Pomacea canaliculata (Mollusca, Gastropoda) in Patagonia: potential role of climatic change in its dispersion and settlement

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Abstract

Pomacea canaliculata (Lamarck, 1822) (Mollusca Gastropoda) shows a large native distribution range in South America, reaching as far south as 37º S (Buenos Aires, Argentina). This species was deliberately introduced into Southeast Asia around 1980 and subsequently underwent a rapid intentional or accidental dispersal into many countries in the region. It was also introduced into North and Central America and Hawaii. In this contribution we record the presence of *P. canaliculata* in Patagonia, assessing the possible influence of climatic change in the new establishment of this species there. Three samplings (between September 2004 and April 2005) were carried out at 38º 58' 20.2" S-68º 11' 27.3" W. In the sampling we found two adult specimens of *P. canaliculata* and numerous egg clutches. *Pomacea canaliculata* is naturally distributed in the Plata and Amazon Basins. The southern boundary of this species has been established as the isotherms of 14 ºC and 16 ºC in Buenos Aires province, and precipitations of 900 to 600 mm/year. This study also analysed variations in annual temperature and precipitation in Patagonia. Average temperatures show an increase over the years, although not constantly. Important modifications in precipitation regime in northern Patagonia, triggered by global climatic changes, could be beneficial for the settlement of populations of *P. canaliculata* in this new area, where precipitation increased enough to reach values similar to those in the southernmost area of distribution of this species.

Keywords: dispersion, *Pomacea canaliculata*, Patagonia.

Pomacea canaliculata (Mollusca, Gastropoda) na Patagônia: o papel potencial da mudança climática em sua dispersão e estabelecimento.

Resumo

Pomacea canaliculata (Lamarck, 1822) (Mollusca Gastropoda) mostra um grande alcance de distribuição natural na América do Sul, chegando até os 37º S (Buenos Aires, Argentina). Esta espécie foi introduzida propositalmente no sudeste da Ásia, por volta de 1980 e, mais tarde, se submeteu a uma dispersão de forma rápida intencional ou acidental em muitos países da região. Também foi introduzido na América do Norte, América Central e Havaí. Nesta contribuição se confere a presença de *P. canaliculata* na Patagônia e se considera a influência das alterações climáticas no novo estabelecimento desta espécie no local referido. Três coletas (entre setembro de 2004 até abril de 2005) foram realizadas (38º 58' 20.2" S and 68º 11' 27.3" W). Nelas encontraram-se dois exemplares adultos de *P. canaliculada* e numerosas desovas. *P. canaliculata* distribui-se naturalmente nas regiões das Bacias do Prata e Amazonas. O limite sul desta espécie foi estabelecido nas isotermas de 14 ºC e 16 ºC na província de Buenos Aires, com precipitações de 900 a 600 mm. Também são analisadas as variações na temperatura anual e a precipitação na Patagônia. As médias de temperatura mostram um aumento no decorrer de dois anos. Modificações importantes no regime de precipitação no norte da Patagônia poderiam ser benéficas para o estabelecimento das populações de *P. canaliculata* nesta nova área, onde as precipitações aumentaram o suficiente até atingir os valores similares aos da região mais austral citada para a distribuição desta espécie.

Palavras-chave: dispersão, *Pomacea canaliculata*, Patagônia.

1. Introduction

Pomacea Perry, 1810 (Gastropoda: Ampullariidae) includes many species widely distributed throughout South and Central America and the Caribbean. Only *Pomacea paludosa* (Say, 1829) has a natural geographic range reaching into the southwestern United States (Cowie, 2002). Some *Pomacea* species are considered as a valuable resource for monitoring water quality in northeast Brazil (Coler et al., 2005).

