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Short Communication

Potential dispersal of aquatic snails by waterbird endozoochory in neotropical wetlands

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Abstract: Waterbird-mediated zoochory is one of the main ecological mechanisms by which non-flying freshwater invertebrates can disperse between isolated wetlands. Passive dispersal through gut passage inside waterbirds (endozoochory) may explain how many organisms spread in the landscape. Here, we evaluate the potential for dispersal of aquatic snails by three waterbird species in neotropical wetlands. A total of 77 faecal samples from *Coscoroba coscoroba* (n = 28), *Dendrocygna viduata* (n = 36) and *Anas flavirostris* (n = 13) were collected in the field and taken to the laboratory. There, the samples were examined under a stereomicroscope to check for the presence of gastropod shells. We found 496 intact gastropod shells, and *Heleobia piscium* was the most abundant species (n= 485). We also found two shells of *Drepanotrema* sp. and nine others distributed between two different morphotypes of Planorbidae. Snails were present in 20.8 % of all samples, and were more frequent in faeces of coscoroba swan (50%) than the other two bird species. Our data suggest that aquatic snails may disperse by avian endozoochory between neotropical wetlands, with vectors including migratory bird species.
Keywords: *Gastropods; waterfowl; wetlands; neotropics.*

Dispersão potencial de caramujos por endozoocoria de aves aquáticas em áreas úmidas neotropicais

Resumo: A zoocoria mediada por aves aquáticas é um dos principais processos ecológicos que explicam como invertebrados não-voadores habitantes de água doce se dispersam entre áreas úmidas isoladas. A dispersão passiva que ocorre através no interior dos intestinos de aves aquáticas (endozoocoria) pode explicar como estes invertebrados se distribuem na paisagem. Neste trabalho, avaliamos o potencial de dispersão de caramujos aquáticos por endozoocoria promovida por três espécies de aves aquáticas em áreas úmidas neotropicais. No total, 77 amostras fecais de capororoca (*Coscoroba coscoroba,* n = 28), irerê (*Dendrocygna viduata*, n = 36) e marreca-pardinha (*Anas flavirostris*, n = 13) foram coletadas em campo e levadas ao laboratório. As amostras foram examinadas em estereomicroscópio para verificar a presença de conchas de gastrópodes. Encontramos 496 conchas intactas, sendo *Heleobia piscium* a espécie mais abundante (n = 485). Também encontramos duas conchas de *Drepanotrema* sp. e nove de outros dois morfotipos de Planorbidae. Os caramujos estiveram presentes em 20,8% de todas as amostras, sendo mais frequentes nas fezes do capororoca (50%). Nossos dados sugerem que caramujos aquáticos podem se dispersar por endozoocoria de aves entre áreas úmidas neotropicais, com vetores incluindo espécies de aves migratórias e residentes.
Palavras-chave: *gastrópodes; aves aquáticas; áreas úmidas; região neotropical*

Introduction

How some aquatic invertebrates with low locomotion capacity became widely distributed is an issue that has long intrigued naturalists (Darwin 1859, Bohonak & Jenkins 2003, Van Leeuwen 2012 a, b). Waterbird-mediated zoochory is one of the main ecological mechanisms by which non-flying freshwater invertebrates disperse between isolated waterbodies such as lakes and temporary ponds (Figuerola & Green 2002; Silva et al., 2021, Martín-Vélez et al., 2022). Global distribution, high abundance and flight capacity make waterbirds vital vectors for the dispersal of aquatic invertebrates in the landscape (Figuerola et al. 2003, Brochet et al. 2010). Endozoochory, when whole invertebrates or their propagules are passively transported inside the animal vector, has been demonstrated for a wide spectrum of taxa, including organisms without any apparent adaptation to gut passage, such as rotifers, nematodes and dipteran larvae, and others with a resistant structure that may favour survival during stressful conditions, such as bryozoan statoblasts or whole snails (Brown 1933, Proctor 1964, Malone 1965a, 1965b, Green & Figuerola 2005, Brochet et al. 2010, Laux & Kolsch 2014, Simonová et al. 2016, Lovas-Kiss et al. 2018, Moreno et al. 2019, Silva et al., 2021). Even fish eggs and whole plants can be dispersed by waterfowl endozoochory (Silva et al. 2018, Silva et al. 2019).

