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REVIEW PAPER

The conservation of non-marine molluscs in South America: where we are and how to move forward

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Abstract
South America is a high biodiversity continent with five out of 13 countries considered megadiverse. Many major groups within this fauna exhibit high diversity, including non-marine molluscs. With at least 1401 known species, South American molluscs are seriously understudied. The aim of this paper is to review the conservation status of non-marine molluscs in South America, pointing out significant gaps in knowledge and suggesting possible future directions. According to the most recent IUCN Red List only 231 South American non-marine molluscs have been evaluated, with 84 (36%) categorized as Data Deficient. The main knowledge gaps are in taxonomic inventory, especially in unexplored areas, information about current and historic distributions and population sizes, and basic ecological information. Implementation of integrative taxonomy, ecological and distributional studies, exploration of areas and groups as yet largely ignored, development of researcher networks and improvement of public and political awareness and concern about these important and diverse animals are necessary actions for conservation of non-marine molluscs in South America to have any chance of success.

Keywords Gastropoda · Bivalvia · Freshwater snails · Freshwater mussels · Land snails · Slugs

Introduction

Non-marine molluscs include a number of phylogenetically disparate lineages and species-rich assemblages that represent two molluscan classes, Bivalvia (clams and mussels) and Gastropoda (snails, slugs and limpets) (Lydeard et al. 2004; Cuezzo et al. 2020). They are

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important players in non-marine ecosystems, being key organisms in several environments (Dillon 2000; Barker 2001; Vaughn 2018). Some species are of medical importance (Maldonado et al. 2012; Rollinson et al. 2013) and others are recognized as important invasive species causing economic losses and environmental damage (e.g. Barker 2002; Karatayev et al. 2007; Fischer and Costa 2010; Darrigran and Damboreana 2011). Yet while non-marine molluscs are an important component of biodiversity globally, they are one of the most threatened groups of animals (Lydeard et al. 2004; Régnier et al. 2009, 2015a; Cowie et al. 2017a; Lopes-Lima et al. 2018, 2021; Ferreira-Rodríguez et al. 2019; Böhm et al. 2021).

Our aim, therefore, is to review and summarize the conservation status of non-marine molluscs in South America, pointing out problems and suggesting possible future directions.

Non-marine mollusc diversity in South America

South America has a rich fauna of non-marine molluscs (Simone 2006; Bogan 2008; Strong et al. 2008; Cuezzo et al. 2020). However, there are no accurate and comprehensive lists or estimates of native species richness. As a starting estimate, we can combine the numbers of Pereira et al. (2014) (168 freshwater mussels in South America), Strong et al. (2008) (533 freshwater gastropods in the Neotropical Region) and Simone (2006) (700 land snails in Brazil and nearby areas, a number very close to that of Salvador (2019); 702 species for Brazil), for a total of at least 1401 species (Fig. 1). However, this number is a significant underestimate of the total diversity in South America, especially regarding the terrestrial species. Furthermore, additional species have recently been described, in some cases reporting new ecological interactions (e.g. Mansur et al. 2019; Volkmer-Ribeiro et al. 2019) and demonstrating the likelihood of still unknown biodiversity. Moreover, some areas of South America, including Lake Titicaca in Bolivia-Peru and the Lower Uruguay River of Argentina-Uruguay (Fig. 1D), are considered among the 20 global hotspots for freshwater gastropods (Strong et al. 2008). Other regions have been recently inventoried, revealing a rich fauna of land snails (e.g. Wendebourg and Hausdorf 2019; Breure et al. 2022). However, there remain several poorly studied regions that make it even more difficult to obtain an accurate estimate of the real number of species.

Conservation status

Globally the large number of recent extinctions seems to indicate that we are facing a net and rapid loss of biodiversity, an extinction crisis (Cowie et al. 2022). The Red List of the International Union for Conservation of Nature (IUCN) is widely recognized as the world's most comprehensive and objective tool for assessing the risk of extinction of plant and animal species. Lydeard et al. (2004) noted the high number of non-marine molluscs in the global IUCN Red List, and the high level of extinction of these species. Subsequent studies have made it clear that far more species are known to be extinct, although not included in the regularly updated versions of the Red List (Régnier et al. 2009, 2015a, b; Cowie et al. 2017a, 2022). In fact, molluscs are the major group of organisms with the most recorded extinctions, mainly as a result of destruction of habitat but also the often interwoven impacts of invasive species (Lydeard et al. 2004;

Fig. 1 Some native species of South America. A—Specimens of *Acostaea rivoli*, a critically endangered species of South American river oyster; B–A healthy population of *Anodontites trapesialis*, the largest South American mussel; C—*Aylacostoma chloroticum* held in a captive breeding facility during the propagation program in Argentina; D—Oviposition of *Pomacea megastoma*, an endemic species of the Uruguay River basin and included in the list of endangered species of Uruguay; E—*Leiostracus perlucidus*, an emerald green land snail suggested but not yet adopted as a flagship species for mollusc conservation; F—*Phyllocaulis renschi*, an endangered slug in Brazil. Photos: A—Carlos Lasso, B—Igor Miyahira, C—Roberto Vogler, D—Cristhian Clavijo, E—Antonio Carlos Freitas, F—Suzete Gomes

Cowie et al. 2017a; Lopes-Lima et al. 2018; Cowie 2021). An estimate of between 3000 and 5100 mollusc species have gone extinct because of human activities, aside from many local extirpations and functional extinctions, the vast majority of them being non-marine species (Cowie et al. 2017a, 2022). Unfortunately, there is not enough available funding, or even the desire, to protect everything, and thus priorities must be set. However, only ~ 9000 mollusc species, roughly 11% of the ~ 84,000 known (excluding fossil-only) mollusc species (MolluscaBase editors 2022), have been evaluated by IUCN and approximately 25% of these are categorized as Data Deficient (DD) (IUCN 2021). For many of these DD species the threats were recognized but the information available on distribution, reproduction, population structure and other aspects of species biology was insufficient for them to be placed in any of the "Threatened" categories, i.e. Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). This contrasts with mammals and birds, for which 91% and 100%, respectively, of all known species have been evaluated with only around 5% categorized as DD (IUCN 2021).

In order to evaluate the situation in South America in a more detailed way, we extracted the original data from the IUCN (2021) Red List, using as filters: Mollusca for "Taxonomy", South America for "Land Regions", and Freshwater and Terrestrial for "Systems". We obtained 249 records. This list was screened for erroneous entries, i.e. non-native species, estuarine or marine species and species incorrectly listed for South America, which were removed, to leave 231 species of native South American terrestrial and freshwater molluscs evaluated by IUCN: 41 bivalves and 190 gastropods (111 freshwater, 79 terrestrial), distributed across all IUCN categories (Table 1, details in Supplementary Information). Among the 231 assessed species included, 84 were classified as DD, more than in any other category (36% of all evaluated species). In Europe, where there has been a considerably higher number of studies of terrestrial gastropods than in South America, 10.1% of evaluated land snails have been categorized as DD (Neubert et al. 2019). Considering the total number of 1401 species of native non-marine molluscs in South America (itself a gross underestimate), only 16.5% have been evaluated, a tiny fraction of overall biodiversity. According to Lopes-Lima et al. (2018), the Neotropical region is the region with the highest number of mollusc species "Not Evaluated" by IUCN.

