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Research Article

Distribution, conservation assessment and management perspectives of Chilean micro-snails of the family Charopidae

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Abstract

The biodiversity of molluscs is highly threatened in marine, terrestrial and freshwater ecosystems worldwide. This research aimed at studying the distribution and conservation status of eight poorly-known micro-snails of the genera *Stephacharopa* and *Stephadiscus* in Chile. We performed a comprehensive review of literature and databases to determine the occurrences of the species, which were mapped on vector layers containing protected areas and human development infrastructure to find potential threats. Conservation status assessment was performed following the criteria and tools implemented by the International Union for the Conservation of Nature (IUCN) Red List and NatureServe. We also conducted species distribution models, based on maximum entropy, to identify areas that should be prioritised for conservation. Two species meet the criteria for IUCN listing as Critically Endangered (CR), four Endangered (EN), one Vulnerable (Vu) and one Least Concern (LC). This classification is rather coincident with equivalent categories obtained under the NatureServe standard, in which two species were ranked as Critically Imperiled (N1), five Imperiled (N2) and one Vulnerable (N3). We found that *Stephacharopa paposensis* is the most at-risk species, with only one occurrence not included in a protected area, followed by *Stephadiscus stuardoi*, with two occurrences, one of them within a protected area. *Stephadiscus lyratus* was the species with the greatest geographic range, accounting for 17 occurrences, seven matching a protected area. We found wider potential ranges in modelled species that may be useful for prioritising conservation measures. Considering distributional data, protected areas and more than 20 plausible threats identified, we propose potential *in situ* and *ex situ* conservation actions to protect these neglected micro-snails.

Key words: conservation biology, endemic species, imperiled micromolluscs, IUCN, land snails, NatureServe, niche modelling, protected areas

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Introduction

In recent decades, the loss and degradation of ecosystems due to human activities has increased to alarming levels worldwide (Chivian 2001; Cardinale et al. 2012; FAO and UNEP 2020). Habitat loss, fragmentation and alteration have been considered as the main cause of species extinction (Rawat and Agarwal 2015). However, environmental pollution, invasive species and overexploitation, amongst other factors, have also contributed significantly to the disappearance or decline of populations (Thomas et al. 2004; Clavero and García-Berthou 2005; Mason 2015; Maxwell et al. 2016). As entities that cause ecosystem disturbances, humankind is also responsible for preserving biodiversity considering that it is not only important for ecological, aesthetic or scientific reasons, but also because human existence depends on the use of biological resources and ecosystem services (Luck et al. 2003; Barker et al. 2010).

Knowledge of geographic distribution of species is crucial for conservation status assessment (Anderson and Martinez-Meyer 2004), acquiring relevance in endemic species (Behroozian et al. 2020). The isolation of the Chilean continental territory generated by the Atacama Desert in the north, the Andes Mountain range to the east, the Pacific Ocean to the west and the Antarctic Ocean to the south, has produced a relatively high biodiversity in the country, reaching 33,000 native species, of which about 25% are endemic (MMA 2022).

Molluscs are highly threatened in marine, terrestrial and freshwater ecosystems worldwide (Régnier et al. 2009; Burlakova et al. 2011). In fact, they have been considered one of the most endangered groups of animals on the planet, even surpassing the number of extinctions of all other taxa combined (Régnier et al. 2009). However, this could be even more serious because the phylum contains a range of poorly-known groups, with many endemic species restricted to one or a few localities. Endemism is one of the most important factors used by the public in conservation biology, surpassing other useful aspects that these could have in the field of conservation (Meuser et al. 2009). On the other hand, from the geographic point of view, molluscs also contain a lot of rare species, rarity being another factor that influences the probability of extinction of organisms (Gaston 1998; Mace et al. 2008).

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species and Natural Heritage Network Element Ranking Systems (NatureServe 2006) are two institutions that aim to list species in conservation categories at different geographical scales (IUCN 2001, 2012, 2019, 2022; NatureServe 2006, 2021). However, the need to apply a legal instrument soon led many countries to create their own classification systems to categorise threatened species (Gärdenfors 2001; IUCN 2003). The first classification of wild species in conservation categories in Chile was published in 2005 as part of Law No. 19,300 (Decreto Supremo No. 75 of 2004, Ministerio Secretaría General de la Presidencia), where 35 species were evaluated. Currently, the conservation categories in Chile are based on those proposed by the IUCN (Squeo et al. 2010), following the Decreto Supremo N° 29 of 2011 of the Chilean Ministry of the Environment (MMA 2022). On the other hand, ecosystems and biota are protected in the Sistema Nacional de Áreas Silvestres Protegidas del Estado (SNASPE) (in English: National System of State Protected Wilderness Areas) (Root-Bernstein et al. 2013; Subsecretaría de Turismo 2015) and its administration oversees the Corporación Nacional Forestal (CONAF) (National Forestry Corporation).

