003), Araya et al. (2003), Lizama and Ambrósio (2003), Feitoza et al. (2004), Lizama and Ambrósio (2004), Mateus and Petrere Junior (2004), Penha et al. (2004a and b), Angelini and Agostinho (2005), Araya et al. (2005), Cutrim and Batista (2005), González et al. (2005), Penha et al. (2005), Schulz and Leal (2005), Silva and Stewart (2006), Mateus and Penha (2007) and Araya et al. (2008).

Analysis

We grouped the publications according to journal, decade (date) and basin. This purposed to have a broad description of the growth studies conducted. In the compilation of the information on the structures used to estimate age, we considered the river basin. To summarize the information on the methods used to determine age, river basins and more than one method were considered. To verify the methods used to identify the period of the formation of the ring and validation of age more than one method was considered or the same species. To determine the causes of ring age formation, the analysis was made considering species and river basin and all the causes that determined the formation of the growth ring were evaluated. Finally, in the analysis of age variation by sex, species whose author analyzed more than one structure or different periods or places were also considered.

Results

Publications by journals, decades and river basins

The studies on age and growth of fish from South America were published mostly in journals (97.1%). The Brazilian Journal of Biology (former Revista Brasileira de Biologia) was the journal with the largest number of papers (15.2%), followed by Acta Scientiarum (former Revista Unimar; 13.0%) and Boletim do Instituto de Pesca (13.0%) (Figure 1).

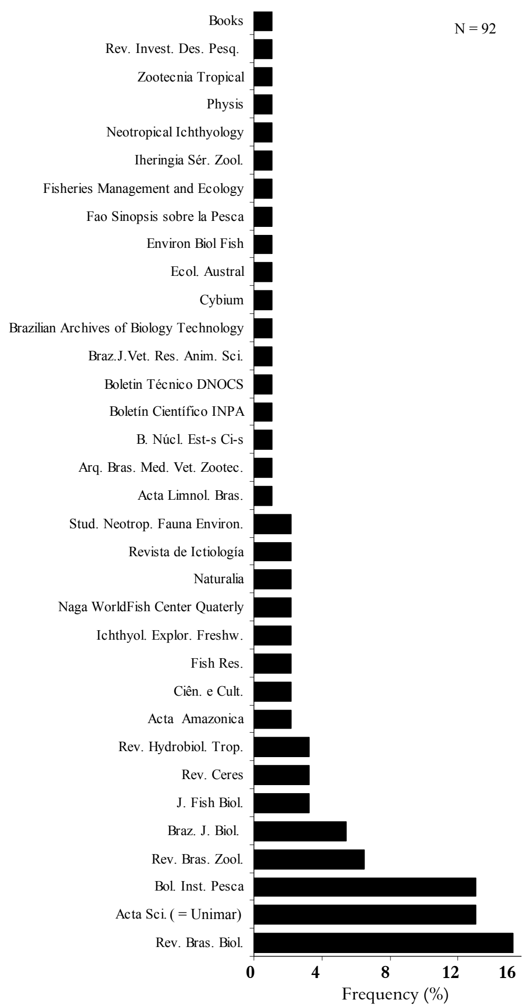

Figure 1. Relative (frequency) of papers by journals and books.

Out of the 92 publications analyzed, the greatest number dealing with age and growth of fish in South America was verified in the 1990s (38.0%), followed by 2000-2008 (32.6%) (Figure 2).

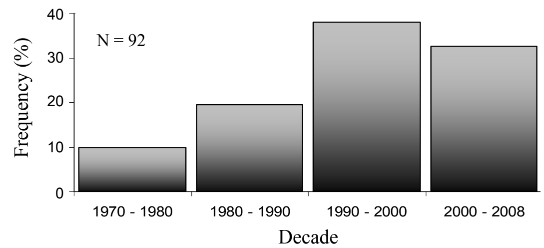

Figure 2. Number of publications (frequency) analyzed per decade.

When analyzing by basin, we noticied that most of the studies were conducted in the Paraná river (14.5%), followed by the Sudeste (6.8%) and Paraguay (4.7%). The Leste and Orinoco basins presented the smallest number of studies on age and growth (0.4% for each).