Gastropod shells are adapted to survive hard environmental conditions and mechanical stress (Chapuis & Ferdy 2012, Havel et al. 2012). Peculiarities of the shell provide physical and chemical resistance that may allow some gastropod species to survive inside the anoxic and high temperature environment of the bird alimentary tract after being ingested, although many shells are excreted empty (or with dead bodies in them) by birds (Cadeé 2011, Wada et al. 2012, Van Leeuwen 2012 a). Avian endozoochory has been considered a plausible explanation for dispersal of some aquatic snails, such as *Physella acuta* (Physidae), *Bithynia tentaculata* (Bithyniidae) and *Potamopyrgus antipodarum* (Tateidae) (Alonso & Castro-Diez 2008, Kappes & Haase 2012, Vinarski 2017, Martín-Vélez et al., 2022). Van Leeuwen et al. (2012 a, b) demonstrated that whole *Hydrobia ulvae* (Hydrobiidae) may survive after gut passage of mallards (*Anas platyrhynchos*), even remaining five hours inside the bird. Considering a waterbird can fly at speeds of 50-78 km/h (Welhun 1994, García-Alvarez *et al*. 2015, Lovas-Kiss et al. 2020), we can assume that snails may be dispersed at different spatial scales, including long-distance dispersal during waterbird migration. Avian vectors have often been proposed as an explanation for the genetic structure of snail metapopulations, or the phylogeography of closely related species (Miller et al. 2006, Holland et al. 2007, Zielske & Haase 2014). Here, we report the occurrence of aquatic snails found in faeces of three waterfowl species, and address the potential for dispersal by waterfowl endozoochory in the neotropic region.

Material and Methods

We analysed data collected in the Coastal Plain of Rio Grande do Sul, southern Brazil, one of the most important regions for waterbird conservation in South America (Silva et al. 2021; Figure 1). We obtained faecal samples of coscoroba swan (*Coscoroba coscoroba*, n= 28); white-faced whistling-duck (*Dendrocygna viduata*, n= 36) and yellow-billed teal (*Anas flavirostris*, n=13) from August 2017 to December 2019 in wetlands located in Tavares and Santa Vitória do Palmar municipalities. Field sample collection and laboratory procedures followed Silva et al. (2021). Briefly, we identified individuals or monospecific groups of three bird species resting or feeding around lake edges, and collected fresh droppings from the grass. We stored samples individually in plastic tubes and frozen (- 4 °C) to avoid fungal infestation. In the laboratory at UNISINOS University, the samples were defrosted, weighed and washed in tap water using a sieve (53 µm). The washed content was analyzed under a stereomicroscope (10x to 1.6x - 5 x of total magnification) to separate the visible snails from other material. We compared the frequency of occurrence of snails in waterfowl faeces through a Chi-square test.

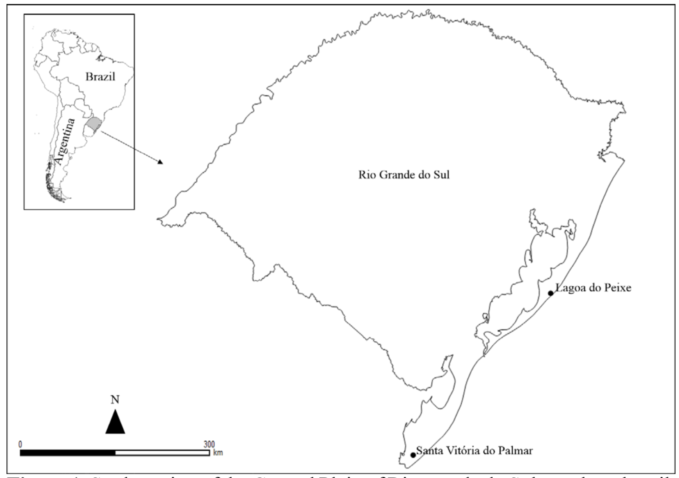

Figure 1. Study region of the Coastal Plain of Rio grande do Sul, southern brazil, where waterflow faecal samples were collected (black dots).

