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Exotic species of freshwater decapod crustaceans in the state of São Paulo, Brazil: records and possible causes of their introduction

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Abstract. Based on recent surveys of the freshwater decapod fauna, distributional data of five exotic species of freshwater decapod crustaceans for the hydrographic basins of the state of São Paulo are presented, as part of a large initiative for a comprehensive survey of the state's biodiversity (BIOTA-FAPESP Program). These species are the North American crayfish *Procambarus clarkii* (Girard) (Cambaridae), the crab *Dilocarcinus pagei* Stimpson (Trichodactylidae) from the Amazon and Paraguay/lower Paraná River Basins, and the palaemonid shrimps *Macrobrachium rosenbergii* (De Man), from the Indo-Pacific region, *Macrobrachium amazonicum* (Heller) and *Macrobrachium jelskii* (Miers), both from the Orinoco, Amazon and the Paraguay/lower Paraná River Basins. Possible modes by which their introduction might have occurred are commented upon and potential consequences are discussed.

Introduction

Introduction of decapod crustaceans in regions other than their natural distribution areas has been mentioned several times in scientific literature. Rodríguez and Suárez (2001) summarized many documented cases of anthropogenic dispersal of marine and freshwater decapod species, and discussed possible factors that could account for their dispersal. Although there are some well known cases of introduction of marine decapod species in Brazil, (Melo 1983, 1989; Bueno 1989; Barreto et al. 1991/1993; Calado 1996; Carqueija and Gouvêia 1996; Negreiros-Fransozo 1996; Tavares and Mendonça 1996; Mantelatto and Dias 1999; Melo et al. 2000; Severino-Rodrigues et al. 2000; Mantelatto and Garcia 2001; Melo and Crivelaro 2002), information on the dispersal of freshwater shrimps and crabs due to human activities is sparse or poorly documented, with few notable exceptions such as reports of the Indo-Pacific shrimp, *Macrobrachium rosenbergii* (De Man) in the natural environment of the eastern Amazon region (Barros and Silva 1997; Valenti and New 2000) and in the state of Espírito Santo (Valenti and New 2000).

The freshwater decapod fauna in the state of São Paulo is relatively well known. The first well established records were made by Ortmann (1897) and H. von Ihering (1897). Subsequent authors enhanced this knowledge either by recording additional species or by describing new ones (see Magalhães 1999a for a review of the literature). Magalhães (1999a) summarized the knowledge on the diversity of freshwater decapods in the state of São Paulo by listing 32 species from five families and eight genera. He mentioned the presence of some exotic species but did not make further comments about their occurrence in São Paulo. In fact, data concerning the occurrence of exotic freshwater decapods in São Paulo are sporadic and mostly available as meeting abstracts only (see, for instance, Hirose et al. 2000; Silva et al. 2000; Suzuki et al. 2000; Bueno et al. 2001).

Recent collections for inventorying the freshwater decapod fauna, conducted as part of the BIOTA-FAPESP Program, a large initiative for a comprehensive survey of the state's biodiversity, produced more consistent distributional data on this fauna. In the present paper, we discuss the occurrence of five exotic decapod crustaceans in the state of São Paulo, and comment possible modes by which their introduction might have occurred as well as potential consequences.

Materials and methods

Data on the occurrence of the species were obtained from field collections conducted by the authors, from specimens in scientific collections, from published or unpublished literature (congress abstracts, technical reports), and from personal observation. The specimens were deposited in the collections of the Museu de Zoologia (MZUSP) and Departamento de Zoologia, Instituto de Biociências (DZ-USP), Universidade de São Paulo, São Paulo; Departamento de Zoologia, Universidade Federal do Rio Grande do Sul, Porto Alegre (UFRGS); and Instituto Nacional de Pesquisas da Amazônia, Manaus (INPA). Other abbreviations are: juv. = juveniles; ov. = ovigerous; RPPN = Reserva Privada do Patrimônio Natural; spec. = specimens. Terms related to species introductions follow the definitions used by Holdich and Gherardi (1999).