The three South American species evaluated as Extinct in the Wild (EW) on the Red List belong to *Aylacostoma*, a genus of freshwater snails: *Aylacostoma stigmaticum*, *A. guaraniticum* and *A. chloroticum* (Fig. 1C), all from the border between Argentina and Paraguay. Subsequent to the IUCN evaluations, Vogler (2012) reported an extant population of *A. chloroticum* in Argentina; Peso et al. (2013a, b) reported that *A. guaraniticum* and *A. stigmaticum* were not represented by any captive populations and are presumably extinct; and Vogler et al. (2014) described a new species (*Aylacostoma brunneum*) from captive populations, with wild populations of this species assumed to be extinct. The Extinct (EX) South American freshwater species on the Red List is *Littoridina gaudichaudii*, a species of Ecuador for which there is little information (IUCN 2021) and that would probably be better evaluated as DD; even the range of the species is unknown. The EX terrestrial species are *Tomigerus gibberulus*, *T. turbinatus* and

Table 1 Categorization of South American species of non-marine molluscs in the IUCN Red List (version 2021–3), excluding non-native species, estuarine or marine species and species incorrectly listed for South America

	LC	DD	NT	VU	EN	CR	EW	EX	TOTAL
Freshwater Gastropoda	36	62	1	7	0	1	3	1	111
Terrestrial Gastropoda	0	12	0	19	13	32	0	3	79
Bivalvia	24	10	0	4	2	1	0	0	41
Totals	60	84	1	30	15	34	3	4	231

LC—Least Concern, DD—Data Deficient, NT—Not Threatened, VU—Vulnerable, EN— Endangered, CR, Critically Endangered, EW—Extinct in the Wild, EX—Extinct

Megalobulimus cardosoi, all from Brazil. However, in the most recent edition of the Brazilian Red List, *T. gibberulus* is categorized as EN and *M. cardosoi* as CR (ICMBio 2018). These inconsistencies reinforce the need for updates of the IUCN evaluations and of regional lists.

In South America, Colombia, Peru, Chile, Brazil, Uruguay and Paraguay have national Red Lists including non-marine molluscs; but only in Colombia, Chile, Peru and Brazil were evaluations based on the IUCN criteria (IUCN 2012). All these lists are official and the species listed have legal protection in the respective countries. In the most recent national Red List of Brazil there are 17 non-marine molluscs (two bivalves and 15 gastropods); in Colombia, one estuarine bivalve; in Chile, 48 gastropods (43 terrestrial and 5 freshwater); in Uruguay, 93 species (40 bivalves, 29 freshwater gastropods and 24 terrestrial gastropods); in Peru, three terrestrial gastropods; and in Paraguay, 24 terrestrial gastropods, 10 freshwater gastropods and nine bivalves (see Supplementary Information for the complete list of species). Some other countries like Argentina have unofficial Red Lists (not edited by a governmental ministry or similar), and species listed in these lack legal protection. Rumi et al. (2006) listed 45 endangered freshwater gastropods in Argentina based on the IUCN criteria, and recently, a list of terrestrial gastropods was generated according to their distribution in ecoregions and sub-ecoregions of the country (Santos et al. 2020), as a preliminary step towards evaluation of their conservation status. Even in countries with official Red Lists, the number of species evaluated compared to the total number of species is very low. In Brazil, only 144 non-marine molluscs have been evaluated (Santos et al. 2015) from an estimated total of 1074 (Simone 2006). Regional efforts have also been undertaken directly by the IUCN, for example, the Tropical Andes initiative (including areas of Bolivia, Peru, Ecuador and Colombia) that evaluated 34 endemic freshwater molluscs and listed six in the Threatened categories (Tognelli et al. 2016; see also Supplementary Information).

The Alliance for Zero Extinction (http://zeroextinction.org/) selects sites worldwide for species conservation, using as the main criterion the presence of one or more species categorized as EN or CR by IUCN; in South America 105 sites have been selected. The selection is based mainly on vertebrates, mostly because they are better known and more comprehensively evaluated and categorized using the IUCN criteria compared to invertebrates. There are regional developments of this initiative (e.g. Brazilian Alliance for Zero Extinction, BAZE), allowing more sites to be included. BAZE selected only six sites based on the distributions and threats faced by non-marine molluscs. However, the selection of a site does not offer automatic protection for the area, and the species that triggered the selection remain under threat.

IUCN criteria: suitable for non-marine molluscs in South America?

One of the advantages of the IUCN categories and criteria (IUCN 2012) is to provide a single method for evaluating the conservation status of all living creatures in a uniform, rigorous and comparable way. The IUCN criteria were primarily developed for terrestrial vertebrates and their application for most invertebrate taxa, as well as for some other aquatic organisms, is often difficult, as has been discussed by various authors (e.g. Cardoso et al. 2011; van Swaay et al. 2011; Régnier et al. 2015a; Cowie et al. 2017a; Torres-Florez et al. 2018; Lopes-Lima et al. 2021; Cowie et al. 2022).

Régnier et al. (2009) used information available on the IUCN Red List, as well as specialist knowledge to estimate levels of extinction of non-marine molluscs worldwide and considered 19 South American non-marine molluscs as "Extinct" (11 as possibly extinct ("EX?"), 3 EW, and 5 EX). Among these 19 species there is one mussel and 16 gastropods (6 freshwater and 10 terrestrial); most of these species are from Brazil (11), but also Paraguay (3), Argentina (3), Colombia (2), Venezuela (2) and Ecuador (1). In contrast, only seven South American species were listed as EX or EW on the IUCN Red List; and the situation remains the same (IUCN 2021). Thus, specialists perceived a likely extinction level more than twice as high as the Red List estimate. Cowie et al. (2017a), using the same approach, updated the analysis of Régnier et al. (2009) and confirmed that additional species were considered extinct by specialists. However, considering the high proportion of species of uncertain status, it is quite probable that there are still more hidden extinctions. Régnier et al. (2015a) randomly selected 200 terrestrial gastropods from across the world to be analyzed in three ways: 1) evaluated by specialists based on their personal knowledge, 2) evaluated by using the IUCN criteria alone, and 3) modeled mathematically to infer extinction probabilities. Based on the IUCN criteria all 24 species selected from South America were classified as DD, which was very similar to the assessment of Lopes-Lima et al. (2018), in which most Neotropical freshwater mussels were classified as DD. The mathematical model considered three of the 24 species as "Probably Extant" and all other species as "Unable to Decide". The specialists' assessment considered five species as "Not Threatened" and all others as "Impossible to Decide". These authors (i.e. Régnier et al. 2009, 2015a; Cowie et al. 2017a) did not suggest giving up the IUCN criteria but argued that their use significantly underestimates levels of extinction among molluscs, and invertebrates generally, because of both their immense diversity and the lack of adequate data to evaluate them according to the IUCN criteria. Certainly, the IUCN criteria have been the most widely used tool to evaluate extinction risk but other methods can be used to assess relatively poorly known invertebrate taxa. The most obvious approach is simply to accept the opinion of the specialists. The daily life of biodiversity research with field trips and literature surveys can permit a rough idea of the conservation status of a particular species. In the study of Régnier et al. (2015a), the specialists' opinion quite closely matched the mathematical model. Though not precise and to some extent biased, this approach can provide some sense of a species' status, which is better than an IUCN evaluation of DD that tends to leave a species in limbo.