In the present study, we applied the tools, criteria and categories developed by the IUCN and NatureServe to assess the conservation status of terrestrial micro-snails of the family Charopidae Hutton, 1884. This taxon is represented by species from Central and South America, South Africa, Australia, New Zealand and some islands of the Pacific, Atlantic and Indian Oceans (Stuardo and Vega 1985; Valdovinos Zarges 1999; Muratov et al. 2005; Salvador et al. 2020). Most of the Charopidae species are from humicolous habitats so they can be found in leaf litter in humid wooded areas (Miquel and Ramírez 2011; Miquel and Araya 2013; Araya and Catalán 2014). Multiple threats have been recognised potentially affecting the species of the group, including habitat loss, fragmentation and degradation, land uses changes, agriculture, logging and subsistence harvesting of wood, tourism, global warming, rainfall, floods, snowfall storms, volcanism, fires, invasive species and domestic and feral animals (Herbert 2004; Barker 2012; Vermeulen et al. 2014; Cuezzo et al. 2021; Collado et al. 2023).

In Chile, charopids reach a high diversity (Miquel and Cádiz Lorca 2008; Miquel and Barker 2009), accounting for 17 genera (Stuardo and Vega 1985; Valdovinos Zarges 1999; Miquel et al. 2007; Miquel and Cádiz Lorca 2008; Miquel and Araya 2013; Araya et al. 2017; Araya and Miquel 2018). *Stephacharopa* Miquel & Araya, 2013 and *Stephadiscus* Hylton Scott, 1981, the focus of this research, are two taxa represented by species of small size, usually less than 4 mm (Miquel and Cádiz Lorca 2008; Miquel and Ramírez 2011; Araya and Miquel 2018). Ectothermic traits of species, low vagility, probable low fecundity and particular habitat requirements (often wooded areas with leaf litter), all of them combined, makes species in the group potentially vulnerable (Cuezzo et al. 2021). Recently, several species in the genus *Radiodiscus* Pilsbry in Pilsbry & Ferriss, 1906 (Charopidae) were listed as critically endangered or endangered in Chile (Collado et al. 2023). At present, however, the conservation status or risk of extinction has not been assessed for none of the species of *Stephacharopa* or *Stephadiscus* in the country.

The aims of this study were to determine the distribution of micro-snail species in the genera *Stephacharopa* and *Stephadiscus* in Chile and assess their conservation status using the criteria and tools implemented by IUCN and NatureServe and propose conservation actions. In addition, we identified potential distributions of species or habitats with similar environmental conditions that can be incorporated into future management plans.

Methods

Species records and occurrence data

The genera *Stephacharopa* and *Stephadiscus* comprise eight species in Chile, four in each genus (Gould 1846; Hylton Scott 1969, 1970, 1973, 1979; Stuardo and Vega 1985; Valdovinos Zarges 1999; Tablado and Mantinian 2004; Miquel and Cádiz Lorca 2008; Miquel and Barker 2009; Rodríguez et al. 2012; Araya and Miquel 2018; Aldea et al. 2019; Cuezzo et al. 2021; MolluscaBase 2021a, 2021b). The genus *Stephacharopa* is represented by *S. calderaensis* Miquel & Araya, 2013, *S. distincta* (Hylton Scott, 1970), *S. paposensis* Miquel & Araya, 2018 and *S. testalba* (Hylton Scott, 1970). The genus *Stephadiscus* comprises *S. celinae* (Hylton Scott, 1969), *S. lyratus* (Couthouy in Gould, 1846), *S. rumbolli* (Hylton Scott, 1973) and *S. stuardoi* Miquel & Barker, 2009. The dataset on species including the geographic coordinates of occurrences was obtained from literature and the Global Biodiversity Information Facility (GBIF) database (https://www.gbif.org/occurrence/search?q=Stephadiscus) (Suppl. material 1). Presence occurrences without geographic coordinates were georeferenced using the radius-point method (Wieczorek et al. 2004; Escobar et al. 2016) in the GOOGLE EARTH (v.7.3.3.7786, Google Inc.) software (Suppl. material 1).