Results

Cambaridae Hobbs Jr.
Procambarus clarkii (Girard)

Material – Brazil, São Paulo: Taubaté, córrego no bairro Vila Nogueira, 23°00′48″S 45°33′31″N, 9.xii.2003, 1♂ (MZUSP 16124); Rio Tietê Basin, São

Paulo, Parque Municipal Alfredo Volpi, 23°35′16″S 46°42′09″W, 22.vii.1999, 2♀ (MZUSP 14501); idem, 14.ix.1999, 2 spec. (MZUSP 14502); idem, 17.ix.1999, 3 spec. (MZUSP 14503); idem, 15.x.1999, 3♂ 1♀ 3 juv. (MZUSP 14504); idem, 29 spec. (MZUSP 14505); idem, 10.xii.1999, 16 spec. (MZUSP 14506); idem, 21.xii.1999, 8 spec. (MZUSP 14507); idem, 27.vii.2000, 1 ov. ♀ (MZUSP 14508); idem, 29.xi.2000, 1 ov. ♀ (MZUSP 14509); idem, 20.ii.2001, 1 ov. ♀ (MZUSP 14510); idem, 15.iii.2001, 1 ov. ♀ (MZUSP 14511); idem, 4♂ 5♀ (INPA 871); idem, 4♂, 2♀, 24.xii.1990 (UFRGS 03102); São Paulo, bairro do Butantan, iii.1996, 1♂ (MZUSP 11271); Rio Tietê Basin, Embu, bairro de Itatuba, pesqueiro do Gaúcho, 23°38′07,9″S 46°53′45,1″W, 5.ii.2002, 8♂ 3♀ (MZUSP 15001); idem, 6♂ 5♀ (MZUSP 15002); idem, 4.ii.2002, 2 spec. (MZUSP 15003); idem, 3 spec. (MZUSP 15004); Rio Tietê Basin, Embu, córrego do bairro de Itatuba, 23°37′55,3″S 46°53′35,4″W, 4.ii.2002, 6♂ 6♀ (MZUSP 15005).

Remarks – The crayfish *Procambarus clarkii* is native to south-central United States and northeastern Mexico, and has a distributional range extending from northern Mexico to Florida, southern Illinois and Ohio, in the United States (Hobbs Jr. 1989). Due to its commercial significance both in terms of fisheries and aquaculture or as an aquarium animal, the species has successfully been introduced in several countries around the world (Huner 1977, 1986, 1995; Hobbs III et al. 1989; Henttonen and Huner 1999; Rodríguez and Suárez 2001). In Brazil, the first report of its occurrence was provided by Huner (1986) based on an account made to him about a successful introduction around the city of São Paulo (J. Huner, in litt. to C.M.). We observed the commercial selling of this species in some pet shops back in 1985 and it continues as strong as ever today. So far the only confirmed records of a natural environment colonization by *P. clarkii* in Brazil are the ones made above.

Palaemonidae Rafinesque

Macrobrachium rosenbergii (De Man)

Material – Brazil, São Paulo: Rio Tietê Basin, Brejo Alegre, 21°07′S 50°10′W, i.2001, 1♂ (MZUSP 13918); Pindamonhangaba, viveiros experimentais de cultivo do Instituto de Pesca, no date and collector, 1♂ (MZUSP 13456); idem, 1♂ (MZUSP 13457); idem, 1♂ (MZUSP 13458); criação, Instituto de Pesca, 1988, 1 ov. ♀ (MZUSP 9588); idem, 1♂ (MZUSP 9589); cultivado no Instituto de Pesca, 1985, 1♂ (MZUSP 7170); several juv. (UFRGS 756); idem (UFRGS 815); 3♂, 1♀ (UFRGS 816), from Instituto de Pesca – SP, 19.iii.985; 1♂ (UFRGS 882), São Paulo, 3.iii.1985; 1♂ (UFRGS 00883), São Paulo, 3.iii.1985.

Remarks – The species is characterized by the long rostrum bearing 11–14 dorsal and 8–10 ventral teeth, with the tip slightly curved upwards. Telson has a distinct posterior margin, with the median point not overreached by the inner pair of posterior spines. Adult males have very long, strong second pereiopods, usually with blue or orange color. Although morphologically similar to

M. amazonicum, the asiatic species has more teeth in the dorsal margin of the rostrum, which are more regularly spaced in its distal portion, and its chelipeds are clearly stronger then those of *M. amazonicum*. In addition, *M. rosenbergii* reaches a very large size with a very robust appearance. Except for the large male specimen from Brejo Alegre (Rio Tietê Basin) that was actually caught in the wild, all other *M. rosenbergii* listed herein are from freshwater shrimp culture facilities.