Pomacea canaliculata (Lamarck, 1822) is the species of this genus that shows the largest range. It is found in floodplains and marshy areas of the rivers in the Plata Basin, mainly the Paraná and Paraguay Rivers. It also lives in marshy areas of the Amazon Basin. It is abundant in Argentina, Brazil, Bolivia, Paraguay, and Uruguay (Cowie and Thiengo, 2003). However, precise delimitation of its geographic range requires the previous elucidation of confusing taxonomic problems or else a clear statement of the criteria followed in the use of this name (Cazzaniga, 1987, 2002). In Argentina the range of this species covers a large area, reaching as far South as 37º S, in the province of Buenos Aires (Martín et al., 2001).

Pomacea canaliculata was deliberately introduced into Southeast Asia around 1980 and subsequently underwent a rapid intentional or accidental dispersal in many countries in the region (Cowie, 2002). It has a severe impact on rice fields, as well as on taro and lotus crops (Yusa et al., 2006). The aggressiveness and strength of this invasion has been widely dealt with in the literature (Yusa and Wada, 1999; Cowie, 2002). It was also introduced into North and Central America (Cowie, 2002) and Hawaii (Cowie, 1997). Many characteristics of this snail have been mentioned as causes of its success in the invaded areas, i.e., it is a food generalist (Yusa et al., 2006), it lacks natural enemies in the invaded areas, it has high fecundity, it tolerates a wide range of temperatures and high levels of pollution (Lach et al., 2000).

In this contribution we record the presence of *P. canaliculata* in Patagonia, assessing the possible influence of climatic change on the establishment of this species there.

2. Material and Methods

Three samplings (09/29/2004; 12/18/2004 and 04/16/2005) were carried out at Balneario La Herradura (38º 58' 20.2" S-68º 11' 27.3" W), near the Limay River at Plottier, province of Neuquén, Argentina (Figure 1). On 04/16/2005, a search for adults in the sediment down to 25 cm depth was conducted, and the number of egg clutches was counted. The collected snails were measured according to Estebenet and Martín (2003). The identification was based on shell morphology (Simone, 2006), internal anatomy, especially by the penis and apical gland features (Simone, 2004) and by the features of the egg clutches (Estebenet and Cazzaniga, 1993). The material was deposited in the Invertebrate Zoology Collection at the Museo de La Plata (MLP 12136).

2.1 Environment characteristics

Balneario La Herradura is an area with ponds near the Limay River. These ponds have a bottom of a thin layer of sand, with organic matter, roots of aquatic weeds (reeds and other macrophytes), among which predominate *Myriophyllum* sp.; *Azolla* sp.; *Potamogeton* sp.; *Ludwigia* sp. Below this layer lie the gravels of the riverbed. In the middle of the ponds, where there are no macrophytes, there are no fine sediments. Physico-chemichal properties of the environment are synthesised in Table 1. The river flow is at this point ruled by the regime of the Arroyito hydroelectric Central, located 40 km upstream. During the first sampling, the flow was under 350 m^3/seg; during the second sampling it was over 1.000 m^3/seg; during the third one it was back down at 316 m^3/seg.

The area studied is included in the 14º and 16º isotherm (6º and 8º in winter; 22º in summer), and annual average precipitation is 200 mm (historical data 1961-1980; National Meteorological Service). It is a region traditionally classified as arid or semi-arid within the Monte Province (Cabrera and Willinks, 1980) or, more recently, in the Andean Region, Central Patagonian Subregion, Central Patagonian Province (Morrone, 2001).

During 2004 the average temperature was 15.62 ºC, in agreement with historical values. Contrarily, precipitation reached 470.43 mm, a figure well above the historical average (Figure 2).