Results

We found 496 intact shells of four different gastropod taxa, *Heleobia piscium* (Hydrobiidae, n= 485; Figure 2), *Drepanotrema* sp. (Planorbidae, n= 2; Figure 3) and nine shells of two other unidentified genera of Planorbidae. Snails were present in 20.8 % of the total samples, and were more frequent in faecal samples of coscoroba swan (57.1%; n=16) than white-faced whistling-duck (2.8%; n=1) and yellow-billed teal (7.7%, n=1). Snails were also more abundant in coscoroba swan samples (X^2 = 1388,2; *df* = 3; *P* < 0,001) than the other two waterfowl species, and this result was influenced by the high abundance of *Heleobia piscium* shells (Table 1). We confirmed the presence of snail bodies inside 68 shells of *Heleobia piscium* (14%), by close inspection under the microscope. The dispersed shells of *Heleobia piscium* had 2.9 mm length (ranging from 2.4 to 3.5 mm) and 1.9 mm width (from 2.4 to 3.5 mm). *Drepanotrema* sp. shells had 4.9 mm length (4.7 mm to 5.5 mm) and 1.3 mm width (1.2 mm to 1.6 mm).

Discussion

Dispersal by avian endozoochory is an accepted explanation for dispersal of some aquatic snails, and the survival by gastropods of passage through avian guts has been repeatedly demonstrated (Cadeé 2011, Wada et al. 2012, Van Leeuwen *et al*. 2012 a, Simonova et al. 2016). Although our method necessarily involved freezing of the samples, making a survival test unfeasible, our study provides evidence that endozoochory may be a valid dispersal process for four different snail taxa in wetlands of southern Brazil. Further studies in which fresh

Figure 2. Helobia piscium shell with parts of animal body inside, found in a faecal sample from coscoroba swan.

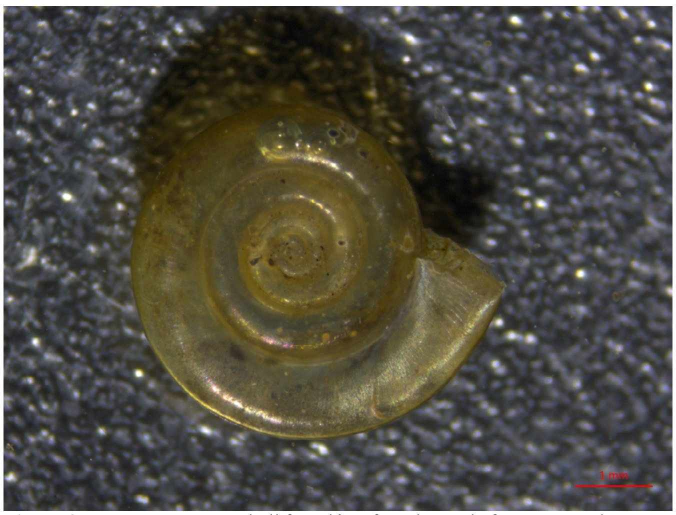

Figure 3. Drepanotrema sp. shell found in a faecal sample from coscoroba swan.

samples are analysed immediately after collection in the field are needed to assess whether these snails were indeed viable.