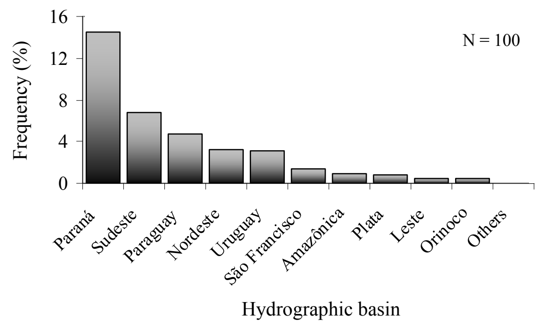

Figure 3. Frequency of studies analyzed by river basin (others=rivers from the French Guiana).

Methods for the determination of age

Calcified structures were used in most of the papers to determine age (58.6%), followed by the method of length frequency distribution (36.3%) (Figure 4).

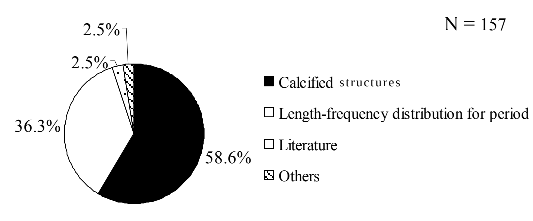

Figure 4. Number of papers (frequency) by the method used to determine age in South America. Others = length per gonadal maturation.

Structures of age estimate

Scales were the preferred structure to study age of fish (50.0%) in the papers, followed by otoliths and vertebrae (18.8% and 15.6%, respectively) (Figure 5).

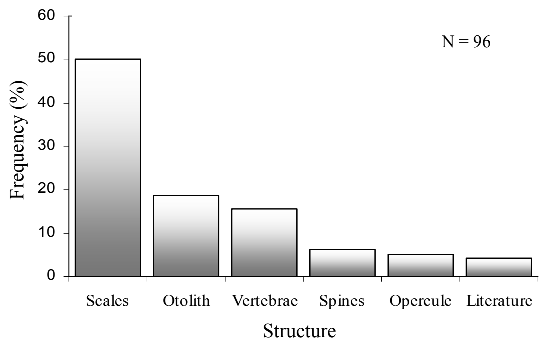

Figure 5. Number of papers (frequency) by bone structures used to estimate the age of fish.

Methods to validate age and to determine the period of formation of the age rings

There are misunderstandings in the literature regarding the distinctions between periodicity of growth increment formation, absolute validation and accuracy of age estimates (CAMPANA, 2001). This was also verified in some studies conducted in South American freshwater fish.

In South America, 52.9% of the aged species have not had their data validated, or presented any corroboration of age interpretation or determination of periodicity of growth increments in accordance with the recommendation made by Campana (2001). The mean length of the fish with the same number of rings per period, called an indirect method by some authors, was used to determine the period of formation of the growth rings and to validate the age of the fish population indirectly (19.6%). The analysis of marginal increment (18.3%) was also used, in general, to determine the period of formation of the ring, as well as the analysis of the opaque or translucent edge of the scale (5.9%) (Figure 6).

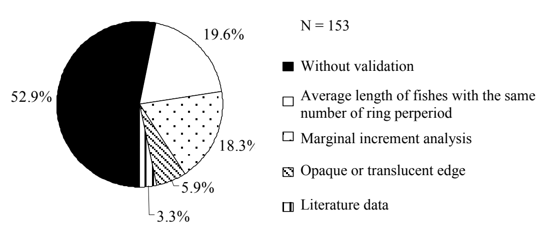

Figure 6. Frequency of the methods used in the works analyzed to determine the period of formation of the growth ring and to validate the age of fish in South America. (Indirect validation = average length of fish with the same number of rings per period; opaque or translucent edge per period).

Period and causes of age ring formation

It was evident that growth marks can be formed in any period of the year; however, the largest occurrence was found in October (9.3%), November (12.3%) and December (10.8%) (Figure 7). These months are characterized by high temperatures, longer days (photoperiod), beginning of the floods and the reproductive period for a great number of species. In addition, May and June (8.3%), when temperatures are lower, was also important for the formation of growth rings.