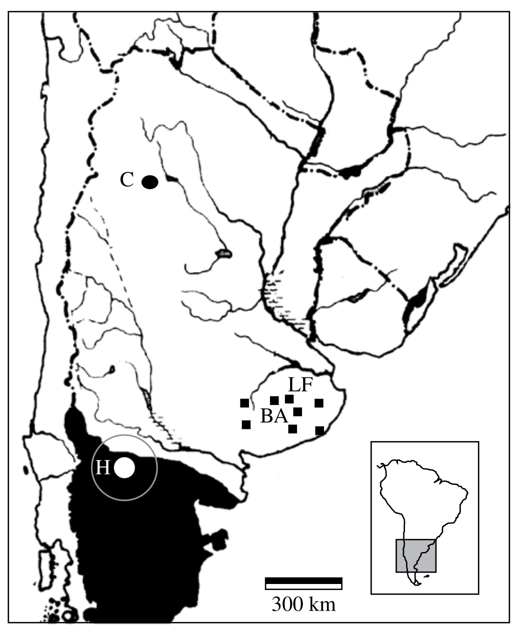

Figure 1. Geographic location of study area. In black the Patagonian subregion (after Morrone, 2001); white circle, Balneario La Herradura, province of Neuquén, Argentina; black squares, southern localities of natural range of *P. canaliculata* (after Martín et al., 2001); black circle locality at province of Catamarca (after Cazzaniga, 1987); H; province of Neuquén; BA, province of Buenos Aires; C, province of Catamarca; LF, Las Flores city, province of Buenos Aires.

3. Results and Discussion

In September 2004 we found two adult specimens of *Pomacea canaliculata* in these ponds. The specimens have 49.50 and 49.73 mm total length; 45.50 and 44.58 total width and 45.82 and 45.91 mm body whorl length (measurements taken according to Estebenet and Martín, 2003). On 12/18/2004 no snails or egg clutches were found, because of the increased caudal at that moment. The sampling on 04/16/2005 yielded no specimens on the surface nor within the sediment; only numerous egg clutches were found. Density of egg clutches varied between 0.57 and 1.86 per square metre of reed area (x = 0.93, ds = 0.32, n = 4). This sampling also yielded numerous specimens of *Diplodon* sp. (Mollusca: Bivalvia: Hyriidae).

Pomacea canaliculata is naturally distributed in the Plata and Amazon Basins. The northern boundary of its range is variable according to the taxonomic criteria used (Cazzaniga, 1987). Martín et al. (2001) established as southern boundary of this species the isotherms of 14 °C and 16 °C in Buenos Aires province, and precipitations of 900 to 600 mm. These authors contrasted the poor dispersion capability of this snail in the area (they only recorded it in four localities south of 38° S) with the extraordinary dispersion it had in Southeast Asia. They assumed that the geographic and climatic characteristics south of the Ventania and Tandilia hills in Buenos Aires province are not the optimal ones for a rapid and effective dispersion of the species. According to them this is because of the fluvial physiographic characteristics and the climatic conditions that require short reproductive periods (compared to those in tropical areas) and a hibernation period. Martín et al. (2001) observed the inability of *P. canaliculata* to disperse southwards of the boundaries mentioned, even along the same river basin. The western boundary in Argentina was detailed by Cazzaniga (1987), who identified populations of *P. canaliculata* in western Argentina in the province of Catamarca (28° 30' S-65° 15' W), in an area with average temperature of 28 °C and an annual precipitation of 458 mm (historical data 1961-1990, National Meteorological Service).