IUCN conservation assessment

Under the IUCN guidelines, the species can be classified in one conservation category according to five criteria, which can work independently or combined (IUCN 2001, 2019). Criterion A covers population size reduction, Criterion B geographic range, Criterion C small population size and decline, Criterion D very small or restricted population and Criterion E quantitative analysis of the probability of extinction. The IUCN has established nine conservation categories: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) and Not Evaluated (NE).

We applied Criteria B and D (D2) to assess the conservation status under the IUCN guidelines due to the difficulty of applying criteria A, C and E since they lack information regarding Chilean micro-snail species. The application of Criterion B requires the estimation of the extent of occurrence (EOO) (sub-criterion B1), which represents the area in km^2 formed by the polygon that forms the line that encloses all the occurrences of the species and/or area of occupancy (AOO) (sub-criterion B2), the area within its extent of occurrence obtained from the sum of each occurrence with respect to a 2×2 km^2 grid cell and then meeting at least two of these conditions: a) severely fragmented or known to exist in no more than $1 \leq 5$ or ≤ 10 locations, b) continuing decline or c) extreme fluctuation. For the taxa studied, we used conditions a) and b) considering available data. In the last case, we used sub-condition (iii): continuous decline projected in area, extent and/or quality of habitat. The EOO and AOO parameters were obtained in the Geospatial Conservation Assessment Tool (GeoCAT) portal (Bachman et al. 2011), which uses a file of geographic coordinates of the species to provide a preliminary semi-automatic evaluation of the conservation status of a taxon. In the case of the EOO, we use the minimum convex polygon (MCP) and, for the AOO, a 2×2 km^2 grid cell around the occurrence (IUCN 2012, 2019). For species with few occurrences, we also use criterion D, specifically D2. According to the IUCN (2019, 2022), a species qualifies for Vulnerable D2 if the area of occupancy is very restricted (typically less than 20 km^2) or exists at typically five or fewer locations and if there is a plausible natural or anthropogenic threat.

NatureServe conservation assessment

NatureServe weighs three different factors at once: rarity, threats and population trends. Rarity refers to range extent and area of occupancy, population size and number of occurrences and/or percentage of area with good ecological viability and/or ecological integrity. Threats consider the average impact of different threats facing or potentially facing species, while population trends include long- and short-term temporal variation (NatureServe 2006; Master et al. 2009; Faber-Langendoen et al. 2012). The system allows researchers to categorise species and ecosystems according to the geographical rank to be applied: Global (G), National (N) and Sub-national (S). There are five NatureServe conservation categories: Critically Imperiled (1), Imperiled (2), Vulnerable (3), Apparently Secure (4) and Secure (5). For example, if a species is classified as Critically Imperiled at the Global Rank, it will be ranked as (G1), but if it is classified at the National Rank as Critically Imperiled, it will be ranked as (N1). To assess the conservation status of species, we use the parameters EOO, AOO, number of occurrences, threats and ecological viability (habitat availability), entering the values or estimates in the Conservation Rank Calculator developed by the organisation (NatureServe 2021). Population trends were set as "unknown" due to lack of information. The threats and habitat available for species were obtained examining satellite images on the software Google Earth and merging species occurrences with road works, hydrographic and urban development vector layers available in the Biblioteca del Congreso Nacional de Chile (Library of the National Congress of Chile) (https://www.bcn.cl/siit/mapas_vectoriales), which were qualitatively examined in QGIS v.3.22.7 software (QGIS Development Team 2021). Literature, government sources and the media were also used to identify threats that subsequently allowed us to propose conservation measures.

Mapping of protected areas

To find out whether populations are located inside protected areas, we merged species occurrences with the SNASPE vector layer available at the Library of National Congress of Chile in QGIS, together with a topographic layer representing the Chilean territory obtained from the same source. Distribution maps, including MCPs, occurrences, country regions and SNASPE areas were made using GeoCAT and QGIS.

