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## Conservation implications of behavioural interactions between the Giant African Snail and a Native Brazilian species

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The Giant African Snail *Achatina fulica* is widely considered one of the most invasive species in the world. *Megalobulimus paranaguensis* is a snail endemic to the Brazilian Atlantic Rainforest. Data on possible interactions between *A. fulica* and terrestrial mollusc species are scarce. We tested whether the presence of *A. fulica* affects the behaviour of *M. paranaguensis*. We put three individuals of *A. fulica* and three individuals of *M. paranaguensis* in the same aquarium and quantified the time spent in seven behaviours, during three nights ( $n = 72$  individuals for *A. fulica* and *M. paranaguensis*). We also tested the effect of sexual maturity, putting juvenile and adult individuals of both species in the same aquarium. We found behavioural differences between species, among individuals exposed to interspecific interactions and in interactions between these factors, but there was no difference in behaviour between juveniles and adults in the same species and between species. *Achatina fulica* changed its behaviour in interspecific interaction, becoming more active than usual, but *M. paranaguensis* did not change its behaviour in the presence of the alien species. Our results show that interspecific interaction has an effect on the behavioural patterns of the alien species, and the main factor negatively impacting *Megalobulimus* populations in Brazil is probably the non-specific control of *A. fulica* and the alteration and destruction of its habitats.

KEY WORDS: *Megalobulimus paranaguensis*, *Achatina fulica*, biological invasion, native invertebrates, competitive exclusion.

### INTRODUCTION

Alien species are a significant ecological problem. Competition for resources usually occurs between native and alien species (Bøhn et al. 2007) and can alter natural

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communities (Parker et al. 1999). Niche overlap is usually high in this situation, and intense competition may lead to rapid decline and even the extinction of native populations (Novacek & Cleland 2001; Webb et al. 2002; Bøhn et al. 2007). The interactions between native and alien species are multifaceted, and include hybridisation, introgression, mutualisms, behavioural and trait shifts, direct predation, niche displacement and competitive exclusion, and can result in extinction (Mooney & Cleland 2001).

The Giant African Snail, *Achatina fulica* Bowdich 1822, is considered one of the most highly invasive species in the world (Lowe et al. 2004), with numerous associated negative environmental impacts. This snail can act as an intermediate host of several nematode species, including *Angiostrongylus cantonensis* (Chen 1935), which causes eosinophilic meningoencephalitis (Teles et al. 1997; Caldeira et al. 2007). Thus, both the parasite and its host represent a public health concern in Brazil as they are present in many Brazilian states (Thiengo et al. 2007, 2013). *Achatina fulica* is a generalist species in terms of its diet (Albuquerque et al. 2008), and one snail can lay clutches of up to 400 eggs, with an annual production of up to 1200 eggs (Rault & Baker 2002). On the islands in the Pacific and Indian Oceans, biological control efforts against *A. fulica* (including the introduction of predatory snails and flatworms) have caused the extinction or decline of endemic island species of land snails (Cowie 1992, 1998, 2001; Civeyrel & Simberloff 1996; Sugiura et al. 2011; Holland et al. 2012), due to the general predatory habits of the introduced predators. However, neither competition between *A. fulica* and the native fauna nor any other negative effects were demonstrated in these studies, despite reported predation by *A. fulica* on invasive veronicelid slugs in Hawaii (Meyer et al. 2008). This observation, especially when combined with the biological characteristics of this species, suggests that *A. fulica* may pose a threat to native land snail fauna.

*Megalobulimus paranaguensis* (Pilsbry & Ihering 1900) was originally described in the Brazilian state of Paraná, as well as in Peruibe and Iguape, southern coastal cities in the state of São Paulo (Morretes 1954; Simone 2006) and the north of Santa Catarina State (Agudo-Padron 2014). The species exhibits low population density (Eston et al. 2006) and, like various native terrestrial mollusc species (Simone 1999), exhibits low reproductive potential, laying only 2–5 eggs per clutch (Sobreira & Molina 2002). It buries itself in the soil or leaf litter of rainforests during the day and during its dormancy period (Bequaert 1948; Morretes 1952). The species also exhibits unusually high longevity, and can reach 35.5 years of age (Fontenelle & Miranda 2012). The population dynamics of the genus is poorly understood because these species are cryptic, and not commonly observed. Many species in the genus *Megalobulimus* are endangered because they are often mistaken for the giant African snail *A. fulica* and killed (Colley & Fischer 2009). They are also endangered because of the degradation of their natural habitat (Bequaert 1948; Miranda et al. 2015). A number of studies report population declines (Fischer & Colley 2005), probably due to large-scale deforestation that has occurred in some regions of Brazil (Bequaert 1948), and some data suggest risk of extinction of certain species (Leme 1989; Leme & Indrusiak 1990). Moreover, climate change may pose an additional threat for species of the genus (Beltramino et al. 2015).