Some reports indicate that *Heleobia piscium*, the most abundant species observed in our study, is distributed in the Coastal Plain of Rio Grande do Sul and in the region of La Plata River estuary (Darrigran *et al.* 1998, Pfeifer & Pitoni 2003, Coimbra et al. 2013, Martin & Díaz 2016). *Drepanotrema* species are mostly endemic to the Neotropical region, occurring in Southern Brazil, Uruguay and Argentina (Rumi *et al*. 2006, Núñez et al. 2010, Martin *et al*. 2013, Palasio et al. 2019). Shells of *Heleobia piscium* were found in faeces of coscoroba swan and white-faced whistling-duck, and *Drepanotrema* sp. in coscoroba swan. Coscoroba swan is a migratory species and can move up to a thousand kilometres in their seasonal displacement between Argentina and Brazil (Silva et al. 2020). Similarly, white-faced whistling-duck covers hundreds of kilometres in their regular movements through the region, according to resource availability. The distributions of *Heleobia piscium* and *Drepanotrema* sp. overlap with those of coscoroba swan and white-faced whistling-duck, this being consistent with a role for these birds as vectors of snail dispersal.

Table 1. Intact gastropod shells found in faecal samples of three waterbird species in southern Brazil.

Waterbird	Gastropods	Number of shells	Number of samples with shells	Percentage of samples with shells
Coscoroba swan				
	Heleobia piscium	479	9	32.1%
	Drepanotrema sp.	2	1	3.6%
	Planorbidae - Morphotype I	7	5	17.8%
	Planorbidae - Morphotype II	1	1	3.6%
White-faced whistling-duck				
	Heleobia piscium	6	1	2.8%
Yellow-billed teal				
	Planorbidae - Morphotype I	1	1	7.7%

Two unidentified Planorbidae morphotypes (Morphotypes I and II) showed morphology characteristic of young individuals, and for that reason the identification to a lower taxonomic level was not possible. Morphotypes I and II were found in coscoroba swan samples, and Morphotype I was also found in faeces of yellow-billed teal, a resident waterfowl that remains in the region all year-round, making local movements between wetlands separated by several km.

Waterfowl body size may lead to variation in the access to different depths for feeding, and consequently to habitat segregation between species (Pöysä, 1983; Green, 1998; Guillemain et al., 2002; Ntiamoa-Baidu et al., 1998). Despite some overlapping, this general pattern was observed for waterfowl in our study, where extremes of body size (large and small) may affect the species composition of seeds dispersed by endozoochory (Silva et al. 2021). Coscoroba swan was the largest bird species (c.3.500 g), and had access to deepest water for feeding (c.1–1.5 m), where they often fed with the head or neck partially submerged (Silva et al., 2021). In contrast, yellow-billed teal (c. 500 g) fed by dabbling at the surface of shallower water (c. 0.5 cm) while white-faced whistling-duck (c. 800 g) fed by submerging their head in the same deep water (Silva et al., 2021). These differences in access to the bottom of the waterbody, combined with possible unknown differences in the preferred diet, may explain the variation in the abundance of shells among waterfowl species.

With the exception of killifish eggs that were found to be retained for at least 30 h inside the digestive tract of coscoroba swan (Silva et al., 2019), there is no information about gut retention times of any other taxa in the waterfowl species studied here. Furthermore, information about flight patterns of South American waterfowl is limited compared with North American or European species. However, considering flight speeds of 50-78 km/h (Welhun 1994) and that a snail may survive at least five hours inside a waterbird (Van Leeuwen et al. 2012 a), it is possible that dispersal of snails recorded in our study may occur over long distances, especially for taxa dispersed by coscoroba swan and white-faced whistling-duck. For example, satellite tracking data from white-faced whistling-duck in Argentina found birds moving up to >600 km away from the capture site, with individuals having daily average movements of 0.1 - 23 km, and a mean of 4 km (Don Pablo Research Team 2012). In this case, stopover sites used during bird displacement can also be important for snail dispersal in the region. Further studies should investigate the survival during gut passage of the snails identified in our study and the success of their dispersal by waterbird endozoochory in neotropical wetlands, as previously demonstrated in other regions.

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Associate Editor

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Author Contributions

Luiz C. Barboza: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Giliandro G. Silva: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Andy J. Green: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Leonardo Maltchik: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Cristina Stenert: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Ethics

This work was authorized by the Brazilian agency SISBIO (n° 59225-1)

Data Availability

The information necessary to replicate this study is present in the manuscript.

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