Macrobrachium amazonicum (Heller)-Figure 1(1, 2)

Material – Brazil, São Paulo: branch of Rio Grande, between Mira Estrela and Cardoso, 20°01′51″S 50°00′59″W, 23.i.2003, 6♀ (1 ov.) (MZUSP 15794); Rio Turvo, between Riolândia and Cardoso, 20°04′29″S 49°48′46″W, 23.i.2003, 3♀ (1 ov.), (MZUSP 15598); 5 km S of Santa Fé do Sul, between Santa Fé do Sul and Canaã, 20°17′35″S 50°55′17″W, 22.i.2003, 9♀ (2 ov.) (MZUSP 15576); Jupiá, 20°45′54″S 51°35′32″W, 22.i.2003, 3♂ 1♀ (15580); Buritama, 21°05′55″S 50°10′31″W, 1♂ 4♀ (1 ov.) (15600); Rio Tietê, reservatório de Três Irmãos, ii.2000–vi.2000, 54 spec. (8 ov. ♀) (MZUSP 13465); Rio Tietê Basin, Penápolis,

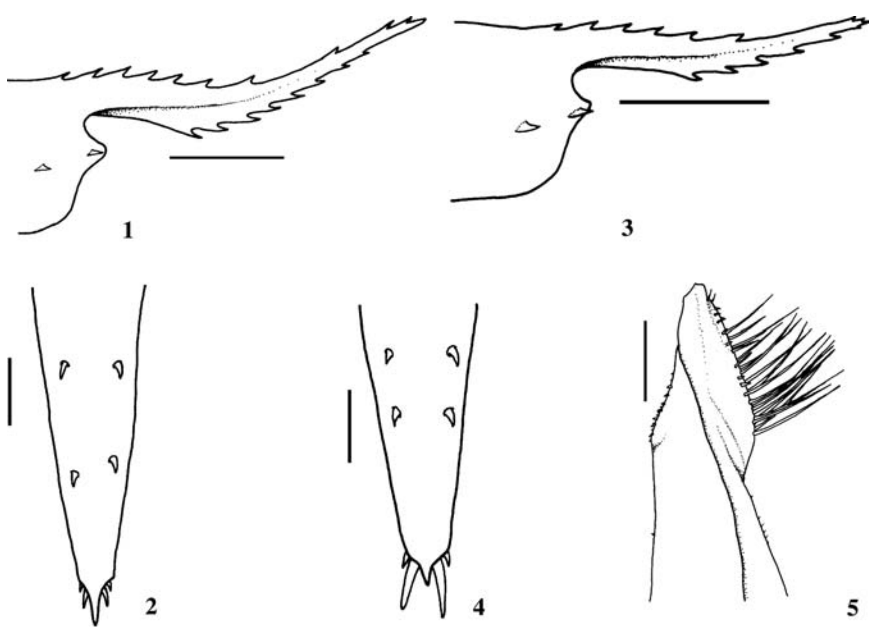

Figure 1. (1–5) *Macrobrachium amazonicum* (Heller), adult ♂, INPA 873. (1) Anterior part of carapace and rostrum, lateral view. (2) telson, dorsal view. *Macrobrachium jelskii* (Miers), adult ♂, INPA 585; (3) anterior part of carapace and rostrum, lateral view (4) telson, dorsal view. *Dilocarcinus pagei* Stimpson, ♂, INPA 872; (5) distal part of the first gonopod, mesio-ventral view.

18.xi.2001, 29 spec. (5 ov. ♀) (INPA 886); Rio Paraná, Reserva Florestal Lagoa São Paulo, Campinal, 21°31′35″S 52°00′33″W, 15.x.2002, 12♂ 10♀ (MZUSP 15573); Rio Tietê Basin, Lins, RPPN Dr. Ivan, 21°34′18″S 49°38′19″W, 21.i.2003, 2♂ 7♀ (2 ov.) (MZUSP 15608); Rio Paraná, Córrego Veado, Presidente Epitácio, 21°43′16″S 52°02′11″W, 15.x.2002, 14♂ 21♀ (MZUSP 15603); Rio do Peixe, Flora Rica, between Flora Rica and Santo Expedito, 21°44′19″S 51°22′45″W, 16.x.2002, 1♂ 1♀ (MZUSP 15596); Rio Paraná, Ribeirão Caiuazinho, Presidente Epitácio, 21°45′39″S 52°45′07″W, 15.x.2002, 19♂ 13♀ (MZUSP 15574); Rio do Peixe, between Parapuã and Martinópolis, 21°56′56″S 50°56′23″W, 16.x.2002, 2♂ (MZUSP 15602); dam at rio Cascata, Rio do Peixe Basin, Marília, 22°12′50″S 49°55′29″W, 18.x.2002, 11♂ 4♀ (MZUSP 15572); Rio Paraná, Primavera, 22°31′03″S 52°59′47″W, 14.x.2002, 15♂ 16♀ (MZUSP 15601); Rio Paranapanema Basin, Sandovalina, 22°33′75.0″S 51°54′61.5″W, 24.viii.2000, 1 spec. (MZUSP 13917); Sandovalina, rio Paranapanema, 22°33′78.0″S 51°54′69.3″W, 24.viii.2000, 23 spec. (MZUSP 13916); idem, 10 spec. (INPA 873); Rosana, Rosana hydroeletric dam, 22°36′32″S 52°51′45″S, 14.x.2002, 9♂ 19♀ (MZUSP 15589); Sandovalina, 22°39′26.8″S 51°25′11.2″W, 25.viii.2000, 25 spec. (DZ-USP); Rio Paranapanema, Salto Grande hydroeletric dam, Salto Grande, 22°54′07″S 50°00′02″W, 12.x.2002, 9♂ 35♀ (MZUSP 15607); Rio Paranapanema, Chavantes hydroeletric dam, Chavantes, 23°06′37″S 49°43′25″W, 11.x.2002, 13♂ 17♀ (MZUSP 15577); Rio Paranapanema Basin, Pirajú, 23°11′06″S 49° 22′ 43″W, 10.x.2002, 1♂ (MZUSP 15582).