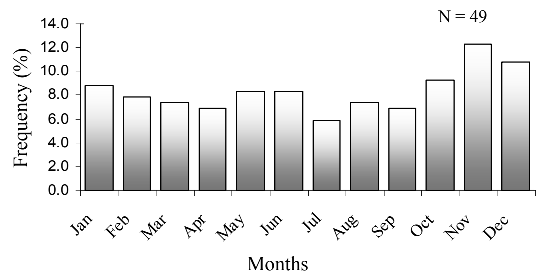

Figure 7. Percentage of the months of occurrence of formation of the growth marks recorded in the consulted publications.

Among the main factors that promoted the formation of growth rings, reported by the authors, was the reproductive period (40.7%) (usually in the summer), in which the species allocates energy for gonadal maturation, migration for displacement and spawnings, followed by fluviometric level (19.8%), which can influence the availability and abundance of foods, and low temperatures and feeding (12.3%), which in turn reduce the metabolic rate of the fish and then influence growth (Figure 8).

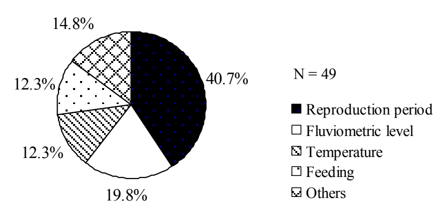

Figure 8. Main causes of growth ring formation. (Others = condition factor, pH, oxygen concentration and environmental conditions (dry period)).

Variation of age by sex

The range of variation in age per sex was the same (between 3 and 15 years). However, we noticed a great number of 5 years old males; whereas the 6 years old females (Figure 9). Thus, it is clear that the studies did not report a huge variation between the ages of the sexes.

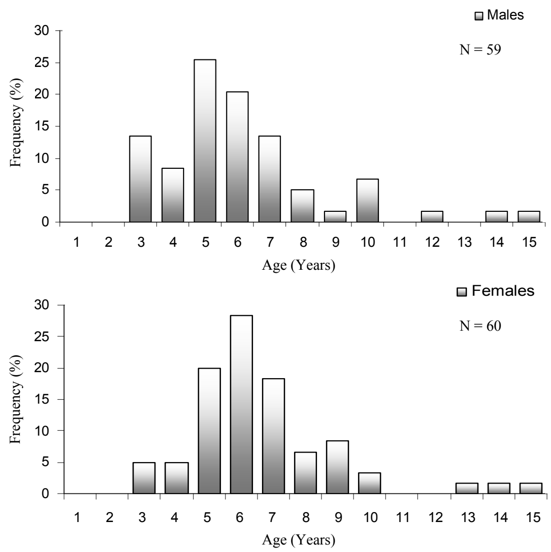

Figure 9. Percentage of the ages found in the analyzed studies.

Discussion

Aristotle (340 BC) seems to have been the first to speculate on the use of bone (scales) strutuctures to determine the age of fish. After developing the microscope in the 1600 s, Antoni van Leewenhoek inspired the Biblical citation against eating fish without scales, illustrated scales of European eel (*Anguilla anguilla*) and burbot (*Lota lota*); he judged that they did not have the same shape and number of circular lines (JACKSON, 2007).

The determination of the annual age of fish is based on, in general, bone structures. Several calcified structures that register growth marks are useful in the determination of fish age, such as scales, vertebrae, spines and rays of the fins, cleithra, opercule, otoliths among other bone structures (CAMPANA, 2001; CASSELMAN, 1983; ISELY; GRABOWSKI, 2007). Scales and otoliths are the most commonly used structures (CAMPANA, 2001; MACEINA et al., 2007).

In South America scales are the most commonly used structure because they are easily collected and even less onerous to prepare (CASSELMAM, 1983; ISELY; GRABOWSKI, 2007) and it is not necessary to sacrifice the individuals (ISELY; GRABOWSKI, 2007). These authors comment on the advantages and disadvantages of using scales and the understimation of age is a major disadvantage. The identification of false annuli can be a critical component of age and growth studies utilizing scales (BEAMISH; McFARLANE, 1987; CAMPANA, 2001; ISELY; GRABOWSKI, 2007).