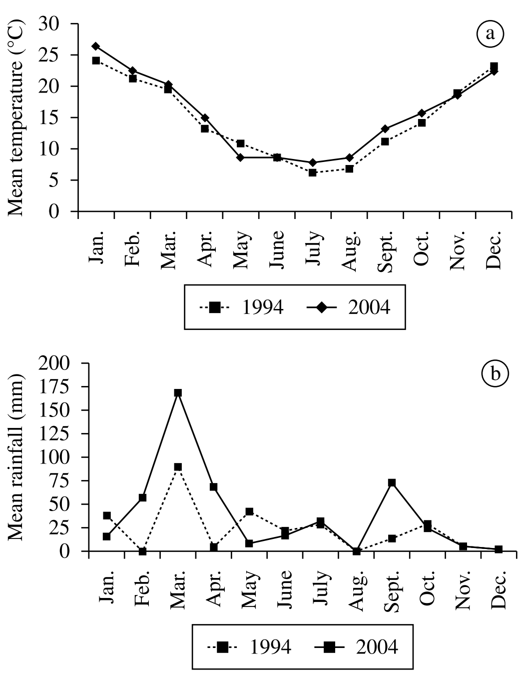

Figure 2. Average values of temperature (a) and precipitation (b) recorded at Neuquén (38.95° S - 68.13° W, province of Neuquén) during 1994 - 2004.

The wide natural range of *Pomacea canaliculata* suggests its great plasticity endogenous and exogenous factors (Estebenet and Martín, 2002), a feature repeatedly seen in the invaded areas of Southeast Asia, demonstrating its great adaptive capacity. *Pomacea canaliculata* can disperse rapidly and – according to habitat characteristics – can adjust by means of changes in the reproductive cycle, feeding and growth pattern. Thus it achieves population settlement (Lach et al., 2000). Likewise, natural predators are missing in the invaded areas (Yusa et al., 2006).

In the temperate areas of its natural range, *Pomacea canaliculata* is reproductively active during approximately six months, i.e., from the end of October until the beginning of April (Martin et al., 2001), when air temperature is above 20 °C. There is no marked difference between the historic temperature values in an area next to the southernmost boundary of the distribution range (Las Flores city, Buenos Aires province, Figure 1) and the new locality (Figure 3a). This suggests that temperature is not a limiting factor for the establishment of populations. Estebenet and Cazzaniga (1992) demonstrated that temperature is a determinant factor in growth patterns and consequently is related to the sexual maturity age, the time it takes to reach this age, fertility, and longevity. Under conditions of marked thermal seasonality, maturity is reached at 13 months, while at constant water temperature of 25 °C this period is reduced to 10 months (Estebenet and Cazzaniga, 1992). Observations in invaded areas of Southeast Asia indicate that the time necessary to achieve maturity is much less, e.g., two to three months for populations in the Philippines and Japan (Cowie, 2002). Martín and Estebenet (2002) also observed interpopulation variations in some life cycle parameters (e.g., survivorship rate, growth rate, beginning of reproductive season, size and age at maturity, size and number of eggs, and hatched

Table 1. Environmental characteristics of the ponds at Balneario La Herradura, Plottier, measured on 04/16/05.

	Temperature (°C)	Dissolved O_2 (mg/L)	Saturation OD	pH	Conductivity (µs/cm)
Pond without vegetation	13.14	8.98	88.2	7.83	172.5
Pond with vegetation	14.83	3.83	39.1	7.22	182.3
Limay River	14.64	8.96	91.1	7.77	85.4

individuals) even among populations growing under similar climatic conditions and in the same basin. These observations suggest the great ability of the species to adapt to different environmental conditions.

The potential new range in northern Patagonia shows similar thermal characteristics to the province of Buenos Aires. However, historic precipitation values are very different (Figure 3b). Despite the fact that *Pomacea canaliculata* is capable of surviving buried for over three months, low precipitation is a limiting factor. Cazzaniga (1987) mentioned the survival capability of this snail in areas with precipitation deficit where values only reach 300 mm annually.