Remarks – Adults of *M. amazonicum* are easily characterized by the long and sinuous rostrum, which is arched over the orbits and obliquely curved upwards in its distal portion, and by the conical shape of the telson, which tapers gradually towards the tip. The posterior margin ends in an acute median point with no distinct discontinuity and bears two pairs of spines, the inner one not overreaching the apex of the telson. However such characters are not so marked in juveniles and immature specimens, which add some difficulties to their identification. At this stage, they could be confused with *M. jelskii* or even *M. acanthurus*, which have similar morphology. Ovigerous females of *M. amazonicum* carry numerous and relatively small eggs, from which a zoea larva hatches; its larval development can present as many as 11 free-swimming stages (Magalhães 1985). The specimens collected in São Paulo are small to medium sized animals in which the above morphological characters are not so clearly visible.

Macrobrachium amazonicum has a native distribution in the coastal river basins of northern South America (Venezuela to northern Brazil), as well as in most of the Orinoco, Amazon, Paraguay, and lower Paraná river basins (Holthuis 1952, 1966; Rodríguez 1980, 1981; Coelho and Ramos-Porto 1985; López and Pereira 1996; Pettovello 1996; Magalhães 1999b, 2001). The species is also present in the northeastern and eastern states of Brazil (Coelho and Ramos-Porto 1985; Ramos-Porto and Coelho 1990, 1998; Arraes and Ramos-Porto 1994; Barros and Braun 1997), but their distribution in these states is probably due to anthropogenic dispersion for aquaculture purposes (Ramos-Porto and Coelho 1998).

Macrobrachium jelskii (Miers)-Figure 1(3, 4)

Material – Brazil, São Paulo: Rio Tietê Basin, rio Tietê, reservatório de Três Irmãos, ii.2000–xvi.2000, 44 spec (2 ov. ♀) (MZUSP 13550); rio Mogi-Guaçu, Barrinha, 21°11′S 48°09′W, 12.x.1999, 2 spec. (MZUSP 13101); Rio Tietê Basin, Penápolis (21°24′S 50°04′W), 18.xi.2001, 1 ov. ♀ (INPA 888); Penápolis (21°24′S 50°04′W), represa Rio Bonito, 29.vii.1995, 57 spec. (INPA 585); idem, 18.xi.1995, 52 spec. (INPA 586); Rio Tietê Basin, represa de Barra Mansa, Mendonça (21°10'S 49°34′W), 15.xi.2001, 55 spec. (3 ov. ♀) (INPA 887); Lins, RPPN Dr. Ivan, 21°34′18″S 49°38′19″W, 21.i.2003, 9♀ (1 ov.) (MZUSP 15575).

Remarks – The telson of *M. jelskii* always shows a distinct posterior margin, with a clear descontinuity between the lateral margins and the median point. The inner pair of spines of the posterior margin, even in adults, is longer than the median point. The tip of the rostrum is curved upwards, but it is usually straight over the orbits. Ovigerous females carry few and relatively large eggs; larvae hatch as benthonic, well advanced form which goes through three stages until metamorphosis is accomplished (Magalhães 2002).