In South America, estimates of growth parameters were verified through calcified structures and length-frequency between age-classes were the dominant methods. This is possibly due to the lower costs compared to radiochimical dating or the time required for study using other techniques. In spite of the several pointed limitations (ISELY; GRABOWSKI, 2007) with the studies of calcified structures, these are applied well, especially in South America, because the longevity of the fish is shorter compared to the temperate regions.

In the length-frequency distribution in length of cohorts, according to Sparre and Venema (1995) and Isely and Grabowski (2007), an age is attributed to the cohorts, so the size-age combination is obtained, to which is possible to apply the several existent methods for the determination of the growth parameters. The length-frequency distribution presents difficulties in being used in populations of fish, especially for species with multiple spawning that results in multi-modal length-frequency distributions within year class. Other factors as geographic differences in environmental quality, density dependency also result in differential growth within the same time period (ISELY; GRABOWSKI, 2007). According these authors the success of this method requires a large sample drawn at random from the population.

There is a variety of methods for the interpretation of growth structure periodicity (release of known-age and marked fish into the wild; bomb radiocarbon; mark-recapture of chemically-tagged wild fish; capture of wild fish with natural, date-specific markers; marginal increment analysis; captive rearing from hatch and captive rearing of chemically-tagged fish) and age absolute validation (use of known-age fish; bomb radiocarbon; radiochemical dating; length-frequency method (for first few age classes); capture of wild fish with natural, date-specific markers and captive rearing from hatching) and corroboration of age interpretation (tag-recapture analysis; length frequency analysis; progression of strong year-classes; numerical integration of daily growth increment widths; daily increments between annuli; elemental and isotopic cycles and interval between samples) in fishes (CAMPANA, 2001). Besides these methods, another commonly used method to determine the formation period of the age ring and validation of the absolute age, called as indirect method, is the average length of fish with the same number of annuli per period (AGOSTINHO et al., 1991; AMBRÓSIO; HAYASHI, 1997; BARBIERI et al., 1981; BARBIERI; BARBIERI, 1983; BARBIERI; BARBIERI, 1984; BARBIERI; SANTOS, 1987; BARBIERI; BARBIERI, 1988a and b; BARBIERI; BARBIERI, 1989; BARBIERI, 1989;

BARBIERI; CRUZ-BARBIERI, 1989; BARBIERI, 1992; BRAGA, 1999; BRUSCHI JUNIOR et al., 1997; CASTRO, 1998; FENERICH et al., 1975; GOULART; VERANI, 1992; GURGEL; BARBIERI, 1991; GURGEL; BARBIERI, 1994; HARTZ et al., 1998; HARTZ; BARBIERI, 1993; NOMURA, 1975; HARTZ; BARBIERI, 1995; ANTONIUTTI et al., 1985; ORSI; SHIBATTA, 1999).

An analysis of the literature revealed that, in South America, most studies did not validate or corroborated the age estimate, probably because it requires the application of two methods of study, as commented on by Campana (2001) and Isely and Grabowski (2007), to verify that age estimates are corresponding. Two bone structures can be used to validate the ages (BEAMISH; MCFARLANE, 1990). The works of Cordiviola de Yuan (1971), Nomura et al. (1978), Nomura and Barbosa (1980), Nomura (1988), Loubens (2003), Penna et al. (2005) and Silva and Stewart (2006) used two bone structures.

Ageing precision defined as the reproductibility of repeated measurements on a given structure can be statistically measured by average percent error (APE) and coefficient of variation (CV) (CAMPANA, 2001). Coefficient of variation was used by Araya et al. (2003), Fernandes et al. (2002), Ambrósio et al. (2003) and Feitoza et al. (2004). Another approach to evaluate age precision is percent of agreement (PA) (JEPSEN et al., 1999; SILVA; STEWART, 2006).