Studies focusing on interactions among species of terrestrial molluscs that inhabit the same habitat are scarce. It has been suggested that interference among terrestrial snails may be mediated through aggressive behaviour (Cook 2001; Meyer et al. 2008; Kimura & Chiba 2010) or through the production of mucus (Cameron & Carter 1979; Tattersfield 1981; Pearce 1997; Cook 2001). However, few studies have provided explicit evidence of interspecific interactions among land snails, and these studies have been

restricted to European (e.g. Cameron & Carter 1979), and Japanese (Kimura & Chiba 2010) environments. Miranda et al. (2015) found *A. fulica* and *M. paranaguensis* occurring within the same habitat on the Brazilian island Ilha Porchat, located in São Vicente, but they did not find negative interactions between them when they investigated spatial niche overlap. Little is known about interaction between land snails in other environments, especially among native and alien land snail species, and behavioural studies can be informative for understanding this interaction. In this study, we tested whether the presence of the alien snail *A. fulica* affects the behaviour of the adults and juveniles of the native Brazilian species *M. paranaguensis*. Here we tested the hypothesis that the presence of *A. fulica* changes the behavioural pattern and/or activity pattern of *M. paranaguensis*.

## MATERIAL AND METHODS

We collected snails from Ilha Porchat (23°58'46"S, 46°22'08"W), part of the city of São Vicente, in São Paulo, Brazil, and from the mollusc collection of the Biosciences Institute in the Coastal Campus of São Paulo State University (UNESP). We measured the shell length of each snail using a digital caliper with a precision of 0.01 mm. The specimens received water, lettuce and canary bird vitamins ad libitum. We divided the *A. fulica* specimens into two groups: juvenile (shell length < 40 mm) and adult (shell length > 70 mm), according to Kondo (1964). We did not use the young adults (40–70 mm shell length) because the animals were not sexually mature (Kondo 1964). In the case of *M. paranaguensis*, we determined sexual maturity based on the presence of the outer lip in the shell (Bequaert 1948), and we then separated the specimens into groups of juveniles and adults. We acclimated the snails to the experimental conditions in the laboratory for 3 days: 23.5 °C, 75% relative humidity, a photoperiod of 12 hr light/12 hr dark, and 50 × 20 × 20 cm aquariums. We filmed the interactions during the dark 12 hr period, because both species are nocturnal (Bequaert 1948; Tomiyama 2000; Rault & Baker 2002). We inserted three individuals per species with the other species, in the same aquarium with food and water ad libitum, for a total of six specimens in the same terrarium. We also tested the effect of sexual maturity in interspecific interaction, putting juvenile individuals of one species with the adults of the other species. Each experiment was repeated 3 times, and different snails were used in all cases.

Behavioural data were based on 5184 hr of film (36 hr per snail). We recorded the time frequency of seven behaviours for each specimen: (1) *Retracted into the shell* – this is a perfectly quiet state in which the animal may assume one of two stances: (a) retracted into the shell, with the border of the mantle forming a kind of collar around the foot, exposing the pneumostome; or (b) partially retracted, showing the border of the foot close to the cephalic region, which is retracted into the shell (Romero & Hoffmann 1991); (2) *Still with local activity* – the head and foot are out of the shell, and the animal may be: (a) alert: partially or completely extended with tentacle movements, without displacements; (b) making oscillatory movements: this state is similar to the previous state, but with the addition of rhythmic movements of the head, which oscillates horizontally or (c) with complex oscillatory movements: the animal moves the head up and down and back and forth rhythmically through arcs of different angles between the horizontal and frontal planes (Romero & Hoffmann 1991); (3) *Locomotion* – the animal is completely extended, showing the oscillatory movements of the tentacles. When the animal is crawling over glass, locomotory waves may be observed on the sole of the foot. The animal's locomotion is unequivocal (Jurberg et al. 1988; Romero & Hoffmann 1991; Junqueira et al. 2003); (4) *Eating* – the animal's head is lightly retracted into its body with the tentacles lowered. Rhythmic movements of mouth structures may be seen, promoting food displacement (Jurberg et al. 1988; Romero & Hoffmann 1991; Junqueira et al. 2003); (5) *Vertical locomotion* – the animal moves around on the walls of the aquarium, and it makes oscillatory movements of head and tentacles similar to those seen during locomotion (Junqueira et al. 2003); (6) *Interaction between individuals* – the animal uses its

tentacles to touch the tentacles, shell or body of another individual, or it raises the shell of another animal (Junqueira et al. 2003); and (7) *Watering* – the animal enters the water and remains motionless or moves around with tentacles outstretched, making small movements in contact with water (Jurberg et al. 1988).