The distribution of this species is similar to that of *M. amazonicum*, considering either natural or anthropogenic dispersal (Holthuis 1952, 1966; Rodríguez 1980, 1981; Coelho and Ramos-Porto 1985; Ramos-Porto and Coelho 1990, 1998; Arraes and Ramos-Porto 1994; López and Pereira 1996; Barros and Braun 1997; Magalhães 1999b, 2001; Collins 2000).

Trichodactylidae H. Milne-Edwards

Dilocarcinus pagei Stimpson-Figure 1(5)

Material – Brazil, São Paulo: Rio Grande, between Mira Estrela and Cardoso, 20°01′51″S 50°00′59″W, 23.i.2003, 3 juv., (MZUSP 15581); Rio Turvo, between Riolândia and Cardoso, 20°04′29″S 49°48′46″W, 23.i.2003, 1 juv. ♂ 2 juv. ♀ (MZUSP 15592); Rio Grande Basin, Colômbia, 20°10′08.7″S 48°36′83.5″W, 24.vii.2000; 3♂ (MZUSP 13915); Rio Turvo, between Icem and São José do Rio Preto, 20°25′07″S 49°16′03″W, 23.i.2003, 3 juv. ♂ 2 juv. ♀ (MZUSP 15595); Rio Pardo, between Barretos and Guaíra, 20°26′58″S 48°27′16″W, 24.i.2003, 1 juv. ♀ (MZUSP 15593); Rio Grande Basin, São José do Rio Preto, açude municipal, 20°48′S 49°22′W, 12.x.1999, 6♂ 2♀ (MZUSP 13100); idem, 2♂ 1♀ (INPA 774); São José do Rio Preto, represa Rio Preto, 1.viii.1994, 1♂ (MZUSP 12128); Rio Mogi Guaçu Basin, Viradouro, Fazenda Três Barras, 20°54′48.9″S 48°10′29.6″W, 11.viii.2000, 2♂ (INPA 872); Viradouro, 20°55′35.2″S 48°10′28.7″W, 11.viii.2000, 2 ♂ (DZ-USP); Barrinha (21°11'S 48°09′W), rio Mogi-Guaçu, 12.x.1999, 2♀ (MZUSP 13099); idem, 1♀

(INPA 773); Barrinha, Rio Mogi-Guaçu, 21°11′09″S 48°10′35″, 25.i.2003, 6 juv. ♂ (MZUSP 15597). – Paraná: Rio Paranapanema Basin, Londrina, Fazenda Doralice, em lagos, 22.vi.2002, 1 ♂ 1 ♀ (INPA 894).

Remarks – This crab has a strongly convex carapace in the anteroposterior direction, with six or, rarely, seven teeth in the anterolateral margins. They are promptly identified by a distinct transverse carina along the anterior margin of the third abdominal somite in both males and females. In live specimens, the carapace is usually bright red. Its distributional range includes the Amazon, Paraguay and lower Paraná river basins, from Brazil to Argentina (Bott 1969; Lopretto 1981; Rodríguez 1992). The above records extend this range to the upper Paraná River basin, including the states of São Paulo and Paraná.

Discussion

Five exotic decapod species are reported in natural environments in the hydrographic basins of the state of São Paulo (Figure 2), and their occurrence could be related to different causes. The crayfish *Procambarus clarkii* has a worldwide dispersion and Hobbs III et al. (1989) mentioned that introductions of *P. clarkii* in Latin America were probably aiming at commercial aquaculture