Growth in most organisms is a multiplicative process in which the volume and the number of cells increase. Abiotic factors that influence the growth rate in fish include pressure, temperature, salinity, dissolved oxygen, carbon gas, ammonia, pH, photoperiod, season and hydrological regimes. Among the biotic factors are abundance, availability, composition and digestibility of foods, as well as competition for them. Weight, sex, age, maturity, health, exercises, acclimatization, changes of characters, activities in group and debit of oxygen (BRETT, 1979; MENON, 1953; MOHR, 1994) are marked as internal factors. These factors, when combined, can control, limit, modify or active the growth rate, and are reflected in the apposition structures forming the growth marks. Nekrasov (1979) comments that a variation in temperature from 4 to 5ºC is enough to cause reduction in the growth of fish and form rings in bone structures.

The formation of growth marks was related to the reproductive period (AMARAL et al., 1999; BARBIERI; BARBIERI, 1983; BARBIERI; BARBIERI, 1988a and b; BARBIERI; SANTOS, 1988; BARBIERI; BARBIERI, 1989; BARBIERI; CRUZ-BARBIERI, 1989; BARBIERI; AFONSO MARINS, 1990; BARBIERI, 1992; BARBIERI, 1995 a and b; BARBIERI et al., 2000a and b; BARBIERI et al., 2001; BRAGA, 1999; CASTRO, 1998; FEITOSA et al., 2004; GOULART; VERANI, 1992; GURGEL; BARBIERI, 1991; GURGEL; BARBIERI, 1994; SANTOS; BARBIERI, 1991; SANTOS; BARBIERI, 1993) to the pluviometric level (CUTRIM; BATISTA, 2005; LECOMTE et al., 1986; LOUBENS; PANFILI, 2000; MEUNIER et al., 1994; PENHA et al., 2004b; SILVA; STEWART, 2006) and temperature (ARAYA, 1999; BARBIERI et al., 1981; BRUSCHI JUNIOR et al., 1997). These factors, combined with others, (condition factor, pH, oxygen concentration, feeding and environmental conditions) are commented on by Cordiviola de Yuan (1971), Agostinho et al. (1991), Hartz and Barbieri (1993), Reina et al. (1995), Ambrósio and Hayashi (1997), Hartz et al. (1998), Araya and Sverlij (1999), Jepsen et al. (1999), Orsi and Shibatta (1999), Loubens (2003), Fernades et al. (2002), Araya et al. (2005) and Araya et al. (2008).

The minimum and maximum age recorded in the papers was 3 and 15 years. In contrast, in the temperate regions, there are registrations of species up to 140 years (BEAMISH; MCFARLANE, 1990). Three years were registrated for *Apareiodon affinis* (NOMURA et al., 1978), *Astyanax eigenmanniorum* (BARLA et al., 1988), *Steindachnerina insculpta* (SANTOS et al., 1991a), *Astyanax scabripinnis paranae* (BARBIERI, 1992), *Astyanax schubarti* (GIAMAS et al., 1992), *Steindachnerina insculpta* (AMBRÓSIO; HAYASHI, 1997), *Pimelodus maculatus* (BRAGA, 2000), *Satanoperca papaterra* (FERNADES et al., 2002), *Moenkhausia intermedia* (LIZAMA; AMBRÓSIO, 2003), *Hypophthalmus edentatus* (AMBRÓSIO et al., 2003), *Astyanax shubarti* (LIZAMA; AMBRÓSIO, 2004) and fourteen and fifteen years for *Paulicea luetkeni* and *Pseudoplatystoma tigrinum* (REINA et al., 1995) and (LOUBENS; PANFILI, 2000), respectively for males and females.

Conclusion

We found that there was an increase in the studies on aging and growth (32 species until 1993 to 153 species until 2008) of fish in South America, although it is still incipient considering all the 4,475 valid species according Reis et al. (2003). It was clear in this revision that the main challenges for the future are the still needed increase in the number of studies on freshwater fish in South America. In addition, the main weak point referred to validation and it should be thought of as a protocol, as suggested by Campana (2001), Silva and Stewart (2006) and Isely and Grabowski (2007). Using this approach, age and growth estimates would be more rigorously obtained.

The determination of age using bone structures and validation through length-frequency analysis seen valuable for short-lived species and it could be valuable to determine age in South American fish.

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