In Uruguay, the list of priority species of molluscs for conservation elaborated by Soutullo et al. (2013) used a different system of evaluation. Using only the IUCN criteria, most molluscs had been categorized as DD. As these problems also occurred with other taxa, and there was an urgency to categorize the risk of extinction of Uruguayan species, alternative criteria were adopted. The non-marine Uruguayan mollusc species were categorized based on seven criteria: (1) range restricted to Uruguay or a sector of South America including Uruguayan territory but in total less than 200,000 km^2; (2) categorized as VU, EN or CR in the global IUCN Red List or the Red List of the neighboring Brazilian state of Rio Grande do Sul; (3) range less than 20,000 km^2; (4) decrease of more than 20% in population size in Uruguay in the previous 20 years; (5) identified as threatened in Uruguay by one or more previous studies; (6) of particular taxonomic or ecological importance; and (7) of medicinal, cultural or economic value (Soutullo et al. 2013). This system of evaluation categorizes the species as "priority" or "not priority" for conservation. Of the 140 species of non-marine molluscs recorded in Uruguay, 93 were considered priorities for conservation.

The use of these alternative evaluation methods reduces the power of comparison with other lists that use the IUCN criteria, and diminishes the chance of developing a comprehensive global list. Nonetheless, it can provide a temporary, less rigorous solution, until it becomes possible to overcome the data limitations for the use of IUCN criteria for invertebrates. In any case, most conservation decisions are taken within a country by the local government (e.g. Cameron 2016) and it is better to have a local list to guide conservation efforts than to have no list at all. Local Red Lists can be used more readily than the global Red List to guide implementation of conservation actions (Kyrkjeeide et al. 2021), especially if they have legal standing. Thus, it is crucial that countries that do not have a Red List, or have lists that do not include non-marine molluscs, create new lists including these animals. Most South American biomes or catchments are shared by different countries, and therefore it is important that the lists support non-marine molluscs on both sides of the borders (i.e. considering biological and not political boundaries), and that conservationists from all countries involved talk to each other.

Threats to non-marine molluscs in South America

Globally, the three most prominent threats to biodiversity are habitat degradation and loss, impacts of invasive species and exploitation (WWF 2018). Non-marine molluscs are no exception, and habitat loss, pollution and invasive species especially are driving their declines (Cowie 2004; Lydeard et al. 2004; Régnier et al. 2009, 2015a, b, Chiba and Cowie 2016; Cowie et al. 2017a; Lopes-Lima et al. 2018; Ferreira-Rodríguez et al. 2019; Böhm et al. 2021; Cowie 2021) (Fig. 2). Moreover, the weakening of environmental protection and laws are leading to considerable losses in diverse ecosystems (e.g. Abessa et al. 2019; Leal-Filho et al. 2021).

Habitat modification

The most significant habitat modifications in South America began during the second half of the twentieth century when cities and intensive agriculture expanded vigorously (Fig. 2A–C). Several terrestrial and freshwater habitats have been completely modified in the last few decades (Jarvis et al. 2010; Sy et al. 2015), and many mollusc species are sensitive to such modification (e.g. Gerlach et al. 2013; Pereira et al. 2014). For example, in the 1970s around the city of Porto Alegre (Brazil), populations of freshwater mussels, previously abundant and diverse, were seriously affected by water pollution caused by mismanagement of wastewater (Mansur and Veitenheimer 1976). Modification of waterways, notably the damming of rivers to generate hydroelectric power that turns shallow lotic environments into deep lentic environments, has had a major impact on freshwater molluscs (Fig. 2C). The filling of the Yacyretá reservoir on the Paraná River seriously affected the species of *Aylacostoma* that prefer the rapids sections of rivers and are intolerant of standing water and low oxygen levels (Vogler et al. 2015, 2016; Fig. 1C). Other species may also be sensitive to these modifications (Paraense 1982; Mansur et al. 2019; Vogler et al. 2019). Paschoal et al. (2020) described massive mortality of *Anodontites trapesialis* in a reservoir in southeastern Brazil caused by an extreme drought, and concluded that reservoirs, associated with extreme climatic events, negatively affect freshwater bivalve populations and should be considered a conservation concern. The reservoirs also became a source for dispersal and establishment of invasive freshwater species (Darrigran et al. 2007; Havel et al.

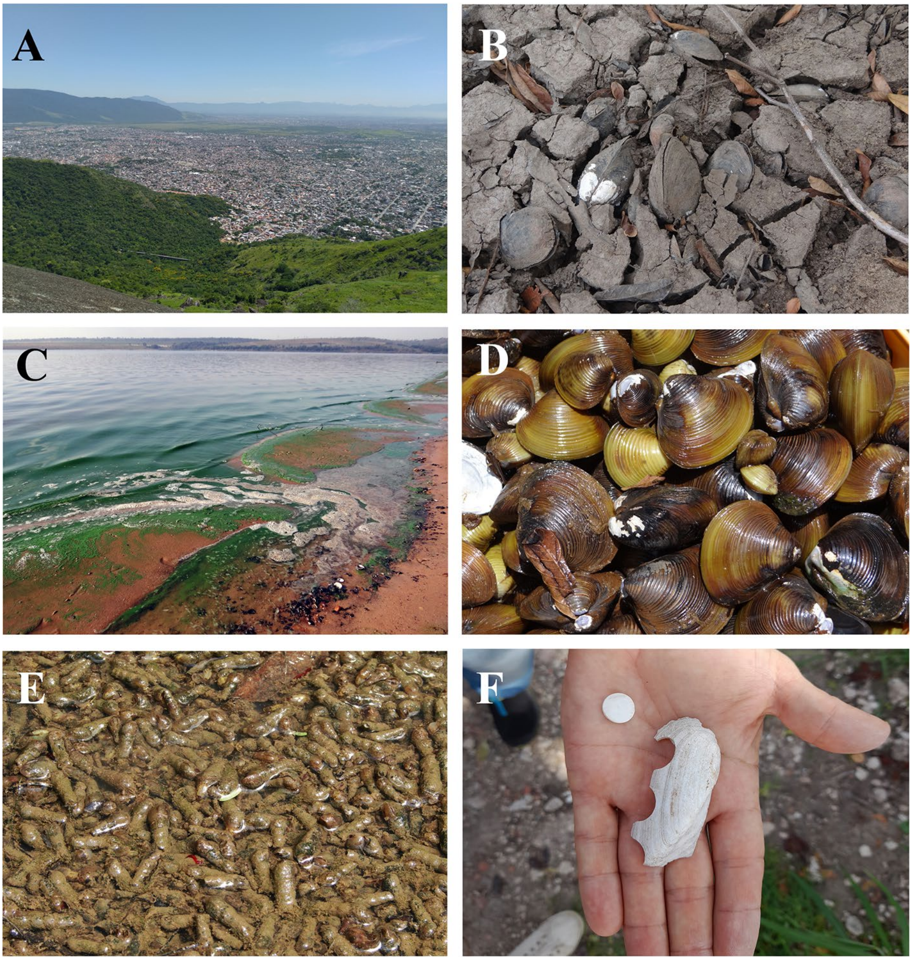

Fig. 2 Threats to the non-marine molluscs of South America. A—A common pattern of habitat modification in several South American cities: forest preserved on the hilltops and the lowlands developed as a city; B—Mussels stranded in dry substrate: extreme droughts, whether or not influenced by climate change, can affect all non-marine molluscs; C—Mixed effects of habitat modification in freshwaters: impoundments can facilitate cyanobacteria blooms as well as the introduction of invasive species; D—A high density population of invasive *Corbicula fluminea*; E—A population of the invasive *Melanoides tuberculata* covering the entire river bottom; F—A button and a shell of *Diplodon parallelopipedon* found at an old button factory in Argentina. Photos: A–E—Igor Miyahira, F—Cristhian Clavijo

2015; Miyahira et al. 2020). The construction of dams changes river dynamics, hampering the migration of the fish hosts of Unionida (Torres-Florez et al. 2018), and thereby making several populations unsustainable in the long term. Moreover, the artificial lakes flood large areas of land that affects the terrestrial fauna (Olazarri 1980, 1981).