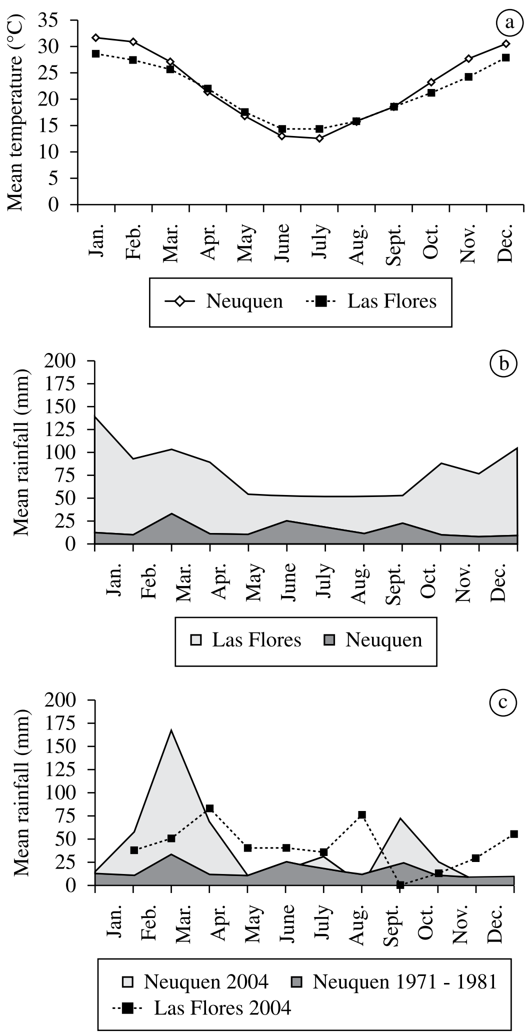

Figure 3. a) Comparison between historic values (1971-1981) of average air temperature in °C; b) total annual precipitation in mm at Las Flores (36.06° S and 59.10 W, province of Buenos Aires) and Neuquén (38.95° S and 68.13° W, province of Neuquén); and c) comparison among the total precipitation in mm in Neuquén; recorded in 2004 and historic values for the same locality, and total precipitation in mm recorded in 2004 at Las Flores city. (National Meteorological Service, Argentina).

Cordon et al. (2000) and Nordenstrom (2006) studied climatic change based on data of the Observatorio Agrometeorológico - Estación Experimental INTA, in the upper Rio Negro Valley (EEA), about 40 km East of Plottier. According to these studies, between 1923 and 1987 average annual precipitation in that area was 197.7 mm, defining the area thus as arid-semiarid. Records obtained between 1970 and 2000 render an average annual precipitation of 254.8 mm. Average air temperature at EEA records an increase of about 0.8 ºC over the past 30 years and a repeated value above 15 ºC has been observed for several years during the last decade. This study also analysed variations in annual temperature and precipitation. Average temperatures show an increase over the years, although not constantly.

Minimal values for the 1970, 1980, and 1990 decades are very close, but there is a marked increase in extreme temperatures. Such behaviour triggered the increase of 0.8 ºC recorded in the region. On the other hand, precipitation exhibits a notorious increase (from 200 to 400 mm), an oscillating behaviour and changes in the distribution pattern of precipitation over the year.

These important modifications in the precipitation regime in northern Patagonia (Figure 3c), triggered by global climatic changes, could be beneficial for the settlement of populations of *Pomacea canaliculata* in this new area, where precipitation increased enough to reach values similar to those in the southernmost area of distribution of this species.

Climate and environmental characteristics determine the geographic boundaries of species range and also their growth and survival pattern. Global climatic change is one of the factors producing modifications in the geographic range of both native and introduced species (Dukes and Mooney, 1999). The impact that this climatic change has in species distribution depends on specific attributes and their interaction with the environment (Sutherst, 2000). Temperature and humidity are considered the most important variables in species distribution, allowing or not their establishment in new areas (Leach, 2000). However, the effects of trophic chains (competitors, predators) often caused by climatic change also influence the distribution of organisms. When considering the impact of climatic change on the distribution of invasive species Sutherst (2000) remarked the importance of the different elements taking part in an invasion process (area of origin, pathway, and area of destination). These elements should also be considered when assessing alterations in the distribution of native species. The increase in precipitation that occurred in northern Patagonia probably influenced the establishment of newly arrived species in the region.