Species distribution models

We use 19 bioclimatic variables (Fick and Hijmans 2017) (Suppl. material 3), four environmental variables (elevation, evaporation, solar radiation and wind) obtained from WorldClim v.2.0 (www.worldclim.org) and the topographic layer of the Chilean territory. The 23 climatic and environmental variables were downloaded as raster format (30 s, ~ 1 km^2). Each of them was superimposed on the topographic variable and then cut with respect to its limits and transformed into a variable in ASCII format in the ArcGIS v.10.8 software (ESRI 2011). Species distribution analysis was carried out in the MaxEnt v.3.4.4 software (Phillips et al. 2006), which predicts the potential distribution of species according to the environmental conditions of the studied region. For this analysis, the occurrence records of each species and the ASCII variables were loaded into MaxEnt. Models were built using the default parameters and others with 25% testing, setting the logistic output format. The validation of the models was based on the Area Under the Curve (AUC), which represents the total area under the receiver operating characteristic (ROC) curve, whose maximum value is 1. AUC values greater than 0.7–0.8 have useful application in the model (Manel et al. 2001; Loo et al. 2007). The contribution of each variable individually was evaluated using the Jackknife test. Species with a single or two occurrence records were not analysed.

Results

Conservation categories

The genus *Stephacharopa* is distributed in Chile from the Antofagasta Region to the Los Lagos Region, while *Stephadiscus* from the Bío-Bío Region to the Magallanes y de la Antártica Chilena Region (Figs 1A–D, 2A–D). Of these species, *Stephacharopa paposensis* and *Stephadiscus stuardoi* are endemic to Chile, while *Stephacharopa calderaensis*, *Stephacharopa testalba*, *Stephacharopa distincta*, *Stephadiscus celinae*, *Stephadiscus lyratus* and *Stephadiscus rumbolli* are native to Chile and Argentina. Geographical distribution updates show that *Stephacharopa calderaensis* and *Stephacharopa paposensis* inhabit northern Chile, with occurrences in the Atacama Desert, while *Stephacharopa distincta* and *Stephacharopa testalba* inhabit the south of the country. Of these species, *Stephacharopa paposensis* is restricted to one locality (Table 1). *Stephadiscus celinae* and *Stephadiscus stuardoi* occur in southern Chile, while *Stephadiscus rumbolli* and *Stephadiscus lyratus* are confined to austral Patagonia. *Stephadiscus lyratus* poses the largest distribution and number of occurrences in Chile (17), scattered from Los Ríos Region to the Magallanes y de la Antártica Chilena Region (Table 1). *Stephadiscus stuardoi* is restricted to two locations, one in Bío-Bío Region, another in austral Patagonia (Aysén).

GeoCAT analyses recovered EOO values ranging between 0.000 and 285,317 km^2, whereas AOO values between 4 and 64 km^2, considering both genera. When EOO values are lower than AOO, the former must be increased to equal the AOO values according to IUCN (2019). Thus, two EOO values less than AOO must be equal to the AOO value in Table 1.

Based on GeoCat and the IUCN sub-criterion B1 (EOO), two species were listed as Critically Endangered (CR), one Endangered (EN), three Vulnerable (Vu) and two as Least Concern (LC) (Table 1). Applying IUCN sub-criterion B2 (AOO), two species were listed as Critically Endangered (CR), four Endangered (EN), one Vulnerable (Vu) and one Least Concern (LC) (Table 1). *Stephacharopa paposensis* was assessed as Critically Endangered (CR) B1ab(iii) given that EOO < 100 km^2 (B1), it occurs in one locality (a) and projected decline in habitat quality due to disturbance and transformation of its area of occupancy [b(iii)]. Similarly, it was evaluated as Critically Endangered (CR) B2ab(iii) given that AOO < 10 km^2, it occurs in one locality (a) plus the condition b(iii) (Table 1). *Stephadiscus stuardoi* was evaluated as Critically Endangered (CR) B1ab(iii) given that EOO < 100 km^2 (B1), it occurs in two localities very distant from each other (a) plus the condition b(iii) and as CR B2ab(iii) given that AOO < 10 km^2 plus the conditions (a) and b(iii). *Stephacharopa testalba* was evaluated as Endangered (EN) B1ab(iii) given that EOO < 5000 km^2 (B1), it occurs in five locations (a) plus the condition b(iii) and as Endangered (EN) B2ab(iii) given that AOO < 500 km^2 (B2), five locations (a) plus the condition b(iii). *Stephacharopa calderaensis* was evaluated as Vulnerable (Vu) B1ab(iii) given that EOO < 20,000 km^2 (B1), it occurs in six locations (a) plus the condition b(iii) and as Vulnerable (Vu) B2ab(iii) given that AOO < 2000 km^2 (B2) plus the same conditions (a) and b(iii). *Stephacharopa distincta* and *Stephadiscus rumbolli* were evaluated as Vulnerable (Vu) B1ab(iii) given that EOO < 20,000 km^2 (B1), < 10 localities (a) plus the condition b(iii) and as Endangered (EN) B2ab(iii) given that AOO < 500 km^2 (B2), < 5 localities (a) plus the condition b(iii). This latter classification [EN B2ab(iii)] also fits *Stephadiscus celinae*, which was also listed as Least Concern (LC). According to NatureServe, *Stephacharopa paposensis* and *Stephadiscus stuardoi* were ranked as Critically Imperiled (N1), *Stephacharopa calderaensis*, *Stephacharopa distincta*, *Stephacharopa testalba*, *Stephadiscus celinae* and *Stephadiscus rumbolli* as Imperiled (N2), while *Stephadiscus lyratus* Vulnerable (N3) (Table 1, Suppl. material 2).