Habitat modification also affects terrestrial gastropods, and usually leads to disappearance of the native species, and establishment of invasive species (Yeates 1991; Hausdorf 2002; Fig. 2A). Habitat modification also reduces species distributions and suitable areas, hindering conservation efforts (Ovando et al. 2019). Severe damage to the habitat of many species of terrestrial micro-molluscs is caused by the massive tourism that occurs in national parks in Argentina, and in other protected areas of Patagonia. For example, in Tierra del Fuego National Park thousands of tourists come to Ushuaia on transatlantic tours and enter the protected park for a few hours daily. This causes a massive and excessive pressure of people concentrated in a few hours that overexploits the place and in consequence damages the microhabitat of the land snails (Cuezzo et al. 2020). Moreover, in the future, under the influence of climate change, fewer areas are expected to be suitable for land snails of South America (Beltramino et al. 2015).

Modifications in the environment can also favor native species, which may proliferate intensely and disproportionally in crop areas, for example. This has been observed, for example, in the terrestrial slug *Sarasinula linguaeformis*, which is considered native in Brazil and a pest of soybean crops (Thomé 1993; Grisotti and Ávila-Pires 2011), and in the freshwater snail *Pomacea canaliculata*, a native species from southern Brazil and a major pest of pre-germinated rice crops in this area (Brito and Joshi 2016). Although habitat modifications have usually had negative effects on native biodiversity, the relationships of native and invasive species with South American environments are poorly understood.

Habitat modification can also destroy traditions of indigenous South American people. The most important wedding ornament made by the Rikbatsa indigenous people that live on the Arinos River, in the Tapajós River basin (Brazil) is made of polished shells of the mussel *Paxyodon syrmatophorus* (Fanzeres 2020) but a large reservoir is planned for this area and this will impact mussel populations.

Invasive species

The impacts of invasive species are often inextricably linked to those of habitat destruction or modification, as invasive species, such as rats or pigs, may drastically alter habitat, and habitat alteration may facilitate the spread of other invasive species. Invasive species may act in concert with or consecutively with habitat alteration, making it difficult, with some clear exceptions, to say that invasive species, per se, have caused the extinction of another species (Didham et al. 2007; Régnier et al. 2015b; Cowie et al. 2017a; Cowie 2021).

There are many species of non-marine non-native molluscs in South America, most of which came from Europe and Asia (e.g. Darrigran et al. 2020; Miyahira et al. 2020; Fig. 2D-E). Some of these species can cause severe ecological and economic problems. One of the most notable invasive species in South America is the golden mussel (*Limnoperna fortunei*), which can grow vigorously over any kind of substrate, including native mussels or large gastropods (Mansur et al. 2003), and influence environmental quality, mainly because of excessive filtration (e.g. Darrigran 2002; Boltovskoy and Correa 2015). Thus, golden mussels affect both the biota directly and their environments, and are often thought of as important ecosystem engineers (Sardiña et al. 2011; Nakano and Strayer 2014; Boltovskoy and Correa 2015). Several species of native mussels are becoming rarer following the introduction of the golden mussel, but there are no quantitative or population data showing direct displacement of native species (e.g. Darrigran and Damboreana 2011; Sylvester and Sardinã 2015). On the other hand, some gastropods are now using golden mussel conglomerations as refuges (e.g. Mansur et al. 2008).

There are currently 56 known species of introduced land snails and slugs in South America (Rumi et al. 2010; Darrigran et al. 2020). Unfortunately, this does not seem to be a stable number, as new records are constantly reported (e.g. Beltramino et al. 2018; Serniotti et al. 2019). Moreover, there are cryptogenic species, such as some subulinid land snails, that may raise this number. These introduced species are usually found in already disturbed environments (e.g. Hausdorf 2002; Nunes and Santos 2012), but their effects on the native fauna are largely unknown in South America. Some widespread non-native species, such as *Deroceras laeve* or *Bradybaena similaris,* are now found in undisturbed environments, such as the basal subtropical forest of Yungas in northwestern Argentina. The Chinese slug *Meghimatium pictum* has become a serious pest of grapes and strawberries in southern Brazil, and is also a potential intermediate host of *Angiostrongylus costaricensis* that causes human disease in areas where previously only native veronicellid slugs were found (Thomé et al. 1999; Baronio et al. 2014; Rodriguez et al. 2019).

The giant African snail, *Lissachatina fulica*, is probably the most important invasive land snail in South America, even though it was introduced, initially to Brazil, as recently as 1988 (Thiengo et al. 2007). It is now widespread not only throughout Brazil but also in Argentina, Colombia, Ecuador, Paraguay, Peru and Venezuela (Vogler et al. 2013). The dispersal of this species throughout South America raises ecological and public health issues (Thiengo et al. 2007; Fischer and Costa 2010; Pavanelli et al. 2017; Cuasapaz-Sarabia and Salas 2019).

Detailed information on the ecological impacts of most invasive species in South America is lacking. Native terrestrial gastropods also suffer from being confused with invasive species. For example, species of *Megalobulimus*, *Thaumastus* and *Orthalicus* may be confused with the invasive *Lissachatina fulica* in several countries where they occur together (Pecora and Miranda 2014; Patiño and Pilar 2017). Another example of similar confusion has been between the Andean slug *Colosius pulcher*, which is endemic to high altitudes in Ecuador, and *Colosius confusus*, which is a recognized pest of coffee and cultivated flowers in Peru, Colombia and Ecuador, and probably native only in Peru (Gomes et al. 2013).

The effects of other invasive animals and plants on native molluscs are largely unknown, and further efforts are needed to investigate such potential interactions.

Exploitation

The use of non-marine molluscs as a food resource is not widespread in South America and exploitation seems not to be a serious threat to most species, although some species were used prehistorically (Adán et al. 2004; Jackson and Jackson 2008; Gernet and Birckolz 2011; Gascue et al. 2019). These prehistoric uses may have led to changes in local distributions of some species, but overall, these impacts were certainly of minor importance. Nowadays, freshwater apple snails (*Pomacea* spp.) are still eaten (Tognelli et al. 2016; Ramírez et al. 2020; RHC personal experience) and some indigenous people of Venezuela value the freshwater snail *Doryssa hohenackeri* as an important protein source (Lasso 2011). Brazilian species of the native land snail genus *Megalobulimus* were also often consumed by nineteenth century Italian colonizers (Valduga 1985), and some species of *Megalobulimus* and *Pomacea* were used by local people for medicinal and religious purposes in Brazil (Torres 2019), but also in more formal scientific tests of their potential medical applications (Andrade et al. 2015). The use of *Megalobulimus* spp. is of special concern, as some species are included in the IUCN Red List as CR (*M. grandis*) and EN (*M. parafragilior*, *M. fragilior*).

Land snails are a food rich in magnesium, iron and amino acids (Zaragozano, 2017). This has led some producers to create snail farms with the aim of developing a new food source that could be commercialized. This new industry did not prosper in most South American countries since there is no custom of consuming these molluscs (Thiengo et al.