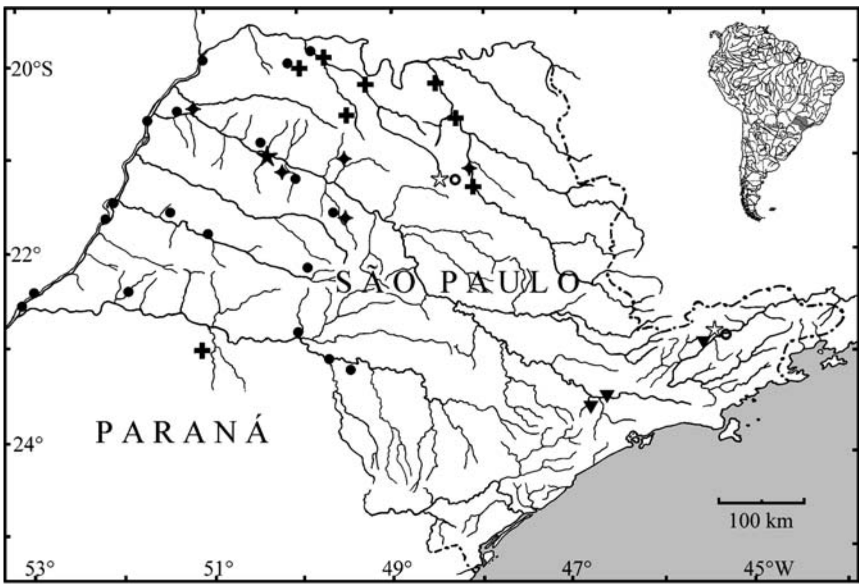

Figure 2. Map with the distribution of the exotic decapod species recorded in the states of São Paulo and Paraná, Brazil. Symbols (solid: occurrence in the wild; open: occurrence in aquaculture ponds): *Procambarus clarkii* = ▼, *Macrobrachium amazonicum* = ●, ○; *Macrobrachium jelskii* = ✦,✧; *Macrobrachium rosenbergii* = ★,☆; *Dilocarcinus pagei* = ✚. (Some symbols may represent more then one locality.)

for United States markets. It appears, however, that this is not the case for Brazil, where the species apparently has never been commercially reared for human consumption. Its occurrence in São Paulo is most problably due to its commercialization as aquarium pet.

In the city of São Paulo, illegal breeding and cultivation of *P. clarkii* has been carried out in several technically poorly conceived small-scale domestic hatcheries in recent years. Juvenile specimens are then sold to local pet shops where this crayfish species is routinely and openly commercialized. Its occurrence in natural environments can possibly be imputed to accidental or even inconsequent release by regretful aquarium keepers.

The shrimp *Macrobrachium rosenbergii* was imported to Brazil from Hawaiian commercial farms in 1977 for aquaculture studies carried out by the Universidade Federal de Pernambuco (Cavalcanti 1998). *M. rosenbergii* was introduced in São Paulo, probably for research purposes, during the early 1980s. During this decade, culture of this species overspread all over the state. Post-larvae came from local hatcheries and also from the states of Pernambuco, Rio de Janeiro, and Espírito Santo. It is certain that *M. rosenbergii* was farmed in earthen ponds in all main river basis of the state. Personal information (WCV) on sporadic capture of specimens in natural waters has been made during the past 20 years. However, there is no report on successful reproduction in the wild.

It seems that there is no well-established population of *M. rosenbergii* in São Paulo. One factor that surely contributes to prevent the establishment of this species in natural waters is the physiological dependence of the larvae to brackish water (Ling 1969). Currently, all *M. rosenbergii* farming in operation in the state of São Paulo are located in river systems that do not drain directly to the coast. The very large adult male specimen collected in the Tietê River Basin at Brejo Alegre in 2001 (see Figure 2) had probably escaped accidentally from a commercial shrimp farm and this escaping may well not have been an isolated occurrence. However, the direction of flow of the Tietê River water system is opposite to the coast line, and the system eventually drains into the Paraná River.

As opposed to *P. clarkii* and *M. rosenbergii*, *M. amazonicum*, *M. jelskii*, and *D. pagei* are endemic to tropical South America, where they have a wide geographical distribution. We hypothesize that they are not native to the upper Paraná River basin, but were deliberately and or accidentally introduced there. The presumptive natural distribution of these species includes the Orinoco (except for *D. pagei*), Amazon, and Paraguay/lower Paraná river basins. They probably evolved in one of these regions after river systems regarded as ancestral of the western paleo-Amazonas-Orinoco and Paraná systems were established along the foreland of the emerging Andes from late Cretaceous/early Paleocene (for a summary of the history of South American rivers, see Lundberg et al. 1998). The Amazonian and Paraguay/lower Paraná decapod fauna have several common elements, and these species would probably have dispersed across these paleobasins after subsequent geological events shifted their boundaries, promoting different sequences of capture of headwater by one or another basin during Tertiary and Quaternary (Lundberg et al. 1998). Whereas the Paraguay/lower Paraná resulted from the uplifting of the Andes and episodes of marine transgressions and regressions in the latest $\sim$ 90 Myr, the upper Paraná has a more ancient origin, probably linked to the South America/Africa separation during Jurassic-Cretaceous (Stevaux et al. 1997). The upper Paraná drains highplain areas of the southern Brazilian Shield, an ancient Precambrian crystalline basement area in which the sedimentary basin of the upper Paraná has been largely non-marine since Triassic (Lundberg et al. 1998). Sedimentological evidences reveal that the paleo-drainage of the Paraná Basin during late Cretaceous is similar to that existent today (Fulfaro and Suguio 1974). Therefore, the two parts of the basin have marked differences in their geomorphology, limnological, and biotic characteristics (Bonetto 1986a). Composition of the upper Paraná aquatic biota is usually very distinct from that of the rest of the basin, as seen for fishes (Bonetto 1986b; Menezes 1988, 1996; Castro and Menezes 1998), microcrustaceans (Lansac-Tôha et al. 1997), and decapods (see below), for instance.