4. Conclusions

Natural ranges of species are dynamic. They may be modified by natural and artificial changes in the environment. To disperse beyond its native range of distribution, a species must overcome a sequence of obstacles which once surpassed, allow it to cross its natural limits. Most of the species that undertake an invasion process can probably never overcome the sequence of obstacles, or at least not in one attempt (Darrigran and Damborenea, 2006). The case of *Pomacea canaliculata* presented herein is an example of this. In this attempt the introduction of P. *canaliculata* into this new environment was not possible. The changes described, together with the characteristics of the area [e.g., absence of natural predators birds such as *Rostrhamus sociabilis* (Vieillot, 1817) and *Aramus guarauna* (Linnaeus, 1766), according to Thiollay, (1994) and Thomas (1996)] suggest that this species has a high probability of becoming established in northern Patagonia. The environment where *P. canaliculata*, was detected is the common environment of a mollusc invader species, *Corbicula fluminea* (Müller, 1776) (Tambussi, personal communication). This fact suggests that the invasability of the cited environment is good, that is it is susceptible to the reception of non-native species. Moreover, in 2007, new egg clutches of *P. canaliculata* were found in the same locality. How many attempts are required for this species to achieve its naturalization in North Patagonia is still unclear.

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References

CABRERA, AL. and WILLINK A., 1980. *Biogeografía de América Latina.* Secretaria General de la Organización de los Estados Americanos. Programa Regional de Desarrollo Científico y Tecnológico. Serie Biología. Monografías 13. 122 p.

CAZZANIGA, NJ., 1987. *Pomacea canaliculata* (Lamark, 1801) en Catamarca (Argentina) y un comentario sobre *Ampullaria catamarcensis* Sowerby, 1874 (Gastropoda, Ampullariidae). *Iheringia Serie Zoologia*, vol. 66, p. 43-68.

-, 2002. Old species and new concepts in the taxonomy of *Pomacea* (Gastropoda: Ampullariidae). *Biocell*, vol. 26, p. 71-81.

COLER, RA., COLER, RR., FELIZARDO, EG. and WATANABE, T., 2005. Applying weight gain in *Pomacea lineata* (Spix 1824) (Mollusca: Prosobranchia) as a measure of herbicide toxicity. *Brazilian Journal of Biology*, vol. 65, p. 617-623.

CORDON, VH., FORQUERA, JC., GASTIAZORO, J., LASSIG, J., BASTANSKI, M. and NORDNSTROM, G., 2000. *Caracterización climática del Alto Valle del Río Negro y Neuquén-Limay inferior*. Cinco Saltos, Río Negro, Argentina: Facultad de Ciencias Agrarias. Universidad Nacional del Comahue. 53 p. Cátedra de Climatología y Fenología agrícola.

COWIE, RH., 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the hawaiian Islands. *Bishop Museum Occasional Papers* 50, 66 p.

-, 2002. Apple snail (Ampullariidae) as agricultural pest: their biology, impacts and management. In Baker, GM. *Molluscs as crop pests* (Ed.). Wallingford: CABI Publishing. p. 145-192.

COWIE, RH. and THIENGO, SC., 2003. The apple snails of Americas (Mollusca: Gatropoda: Ampullariidae: *Asolene, Felipponea, Marisa, Pomacea, Pomilla*): a nomenclatural and type catalog. *Malacologia*, vol. 45, p. 41-100.

DARRIGRAN, G. and DAMBORENEA, C., 2006. Bio-invasiones. In DARRIGRAN, G. and C. DAMBORENEA (Eds.). *Bio-invasión del mejillón dorado en el continente americano*. La Plata, Argentina: EDULP. 220 p.

DUKES, JS. and MOONEY, HA., 1999. Does global change increase the success of biological invaders? *TRENDS in Ecology & Evolution*, vol. 14, p. 135-139.

ESTEBENET, AL. and CAZZANIGA, NJ., 1992. Growth and demography of *Pomacea canaliculata* (Gastropoda: Ampullariidae) under laboratory conditions. *Malacological Review*, vol. 25, p.1-12.