2007). Some native freshwater mussels (e.g. *Diplodon chilensis* and *Anodontites trapesialis*) have been suggested as food resources, but their commercial use was never successfully implemented (e.g. Lara et al. 1988; Sifuentes and Torres 2002). *Paxydon syrmathophorus* was consumed by traditional people in the state of Pará (Brazil) (Barros and Chagas 2019; Barros et al. 2020).

Thus, the use of non-marine molluscs as a food resource in South America has been sporadic and currently seems not to be a major threat to populations of most of the species that are consumed. In these cases, habitat destruction and invasive species seem to be much more serious threats. However, the situation for the freshwater oyster *Acostaea rivoli* is different (Fig. 1A). This species is consumed by local fishermen and other people in Colombia (Granados 1973; Tognelli et al. 2016). It has a highly restricted distribution and its populations are not abundant, which, combined with its exploitation, are the reasons that led to this species being listed as CR by IUCN (Villa-Navarro et al. 2016).

In contrast to the generally minor impact of mollusc consumption, mussel populations, especially in southern South America, were heavily exploited for the mother of pearl (nacre) button industry, especially from around the end of World War II through the 1950s (Fig. 2F). Production in Argentina reached 3600 tonnes (72 million mussels) per year and led to local extirpations (Bonetto et al. 1950; Clavijo 2017), which provides some evidence of how abundant was the past fauna in the Río de la Plata basin. By the mid 1960s the nacre industry crashed because of the emergence of plastic buttons. However, exploitation of mother of pearl by the button industry has appeared again more recently in Brazil (Beasley 2001) and continues to the present day. Concern for the survival of populations of pearl mussels resulted in the first local research on the biology of these species and the first mollusc conservation measures and actions in South America. Much of the knowledge generated during the development of the pearl industry is essential to the conservation of freshwater mussel species today. Unfortunately, all this research was published in the grey literature and is virtually unknown outside the region and among decision makers in the countries affected. Knowledge of the biology and ecology of pearl mussels remains inadequate for proper management (Soutullo et al. 2013; Clavijo 2017). Beasley (2001) proposed a strategy for sustainable extraction, but the real status of the exploited populations remains unknown. In the state of Pará (Brazil) the use of at least three species of limnic bivalves (*Castalia ambigua*, *Prisodon obliquus* and *Triplodon corrugatus*) is common in the handicraft industry for making souvenirs, but there is no available information on the effects on the mussel populations (Barros and Chagas 2019).

Conservation initiatives in South America

All South American countries signed the Convention on Biological Diversity (CBD), thereby committing themselves to species conservation. Nonetheless, few mollusc conservation efforts have been initiated in South America and those that have are limited in scope.

Early conservation efforts

As noted above, the first mussel conservation initiative was a byproduct of the button industry in South America (Clavijo 2017), as it was in North America (Haag 2012). During the period of exploitation and mussel population declines, the life cycles of several species were described and some reintroductions were undertaken. For example, Canzio (1960) reported on the fish hosts of some Hyriidae species and reintroduction of 300,000 larvae. However, these initiatives collapsed together with the nacre industry. Castellanos (1965) undertook an extensive biological study of *Diplodon variabilis* aiming to help maintain the mother of pearl industry sustainably and responsibly.

First draft of a Red List for South America

The first initiative to prepare a comprehensive survey of biodiversity, as well as an Action Plan for the conservation of non-marine molluscs in South America, was by Philippe Bouchet, of the Muséum national d'Histoire naturelle (Paris, France), with support from the WWF and IUCN. He invited present co-author MCD Mansur to participate in the initial organization and writing of the Action Plan in 1994. At that time, few data were available, and substantial work was done gathering information from libraries and museum collections, as well as soliciting expert opinion. Lists of non-marine molluscs were generated for Argentina, Brazil, Colombia, French Guiana, Guyana, Surinam and Venezuela. The final reports were sent to WWF as well as to Mary Seddon (Chair of the IUCN Mollusc Specialist Group), who is responsible for the mollusc component of the IUCN Red List. Some mollusc evaluations carried out at that time are in serious need of updating.

Protected areas

Protected areas, while not the only or even permanent solutions for conservation, remain as a minimum guarantee of the preservation of the various biomes (ecoregions) of South America. Protected areas have usually been planned with a focus on terrestrial vertebrate faunas and may not have effectively protected freshwater faunas (Pittock and Finlayson 2011; Fagundes et al. 2016; Frederico et al. 2018) nor terrestrial gastropods (Ovando et al. 2019; Santos et al. 2020). For effective protection of the freshwater fauna, on establishing a protected area, the entire hydrographic basin must be considered. Protecting a particular stretch of a river does not guarantee that the entire river's fauna will be protected. Freshwater molluscs, for example, usually have patchy distributions and do not occur homogeneously along river courses (Pereira et al. 2011; Miyahira et al. 2017; Vaughn 2018).

For other faunal groups it is common to use (or at least to discuss the use of) ecological corridors to facilitate dispersal within fragmented environments, but this is as yet an almost unexplored possibility for molluscs (Neubert et al. 2019). Although urbanized environments are generally not a focus for conservation efforts, Clements et al. (2006) suggested that such landscapes could be important in the conservation of freshwater molluscs, and others have suggested that parks and other green areas in cities could be important for local conservation of land snails (e.g. Knapp et al. 2008; Lososová et al. 2011; Barbato et al. 2017). However, the absence of historical data will always hinder proper evaluation of the effectiveness of such areas. Undoubtfully some species survive in these tiny areas, which are certainly important, but how many species have been lost from them? More specifically, a highly modified habitat might appear especially suitable under many circumstances but be fatal under other unforeseen circumstances. Sousa et al. (2019) demonstrated that irrigation channels in northern Portugal provide stable conditions for settlement and survival of the freshwater pearl mussel *Margaritifera margaritifera*, but under adverse environmental conditions they become ecological traps; the populations suffered almost 100% mortality after a drought affected the channels.

The umbrella species concept suggests that protecting a single species that occurs throughout the target area (usually a large vertebrate), will lead to the protection of all the other species in the area (usually species with smaller and more restricted ranges) (Roberge and Angelstam 2004; Barua, 2011). However, conservation of an umbrella species will not automatically lead to the conservation of every other species in its range, as they may have different ecological requirements or face different threats (Roberge and Angelstam 2004). For example, it is often supposed that molluscs do not have especially complex or specific environmental requirements and can be preserved in small areas, but many terrestrial snail species, for instance, do indeed have highly specific needs regarding substrate pH, microhabitat temperature and humidity, as well as fine microhabitat structure (Cameron 2016). In addition, the minimum area needed to sustain a viable population and the actual minimum viable population size for most non-marine molluscs are largely unknown. Furthermore, there may, for instance, be specific introduced predators of molluscs that would remain despite habitat restoration targeted at the ostensible umbrella species (e.g. Cowie, 2021; Gerlach et al. 2021).

Flagship species, a different concept from umbrella species (e.g. Barua, 2011), are usually iconic species that represent groups of similar species, a given habitat or a particular locale, and thereby stimulate the conservation of those species and their environments. For example, partulid tree snails, which are under severe threat, have been considered the “flagships” of terrestrial invertebrate conservation on Pacific islands (Cowie and Cook 2001); a partulid even adorned the front cover of the 1990 Red List (IUCN 1990). In Brazil, Santos (2011) proposed *Leiostracus perlucidus* and *Megalobulimus* species as flagships for mollusc conservation, as *Megalobulimus* species are big, with shells often more than 10 cm tall, and the arboreal *L. perlucidus* is a medium-sized snail with a beautiful emerald green color (Fig. 1E). Unfortunately, this proposal still has not gone forward.