Natural dispersion of decapod fauna towards the upper Paraná would have been prevented by the Guaíra Falls, a series of imposing falls which marked the end of the upper course of the Paraná River (Bonetto 1986a) before it had been inundated by the artificial reservoir of the Itaipu dam in 1982. Dispersal across the headwaters of eastern tributaries of the Paraguay River and western tributaries of the upper Paraná River could also have been avoided by the uplifting of the Serra de Maracaju during mid-Pliocene (Stevaux 1994; Stevaux et al. 1997). Although *M. amazonicum* is presently established in some of these western tributaries of the Paraná River (Porto 1998) and basin interconnections are eventually possible during flood season, natural dispersal should not have occurred through this region due to adverse ecological conditions to these species, since they are not typical of headwater environments. Indeed, a longitudinal inventory carried out in the Rio Negro, a eastern tributary of the Paraguay River, rendered no collections of these species in headwater areas (Magalhães 2000).

Disregarding possible synonymies and a few doubtful records, and taking into account only native species in both parts of the basin, there are no common elements among the decapod fauna recorded for both upper and lower Paraná in the historic scientific literature (Ringuelet 1949; Lopretto 1976, 1981, 1998; Boschi 1981; Bisbal 1987; Magalhães and Türkay 1996; Pettovello 1996; Magalhães 2000, 2001; Collins 2000; Collins et al. 2002; see also Magalhães 1999a for other citations). Therefore, the occurrence of *M. amazonicum*, *M. jelskii*, and *D. pagei* in the upper Paraná might be considered as the result of direct (planned or accidental translocations) and/or indirect (displacement of barriers) antropogenic actions, as discussed below.

The introduction of these two shrimp species in São Paulo was reported by Machado (1966) and Torloni et al. (1993). Torloni et al. (1993) confirmed that between 1966 and 1973 *M. jelskii* (and probably also *M. amazonicum)* was introduced in the CESP (Companhia Energética de São Paulo) pisciculture stations as part of the transplantation process of the Scianidae fish, *Plagioscion squamosissimus* (Heckel), from reservoirs of northeastern Brazil. Commenting on *P. squamosissimus*, Torloni et al. (1993) reported that fries escaped to natural environments in the Rio Pardo in 1970, and later dispersed to the Rio Grande, reaching the Ilha Solteira and Jupiá Reservoirs, in the upper Rio Paraná, in 1972. Hence, it is reasonable to assume that the freshwater shrimps could have followed the same pattern of dispersal, as *M. amazonicum*, which is currently a well established and abundant species in the upper Rio Paraná floodplains (Bialetzki et al. 1997), where the species found thriving ecological conditions. The presence of *M. jelskii* in localities of the upper Rio Paraná Basin could also have a similar explanation.

Currently, *M. amazonicum* is experimentally reared in earthen ponds in Jaboticabal, at the Centro de Aquicultura da UNESP (CAUNESP) (Moraes-Riodades 2002) and in cages placed in aquaculture ponds in Pindamonhangaba, at the Instituto de Pesca de São Paulo. Post-larvae are produced at hatcheries of the CAUNESP, from broodstock originally brought from the state of Pará in 1999 and 2001. These animals have been subjected to very strong control procedures to avoid accidental dissemination, and post-larvae are only available for research institutions.

However, *M. amazonicum*, *M. jelskii*, and *D. pagei* may also have been transplanted to some localities in São Paulo from populations occurring in the Pantanal region, in the state of Mato Grosso do Sul. Currently, the practice of 'Pesque & Pague', which are places for game fishing where people pay by weight caught, is widespread in the state of São Paulo. Some fish species captured from natural environments in the Pantanal were sometimes employed to populate ponds and reservoirs used in such activity. Larvae, juveniles, or immature forms of decapods may have been transported inadvertently along with the roots of the aquatic macrophytes, sometimes used as shelter for fish in containers. The crab *D. pagei* or the shrimps *M. amazonicum* and *M. jelskii* are very abundant in habitats formed by large patches of aquatic floating vegetation, a common feature in the extensive floodplain areas of the Pantanal (Magalhães 2000) and Paraguay River Basin (Magalhães 2001).