According to Minorette et al. (2011), the frequencies of each type of behaviour are not independent from each other, and multivariate analyses are necessary for data analysis. We used a principal components analysis (PCA) with an arcsine transformation to convert the non-independent data that represented the different types of behaviour into uncorrelated variables for each individual, and then to verify differences in behavioural patterns documented in the experiment. With the same data, permutational multivariate analysis of variance (PERMANOVA; Anderson 2001) was used with three factors (species, sexual maturity and interspecific interaction) with 999 permutations, to see which factor influenced the behavioural pattern.

RESULTS

We found differences in behaviour between species and among individuals exposed to interspecific interaction, and in the interaction between these factors (Table 1). With the PCA, the activity pattern was successfully explained in the first axis, which explained 59.4% of the variation in the data (Fig. 1). The behaviour of retracting into the shell had the largest positive eigenvector in the first axis, while the other behaviours had negative eigenvalues. Among other behaviours, vertical locomotion had a large eigenvector (Table 2). Specimens with positive values in the first axis of PCA were less active (they spent more time retracted into the shell), while specimens with negative values were more active (they spent more time engaged in other behaviours, especially vertical locomotion). In the second axis which explained 20.4% of the data, the behaviours of eating and vertical locomotion had the largest eigenvectors, with opposite sign, and in the third axis, which explained 10.2% of the data, the behaviours locomotion and eating had the largest eigenvectors, also with opposite signals. PCA differentiated *A. fulica* with and without interaction. Individuals in interaction became more active than usual and engaged in much more vertical locomotion. In *M. paranaguensis*, there were no differences between individuals with or without interaction. In the descriptive data, *A. fulica* specimens were

Table 1.  
Results of permutational analyses of variance (PERMANOVA). Significant values are marked with an asterisk.

Factor	df	MS	F	P
Species	1	0.587	19.903	0.001*
Maturity	1	0.014	0.491	0.667
Interaction	1	0.111	3.768	0.017*
Species/maturity	1	0.008	0.279	0.81
Species/interaction	1	0.121	4.104	0.009*
Maturity/interaction	1	0.003	0.119	0.925
Species/maturity/interaction	1	0.000	0.000	1
Residuals	136	0.029		

MS: mean square.

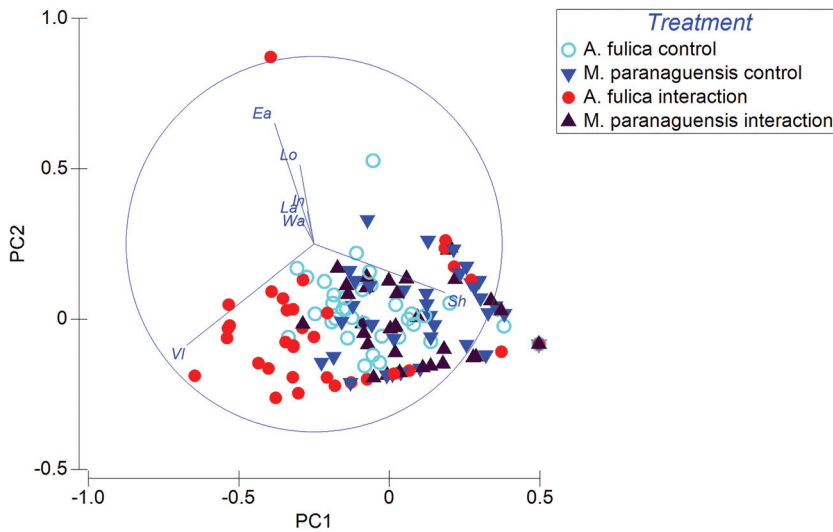


Fig. 1. — Principal component analysis (PCA) biplot for the experiment. Vector captions: Sh = retracted into the shell; La = still with local activity; Lo = locomotion; Ea = eating; VI = vertical locomotion; In = interaction between individuals; Wa = watering.

Table 2.  
Principal component analysis (PCA) results of the experiment.