Relocation, ex situ rearing and conservation plans

There have been some efforts in South America to relocate molluscs to areas where they are less threatened, sometimes including captive propagation of individuals for release to the new locations. Peredo et al. (2005) tested a relocation protocol for native mussels in Chile, following the population over multiple years. The introduced population was considered established after 18 years, indicating that relocation may be a viable tool for conservation. Clavijo et al. (2012) conducted a translocation experiment in Uruguay. Mussels were removed from an area that was impacted by a small dam and reintroduced some kilometers upstream in the same basin. The translocated populations were not followed, but the translocation process itself was accomplished without deaths. Mussel conservation projects elsewhere have used in vitro propagation of glochidia, notably in the USA, Europe and Thailand (e.g. Uthaiwan et al. 2001; Lima et al. 2012). In South America, Lima and Avelar (2010) developed an artificial medium for the propagation of two mussel species, but there has been no further development. It is important to emphasize that the success of relocating mussels depends directly on the presence of host fish, since mussels parasitize fish in the initial phase of their life cycle. Thus, knowing the potential hosts of the mussels should be part of conservation plans.

In the early 1990s, during the initial stages of the filling of the Yacyretá Reservoir (Argentina-Paraguay) a currently ongoing ex situ program was established to maintain in captivity representatives of five *Aylacostoma* species (*A. guaraniticum*, *A. chloroticum*, *A. stigmaticum* and two species not described at that time) that inhabited rapids in the area now flooded by the reservoir (Vogler et al. 2015, 2016; Fig. 1C). This project presupposes ex situ conservation for species maintenance with a goal of eventual reintroduction and is one of the long-lasting conservation initiatives that have been adopted for native freshwater gastropods in South America. During the first few years of the project, at the time the natural populations of *Aylacostoma* were experiencing drastic declines following the initial filling of the reservoir, research was continually carried out to optimize the ex situ conditions that best represented the natural conditions so as to ensure the maintenance and reproduction of ex situ populations. Unfortunately, at that early stage, successfully reproducing populations of *A. guaraniticum*, *A. stigmaticum* and one of the two undescribed species could not be established. At present, those species are not represented by any captive populations and are presumed extinct (Peso et al. 2013a, b). Nonetheless, the project was successful in maintaining reproducing populations of *A. chloroticum* (Fig. 1C) and *A. brunneum*, which was one of the two previously undescribed species, and which was described by Vogler and Peso in Vogler et al. (2014). Within this framework, although the project failed in maintaining ex situ populations of all species, the sustained reproduction over time of *A. chloroticum* and *A. brunneum* represents a success story in the conservation of these endemic freshwater gastropods.

López-Delgado et al. (2009) developed a management plan for conservation of the freshwater oyster *Acostaea rivoli* in the Opia River (Colombia) (Fig. 1A). This initiative embraced policies for species and habitat conservation, through cooperation among the public, government, and the scientific community. The data developed were key to evaluating *A. rivoli* for the IUCN Tropical Andean Red List (Tognelli et al. 2016). This is an example of how important it is that local or regional governments support programs to gain knowledge of the biology and distributions of non-marine molluscs. This species was categorized as CR on the global Red List by Villa-Navarro et al. (2016; as *Acostaea "rivolii"*). Unfortunately, the conservation plan developed for the oyster was not put into action. However, now, 12 years after its development, it seems that the plan will finally be implemented (E. López-Delgado pers. com. to C. A. Lasso, 2021).

Overall, therefore, mollusc conservation in South America is in its infancy, though there have been several valuable efforts made, with some positive results. It is important not only that these efforts are built upon but also that more concerted and broader, long-term initiatives are undertaken.

Future directions

Cardoso et al. (2011) reviewed the main impediments to invertebrate conservation from a global perspective. These impediments include limited funding support for research, little public interest in invertebrate conservation, and lack of necessary data (e.g. taxonomy, diversity, distribution, population densities, etc.). More specifically for freshwater molluscs globally, Lopes-Lima et al. (2018, 2021) and Ferreira-Rodríguez et al. (2019) have outlined the same lack of knowledge and needs for research. Although there has been no comparable comprehensive global assessment of knowledge gaps and research needs regarding terrestrial molluscs, it is clear that those gaps and needs are much like those of their freshwater counterparts.

Conservation of South American non-marine molluscs suffer from all these limitations and, based on our experience, we now offer some suggestions to expand and improve conservation efforts dealing with this fauna. It is time to move forwards. Wilson

(1987) wrote one of the first publications calling attention to invertebrate conservation, and 35 years later the paper can still be read as if written yesterday; the limitations and problems are much the same.

Increase funds for invertebrate conservation

The poor level of funding for invertebrate conservation research is certainly the main hindrance. Most of the time there is a clear lack of interest and complete lack of awareness among decision-makers of the need for conservation of invertebrates (Donaldson et al. 2016). As signatories to the CBD, all South American countries must supposedly treat biodiversity conservation as a priority. The conservation of invertebrates not only protects the species themselves but also the various ecosystem services (in the broad ecological sense, not just services seen as for immediate human benefit) provided by them (Prather et al. 2013; Vaughn 2018). Regional governments should develop special research support lines that include invertebrates. Unfortunately, these funding issues do not seem likely to improve significantly in the coming years (e.g. Tollefson 2019), even though we are dealing with these conservation problems right now.

Overcome taxonomic limitations

Our knowledge of non-marine molluscs in South America is far from complete; the most basic information on many native species is lacking (Table 2; Clavijo and Miyahira 2021), yet it is essential for conservation. Stimulating and increasing taxonomic training is necessary in all South American countries, especially the megadiverse ones. The taxonomic impediment is a reality for molluscs, not only in South America, but in general; even in the USA and Europe, the numbers of taxonomists are far from adequate (Cowie 2014; Eisenhauer et al. 2019). Taxonomic problems lead to difficulties in achieving rigor in basic biological or ecological studies; for example, note the confusion that has surrounded the identities of invasive South American apple snails (Ampullariidae) in Asia (Cowie et al. 2017b). Publishing identification guides or keys is rare, but see Cuezzo et al. (2020), making identification difficult for a non-specialist. Production of this kind of publication must be stimulated, and the current status that they have as counting for little in enhancing a researcher's citation statistics, reputation, chance of promotion and so on (Cowie 2014) must be reversed. Taxonomy itself has to be properly valued, and the long process of adequately training taxonomists must be acknowledged.

A species designated as 'sp.' in a faunal survey has low value for conservation. Guides or keys can help to improve such identifications. However, if doubts remain, it is nevertheless better and less problematic for conservation, to maintain the 'sp.' rather than to use an incorrect name. As an example of this, the apple snail *Pomacea canaliculata*, supposedly a very widely distributed species in South America, was discovered, after deeper anatomical and genetic studies (Hayes et al. 2012), to be restricted to a small portion of the range it had previously been thought to occupy (Cowie and Thiengo 2003). A widely distributed species will receive little attention compared to others with restricted distributions. This is one area where taxonomy is fundamental to conservation.