Another likely reason for the establishment of these three species in the upper Paraná is the inundation of the Guaíra Falls after formation of the Itaipu Reservoir in October 1982. The barrier was then displaced 150 km downriver, allowing possible upstream dispersal of these decapods. The favorable ecological conditions provided by the lentic environment of the reservoir and the adjacent floodplain areas of the upper course would have contributed for a rapid colonization of the region by these species. Such upstream dispersal of lower Rio Paraná faunal components was also verified in some fish species (Agostinho et al. 1992, 1994).

According to Hobbs III et al. (1989), introductions of *P. clarkii* have usually brought negative consequences. Burrowing activity of the species accounts for damage to levees, dams, and irrigated plantation farms, particularly rice fields, as well as in pisciculture earthen ponds. Measures for reducing such environmental damages were introduced in California (USA), Spain, and Japan, where strong pesticides were used in order to eliminate crayfish populations (Huner 2002). Damages associated with the introduction of *P. clarkii* have been reported, for instance, in Spain (Gutiérrez-Yurrita 1998), Portugal (Correia and Ferreira 1995; Ilhéu et al. 2002), Kenya (Mkoji et al. 1999), and Mexico (Rodríguez-Almaraz and Campos 1994).

The crayfish *P. clarkii* is well adapted to survive in temporary habitats (tolerates low oxygen and aerial exposure, persists for extended periods in burrow systems in the absence of surface waters), lack of larval phase (direct development), shows rapid growth rates and early sexual maturation (Huner and Lindqvist 1995). Introduction of this species may cause negative effects to communities of native aquatic organisms, particularly mollusks, amphibians and young fishes (Nyström 2002). Hobbs III et al. (1989) pointed out that polytrophy makes this crayfish a keystone species in controlling species composition of aquatic ecosystems.

However, the most problematic aspect of introducing *P. clarkii* may be related to the widespread introduction of new diseases to native populations of aquatic organisms, as it can act as vector for pathogens. Henttonen et al. (1997) reported the infection of *P. clarkii* by *Psorospermium* spp. and Diéguez-Uribeondo et al. (1994) showed that the species could be a vector for fungi such as *Saprolegnia parasitica* Coker and *Aphanomyces astaci* Schikora. The latter is considered a plague, being responsible for the decimation of many crayfish populations in Spain (Cuellar and Coll 1983), Ireland (Matthews and Reynolds 1992), and Great Britain (Holdich 2000). Although acting as vector for aphanomycosis, *P. clarkii* itself is quite resistant to infection (Evans and Edgerton 2002). Introduction of this species in Brazil may represent a serious ecological problem, since one of the fungus strains isolated from *P. clarkii*, is physiologically adapted to warm waters such as those of tropical and subtropical regions (Diéguez-Uribeondo et al. 1995). Negative effects on species of *Parastacus*, a South American endemic crayfish genus occurring in southern Brazil, are unknown but could be potentially high, as they may not show resistance to this plague at all.

M. rosenbergii has been farmed in dozens of other countries in Easter and Western hemispheres during the past 30 years, but there is little information about its colonization in natural waters (New et al. 2000). Even so, there are no reports of any economic damage or environmental impact related to the introduction of this species (New et al. 2000). Similarly, nothing has been reported about negative ecological effects associated with the introduction of *M. amazonicum* and *M. jelskii* in northeastern of Brazil during the past 60 years. On the other hand, nothing can be stated about the introduction of *D. pagei* because it has been observed only recently.

Hydrographic basins of São Paulo have been suffering from several anthropogenic interventions that drastically changed the aquatic biota, such as man-made dams, removal of the riparian vegetation, inappropriate agriculture practices, contamination by industrial and organic wastes, which increased siltation, increased suspended material, and caused changes of physical and chemical parameters of the water (Tundisi et al. 1999). Introduction of an alien species in a disturbed environment could favor the exotic species over native ones, by means of predation or competition for niches. Some studies have shown that privileging endemic or native species in actions for conservation of natural areas and recovering of disturbed ones is a fundamental aspect for the maintenance of ecosystem biodiversity and for the better understanding of their biotic and abiotic interaction processes (Tundisi et al. 1999). The results presented here suggest that, except for *M. rosenbergii*, these species may be established, and indicate that they are probably widely distributed in the upper Paraná River drainage. Populational studies should be conducted to corroborate this hypothesis.

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