-, 1993. Egg variability and the reproductive strategy of *Pomacea canaliculata* (Gastropoda: Ampullariidae). *Apex,* vol. 8, p. 129-138.

ESTEBENET, AL. and MARTÍN, PR., 2002. *Pomacea canaliculata* (Gastropoda: Ampullariidae): life-history traits and their plasticity. *Biocell*, vol. 26, p. 83-89.

-, 2003. Shell interpopulation variation and its origin in *Pomacea canaliculata* (Gastropoda: Ampullariidae) from Southern pampas, Argentina. *Journal Molluscan Studies*, vol. 69, p. 301-310.

LEACH, JH., 2000. Climate Change and the Future Distribution of Aquatic Organisms in North America. In CLAUDI, R and LEACH JH (Eds). *Nonindigenous freshwater organisms. Vectors, Biology and Impacts*. Boca Raton: Lewis Publishers. p. 399-400.

LACH, L., BRITTON, DK., RUNDELL, RJ. and COWIE, RH., 2000. Food preference and reproductive plasticity in an invasive freshwater snail. *Biological Invasions*, vol. 2, p. 279-288.

MARTÍN, PR. and ESTEBENET, AL., 2002. Interpopulation variation in life-history traits of *Pomacea canaliculata* (Gastropoda: Ampullariidae) in southwestern Buenos Aires province, Argentina. *Malacologia*, vol. 44, p. 153-163.

MARTÍN, P.R., ESTEBENET, AL. and CAZZANIGA, NJ., 2001. Factors affecting the distribution of *Pomacea canaliculata* (Gastropoda: Ampullariidae) along its southernmost natural limit. *Malacologia*, vol. 43, p. 13-23.

MORRONE, JJ., 2001. *Biogeografía de América Latina y el Caribe.* MyT–Manuales y Tesis SEA. Zaragoza, vol. 3. 148 p.

NORDENSTROM, G., 2006. El cambio climático en el Alto Valle. In Red Agraria [Internet]. Available from: <http://www.redagraria.com/meteorologia/Alto%20Valle%20Clima.html>. Access in: Jan. 2006.

SIMONE, LRL., 2004. Comparative morphology and phylogeny of representatives of the Superfamilies of architaenioglossans and the Annulariidae (Mollusca, Caenogastropoda). *Arquivos do Museu Nacional*, v. 62, p. 387-504.

-, 2006. Land and freshwater mollusks of Brazil. São Paulo: EGB; Fapesp. 390 p.

SUTHERST, RW., 2000. Climate change and invasive species: a conceptual framework. In MOONEY HA. and HOBBS, RJ (Eds.). *Invasive species in a changing world*. Washington: Island Press. p. 211-240.

THIOLLAY, JM., 1994. Family Accipitridae (Hawks and Eagles) In DEL HOYO, J., ELLIOTT, A. and SARGATAL, J. (Eds.). *Handbook of the Birds of the World. Hoatzin to auks*. Barcelona: Lynx Edicions. vol. 2., p. 52-205.

THOMAS, BT., 1996. Family Opisthoconidae (Hoatzin). In DEL HOYO, J., ELLIOTT, A. and SARGATAL, J. (Eds.). *Handbook of the Birds of the World. Hoatzin to auks*. Barcelona: Lynx Edicions. vol. 3, p. 24-32.

YUSA, Y. and WADA, T., 1999. Impact of the introduction of apple snails and their control in Japan. Naga, the ICL-ARM Quaterly, vol. 22, p. 9-13.

YUSA, Y., SUGIERA, N. and WADA, T., 2006. Predatory potential of freshwater animals on an invasive agricultural pest, the apple snail *Pomacea canaliculata* (Gastropoda: Ampullariidae), in southern Japan. *Biological Invasions*, vol. 8, p. 137-147.