Table 2 Knowledge gaps and future directions for each need to conserve non-marine molluscs in South America

Need	Knowledge gaps	Future directions
Identity of species	Number of species	Taxonomic review for all groups
	Understudied groups	Prioritize groups and encourage development of new taxonomists
	Taxonomic issues	Integrative taxonomy (morphology, anatomy, genetics, behavior, etc.)
Distribution	Historic distribution	Museum and bibliographic review
	Current distribution	Explore unknown areas
	Variables that explain the distribution	Ecological fieldwork, obtaining environmental information
	Affinities to environmental and geological variables	Improve distribution maps with new data (e.g. climatic, geology, protected areas)
	Potential distribution	Species distribution modeling
Population status	Population sizes	Include population studies in fieldwork
	Population dynamics and trends	Classical dynamics studies, as well as genetics to infer information (e.g. connectivity, diversity) about population trends
	Population health	Minimum viable population and phylogeographic studies
Life History	Age at reproductive maturity, seasonality and longevity	Field and laboratory studies; breeding populations in captive environments
	Reproductive output	Effects of environment on reproduction
Ecology	Interactions with other species and with environment	Field and laboratory studies; ecological modeling
	Effects of anthropogenic modifications	Assess current and potential effects of climate change, habitat modification and invasive species on native non-marine molluscs

Improve distribution data

Information about population trends and reproduction is unavailable for most non-marine molluscs in South America (Table 2) but is essential (e.g. Cameron 2016), not only in order to detect declines, but also because the lack of a temporal component of distributions may preclude evaluation of a species on the basis of the Red List criteria (IUCN 2012). The main approach available that would permit the inclusion of most molluscs in Red Lists in South America, therefore, is to base evaluations primarily on known current distributional data. General patterns of distribution are now available for certain higher taxonomic groups of molluscs (e.g. Rumi et al. 2006; Pereira et al. 2014; Cuezzo et al. 2020). However, detailed knowledge of patterns of distributions of native non-marine mollusc species are rare, with exceptions being certain species of medical importance, like *Biomphalaria* spp. (e.g. Scholte et al. 2012). The distributions of some invasive species have been particularly well studied in South America (Darrigran et al. 2020 and references therein). In some groups, distribution modeling has helped to fill some gaps (e.g. Ovando et al. 2019). Considering the increasing availability of data in on-line repositories, such approaches could be expanded and used for other groups.

Publications documenting faunal surveys have unfortunately often been regarded as of limited broader interest, sometimes appearing only in the grey literature. Nonetheless, this basic information is essential for conservation, especially if identifications are reliable, and some ecological information is also available. Georeferenced distributional data, related to environmental conditions, if possible, and combined with good taxonomic data are a good start towards a better comprehension of mollusc distribution patterns. Information on unsuccessful collection (records of absences in a survey) is also important, although rarely mentioned or published. It is almost impossible to publish absence information alone, and it is probably not necessary or desirable, but if both absence and presence data have been recorded, they should be published together. Sometimes even areas near to scientific institutions are poorly known. Investigation of these areas usually requires minimal financial resources and can reveal healthy populations of native species and even new species (e.g. Martins and Simone 2014; Alexandre et al. 2017; Miyahira et al. 2017; Rangel et al. 2021), despite the anthropogenic impacts to which such areas are subject because of their proximity to cities.

Another problem is the precision of distributional data. It is necessary to describe the distributions of the species in detail, noting precisely where they occur (i.e. geographic coordinates), reflecting better the patchy distributions of most non-marine molluscs. The IUCN criteria consider the distribution of a species in two ways: Area of Occurrence (AOO) and Extent of Occurrence (EOO) (IUCN 2012). In situations in which a species is constrained by particular environmental conditions, it may be plausible to suppose that the species only occurs at the localities from which it has been recorded (AOO). In contrast, if it is supposed that the species occurs in the entire area within the EOO polygon, perhaps because it does not have particular ecological constraints or because it is highly vagile, then evaluation of its distribution based on the EOO may be appropriate. For example, if the only available information on the distribution of *Bartlettia stefanensis* were 'Paraguay River', it is quite possible that the EOO criterion would be used to evaluate its status, but if the detailed information were used, like "it occurs in laterite outcrops in the Upper Paraguay Basin", the AOO criterion could also be used.

In most cases, the distribution of a species is evaluated based on all available information, old and new records. If the objective is to assess the overall distribution of the species, it is not a problem to use all the data available. Indeed, most distribution maps presented in systematics or taxonomic studies reflect such an approach. The biological collections that are the basis for most of the research of taxonomists are also extremely valuable for conservationists (Allmon 1994; Ponder et al. 2001; Newbold 2010; Drew 2011; Cowie 2014; Tarli et al. 2018). Scientific collections contain specimens amassed over time from numerous locations but many of these time/location data are largely unpublished (Allmon 1994; Torres and Darrigran 2013). However, combined with recent survey data, these dated museum data can allow us not only to know where a species now occurs but also to ascertain to what extent its populations have declined, especially as it will be clear that some localities that had historical records are now unsuitable for the species (Miyahira et al. 2019). Clavijo and Carranza (2018) re-surveyed *Cyanocyclas* species populations at localities throughout Uruguay and noticed sharp declines compared with historical records. Although it is clear that some methodological issues can be encountered when comparing data obtained at different times and in different ways, such approaches can still provide insights into trends that can be further investigated and may permit the identification of specific threats.

It is not necessary to emphasize further the importance of collections at major museums, institutes and universities, but small collections are also important for conservation. These collections may contain information from more obscure places essentially ignored by the big institutions. However, the importance of South American museums for understanding and conserving biodiversity has not led to financial support. Recently, the Museu Nacional do Rio de Janeiro, in Brazil, one of the most important in South America, burned down as a consequence of poor maintenance, and with it, thousands of lots of non-marine mollusc specimens were destroyed. Unfortunately, other museums in South America are in no better condition. Thus, stronger state policies to support and preserve the scientific collections are needed. Guidelines to preserve tissue samples for DNA analysis in collections are also important.

Increasing moves towards digitizing collection information are extremely important. Initiatives like Specieslink (http://www.splink.org.br/) or GBIF (https://www.gbif.org/) bring together several institutions and make information available in one place, although few records are illustrated and this must be improved over time. MolluscaBase (https://www.molluscabase.org/) is a key molluscan taxonomic resource. Some authors have used museum collections and other sources of information, in some cases combined with mathematical models, to detect population declines and the probabilities of extinction (Burgman et al. 1995; Cowie 2001; Cowie and Robinson 2003; Régnier et al. 2015a; Akçakaya et al. 2017; Keith et al. 2017; Thompson et al. 2017). Such approaches should be explored further for South American molluscs. For several reasons, there is considerable material in South American collections waiting to be better studied and analyzed. A modern museum can be viewed not only as a repository of old stuff, but as a database of distributions over time, and an important vehicle for disseminating scientific knowledge (Cowie 2014).

Conservation genetics

Information on genetic diversity is of fundamental importance in conservation, since it is the basis of organic variation and generally has a close correlation with fitness (Lanteri et al. 2002). However, the genetic variability of many natural populations is eroded by destruction and fragmentation of natural areas, overexploitation, climate change and the impacts of invasive species (e.g. Lande 1988; Ovando et al. 2019). The most important applications of genetics in conservation are derived from its capacity to assist us in generating a more accurate image of the genetic diversity (or lack thereof) and its geographic structure and the evolutionary processes exhibited by endangered species, which not only enhance knowledge of these species but also are relevant to the management and conservation of their populations (DeSalle and Amato 2004; Domínguez-Domínguez and Vázquez-Domínguez 2009). The main contributions of genetics to biological conservation thus include the resolution of taxonomic uncertainties, genetic management of small and fragmented populations, tracking and mitigation of invasive species impacts, planning and monitoring reintroduction, delimitation of threatened taxa, definition of evolutionary significant units within species for separate management, and design and prioritization of protected areas, as comprehensively reviewed for Latin America by Torres-Florez et al. (2018).