	PC1	PC2	PC3
Eigenvalues	0.067	0.023	0.011
Proportion explained	59.4%	20.4%	10.2%
Cumulative proportion	59.4%	79.8%	90.0%
Eigenvectors			
Retracted into the shell	0.695	– 0.257	0.075
Still with local activity	– 0.073	0.139	– 0.101
Eating	– 0.211	0.643	0.594
Locomotion	– 0.075	0.420	– 0.787
Vertical locomotion	– 0.678	– 0.538	– 0.002
Interaction	– 0.037	0.176	– 0.082
Watering	– 0.035	0.067	– 0.064

found to be more active, spending less time retracted into the shell and more time performing other behaviours, while *M. paranaguensis* was found to be less active, spending more time retracted into the shell (Table 3). When interacting, *A. fulica* had a significant change in its behavioural pattern: it further reduced its retraction into the shell and significantly increased its vertical locomotion. For *M. paranaguensis*, no differences in behaviour were observed.

Table 3.

Mean values of the percentages of behaviours analysed. Standard deviations are shown in parentheses.

Behaviour	<i>A. fulica</i> control	<i>A. fulica</i> with interaction	<i>M. paranaguensis</i> control	<i>M. paranaguensis</i> with interaction
Retracted into the shell	81.45 (8.52)	72.52 (16.12)	89.19 (7.54)	88.40 (7.56)
Still with local activity	1.44 (2.13)	1.34 (2.03)	0.34 (0.64)	0.16 (0.32)
Eating	2.61 (4.19)	3.61 (9.98)	2.01 (2.83)	1.61 (3.06)
Locomotion	4.00 (2.89)	1.65 (2.48)	1.82 (2.73)	2.73 (3.14)
Vertical locomotion	9.61 (5.93)	19.99 (13.65)	5.53 (6.66)	6.69 (5.53)
Interaction	0.24 (0.48)	0.62 (0.81)	0.76 (1.32)	0.34 (0.60)
Watering	0.48 (0.82)	0.32 (0.71)	0.31 (0.72)	0.04 (0.11)

## DISCUSSION

Our results show that interspecific interaction has an effect on the behavioural patterns of the alien species *A. fulica*, but we observed no evidence of an effect of the presence of *A. fulica* on the native species *M. paranaguensis*. *Achatina fulica* became more active and moved more frequently in the presence of *M. paranaguensis*. In this case, *A. fulica* also preferred to perform more vertical locomotion than usual in order to remain in different spatial regions. *Achatina fulica* tended to be more active and more fully explored its environment, while *M. paranaguensis* was generally less active, including in the presence of the second species. These results explain the data from the field study by Miranda et al. (2015), which analysed spatial niche overlap. In this study, no effects of interspecific competition between these species were detected. Sympatric species may avoid competition by altering any of their behaviours that directly affect the utilisation of limited resources (Cook 2001). It is widely accepted that niche differentiation is often the basis for the coexistence of competitors (MacArthur & Levins 1967). Interspecific competition favours niche differentiation between competitors because it is often asymmetric, and also because the dominant and subordinate species may optimise their behaviour in different ways (Maynard-Smith & Parker 1976). In this study, *A. fulica* and *M. paranaguensis* were found to have different activity patterns, and these differences could minimise any effects of competition between them. Differences in activity patterns were also found by Asami (1993) in a study on Polygiridae snails that were present in the leaf litter of Appalachian forests.

Similarly to Minoretti et al. (2011), the PCA evidenced that the behaviour “retracted into the shell” occurred more frequently. According to Romero & Hoffmann (1991), this behavioural pattern indicates less activity.

The effects of interference among terrestrial snails and slugs, like aggressive behaviour (Cook 2001; Meyer et al. 2008; Kimura & Chiba 2010) or the production of mucus (Cameron & Carter 1979; Tattersfield 1981; Pearce 1997; Cook 2001) were not observed in this study, although there have been reports of aggressive interactions

between *A. fulica* and an invasive species of slug in Hawaiian islands (Meyer et al. 2008). These behaviours may be rare in nature, or they may occur under unusual conditions, such as a limited food supply or during the return to aestivation.

From the results of this paper, the main factor that may be considered to be affecting *Megalobulimus* populations is the effort to control *A. fulica* populations, and actions that contribute to the degradation of their natural habitat. Examples of this degradation include soil contamination with salt (Fischer & Colley 2005), and capturing and accidental killing of *M. paranaguensis* during *A. fulica* control efforts (Colley & Fischer 2009), since *M. paranaguensis* superficially resembles *A. fulica* (Thiengo et al. 2007). Consequently, these control activities may reduce the lifespan of *M. paranaguensis*, as suggested by Miranda et al. (2015). The effect of flawed control policies against *A. fulica* and the decline of native land snail fauna have been reported by Cowie (1992, 1998, 2001), as well as by Civeyrel and Simberloff (1996). However, long-term ecological and behavioural studies are necessary in order to quantify and understand the threat posed to Brazilian land snail fauna by the establishment of invasive *A. fulica*.

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No potential conflict of interest was reported by the authors.

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