Although genetic studies have been useful in devising field and laboratory strategies to conserve molluscan biodiversity in several regions of the world (e.g. Ponder et al. 1995; Holland & Hadfield 2002; Hadfield et al. 2004; Liu et al. 2016; Daly et al. 2019), little is known about genetic variation in most South American molluscs, especially from a conservation perspective (Vogler et al. 2015; Santos-Neto et al. 2018; Torres-Florez et al. 2018; Vogler et al. 2019; Oliveira-Hyde et al. 2020). Once again there has been a taxonomic and geographical bias towards gastropods of medical importance (Vidigal et al. 2013), and few genetic studies have been undertaken on South American molluscs to generate knowledge to be used to address conservation questions (e.g. Vogler et al. 2015; Torres-Florez et al. 2018; Vogler et al. 2019; Oliveira-Hyde et al. 2020). Thus, this situation represents a great challenge for South American countries since refining knowledge of molluscan genetics in many groups is of considerable importance for achieving conservation and management goals.

Understand the impacts of climate change

The expected consequences of climate change include altered species distributions and abundances and increased extinction risk for several species (Sen et al. 2016; Cowie et al. 2017a; Lei et al. 2017; Fig. 2B). Traits that make species most susceptible to climate change include restricted distributions and rarity, limited dispersal abilities, specialized habitat, specific dietary requirements, slow reproductive rates, narrow physiological tolerances, and dependence on specific environmental triggers or on interspecific interactions that are likely to be disrupted by climate change (Foden et al. 2008; Pacifici et al. 2015; Foden et al. 2016 and references therein). In addition to the direct effects on habitat quality, climate change will also promote the spread of invasive species to new areas and increase the effects of invasive species already present by altering competitive dominance, increasing predation rates and enhancing the virulence of diseases (Rahel et al. 2008). Furthermore, climate change generates altered environments that facilitate the introduction of new potentially invasive species.

South America has the highest climate change-induced extinction risk of all regions worldwide (Urban 2015; Vale and Pires 2018). Yet it has the lowest number of studies of the vulnerability of species to climate change, and studies of the impacts of climate change on molluscan biodiversity are almost nonexistent, with a few exceptions (Beltramino et al. 2015; Vale and Pires 2018 and references therein). As an example, Beltramino et al. (2015) observed possible constraints on the distribution of *Megalobulimus sanctipauli*, a giant land snail from the Atlantic Forest, when faced with climate change. They also demonstrated that the current network of protected areas in South America may not be highly effective in protecting this species in the future. Climate change may lead to expansion of areas susceptible to invasion by non-native species in South America, as well as worldwide. For example, predictions of suitable future habitat for the New Zealand mud snail, *Potamopyrgus antipodarum*, already present in Chile, include southern Brazil and Uruguay (Silva et al. 2019). Both the studies of Beltramino et al. (2015) and Silva et al. (2019) point to the need for further research to understand the impacts of climate change on South American molluscan faunas, to protect molluscan biodiversity, and to take proactive measures to mitigate the impacts of invasive species.

Furthermore, land gastropods have been identified as a particularly vulnerable group that is expected to be greatly affected by global warming, as they are constrained by low mobility or thermal barriers within their habitats (Foden et al. 2008; Nicolai and Ansart 2017). Nonetheless, anthropogenic climate change is still hardly considered in assessments of the conservation status of gastropod species (Nicolai and Ansart 2017).

Networking

Interaction and sharing of information among South American researchers must be improved. The first step in this direction was the study of Pereira et al. (2014) that brought together mussel specialists from throughout the continent. Another offshoot of this interaction was the creation of BIVAAS (Bivalves de Água Doce da América do Sul—Freshwater Mussels of South America), a group of specialists concerned with mussel conservation. BIVAAS has organized regular meetings associated with regional malacological congresses (BIVAAS 2018). This interchange could facilitate standardization of methodologies, particularly regarding field surveys and monitoring and data collection protocols, thereby allowing better comparability among localities and habitats. Recently, a large group of invasive species specialists published a comprehensive synthesis (Darrigran et al. 2020). Other developments of this group are awaited in the near future. The initiatives undertaken so far clearly represent the first steps. However, networks among researchers in South America could be much more effective. This is especially desirable from a conservation perspective, considering that South American countries have several shared forests and rivers; joint initiatives must be the rule in these cases but must be encouraged in all others. Joint efforts may help to overcome some of the constraints already mentioned.

Public issues

Social factors, public and political, local, national and international, are also important (Cowie 2004; Cardoso et al. 2011; Cowie 2014; Lopes-Lima et al. 2021). How can public awareness of non-marine molluscs in South America be raised, if most people think of snails and slugs as repulsive? We must start by promoting a more positive image of molluscs, and then slowly change the status quo. No one will be concerned about protecting something that they find disgusting or do not really know. Taking into account public expectations of science communication about invertebrates will be key (Salvador et al. 2021).

In South America, it is not usual to use common names for invertebrates species, as is done for most species in North America. Common names should be adopted for South American species, as they can make a species more accessible and understandable to the general public. A scientific name in Latin is impossible for most untrained people to understand. However, it is not possible to create compelling common names for all species, but those species that are more attractive can be flagships for others in the same habitat or locale or for similar kinds of species. Furthermore, the common name must be created and used with caution, and always related to the scientific name, to avoid confusion. Ideally it should relate to a visible feature of the organism.

However, just generating and using common names obviously does not solve the problem. The importance of non-marine molluscs should be demonstrated, and much more visibly in publications, lectures, workshops, and other vehicles, and venues designed specifically for the general public. Molluscs must become more accessible through formal and non-formal education providing information and tools for teachers and students (Rabanaque et al. 2021). With the boom in social media, these platforms must be used effectively to increase awareness of molluscs in a realistic and engaging way among South American people (e.g. Salvador et al. 2021). If the people understand the roles of molluscs in ecosystems, and how they are important to humankind, they could help us to conserve them and influence the decision-makers. Nonetheless, Salvador et al. (2021) showed, somewhat preliminarily, that there is something of a misalignment between what the public finds most engaging about invertebrates (i.e. aesthetics, amazing feats, weird facts) and what science communicators think will foster awareness and support for their study and conservation (importance for environmental and human welfare). In a notable outreach effort, BIVAAS initiated the celebration of Freshwater Bivalves of South America Day, a designated day when researchers and students of freshwater bivalves coordinate their efforts to reach a large audience across the entire continent at the same time (BIVAAS 2019).

Conclusions

Conservation of non-marine molluscs in South America has taken its first steps. Despite having already gathered much important information, there is still a long way to go to achieve effective, continent-wide non-marine mollusc conservation. There is much missing basic information that is deeply important for undertaking new conservation initiatives. New technologies and tools have to be used to improve data quality and results of analyses, including genetic data that are still very scarce. Training of students and technicians in molluscan conservation must be encouraged. Non-marine molluscs play key roles in several ecosystems and that importance has to be highlighted outside scientific circles. The negative image usually associated with molluscs must be left behind so that appreciation of molluscs will become not only for their ecological and economic importance, but also for their intrinsic value (White 2013). The biodiversity crisis that we are going through needs combined effort to overcome. Thus, only with the engagement of researchers, decision makers and society in general can we move forward on the conservation of non-marine molluscs of South America.

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