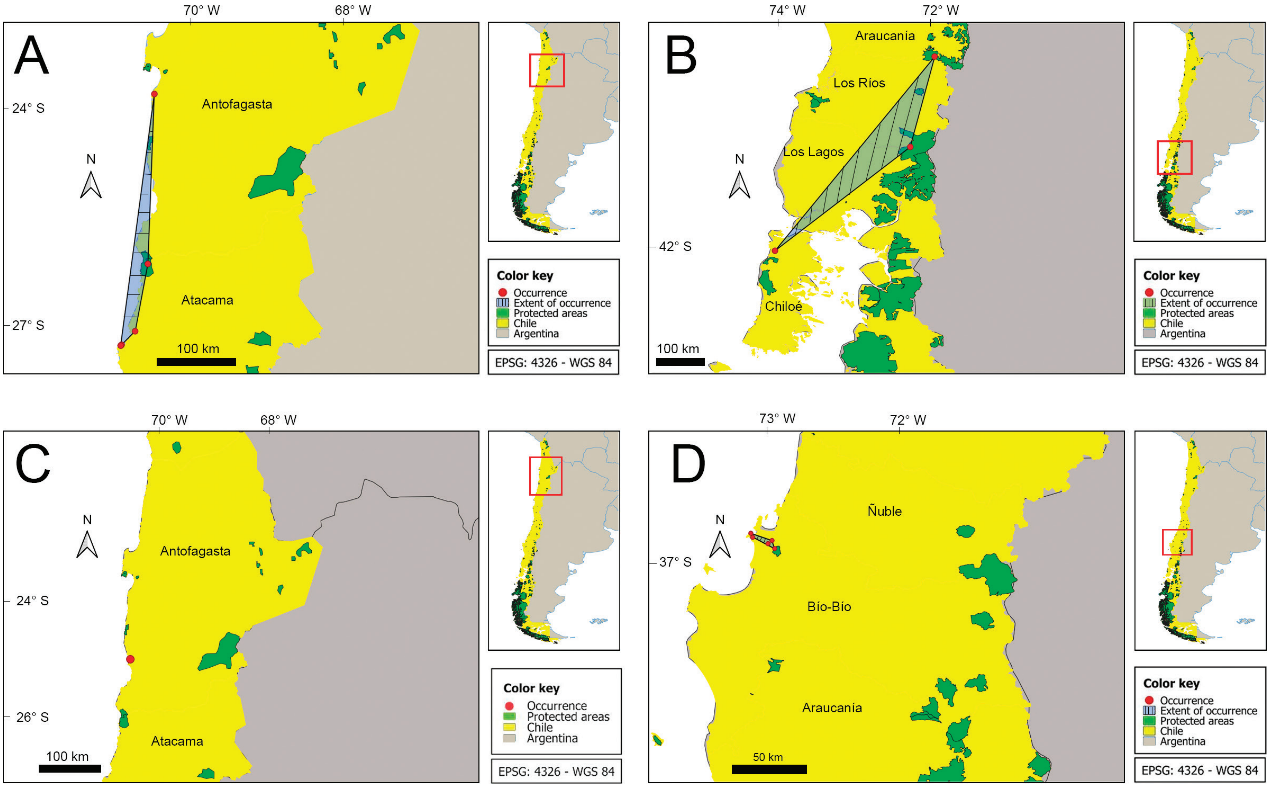

Figure 1. Distribution and occurrences of the Chilean micro-snails of the genus *Stephacharopa*, including protected areas. **A** *Stephacharopa calderaensis* **B** *Stephacharopa distincta* **C** *Stephacharopa paposensis* **D** *Stephacharopa testalba*. The maps were created using GeoCAT and QGIS software (Maps: G.A. Collado).

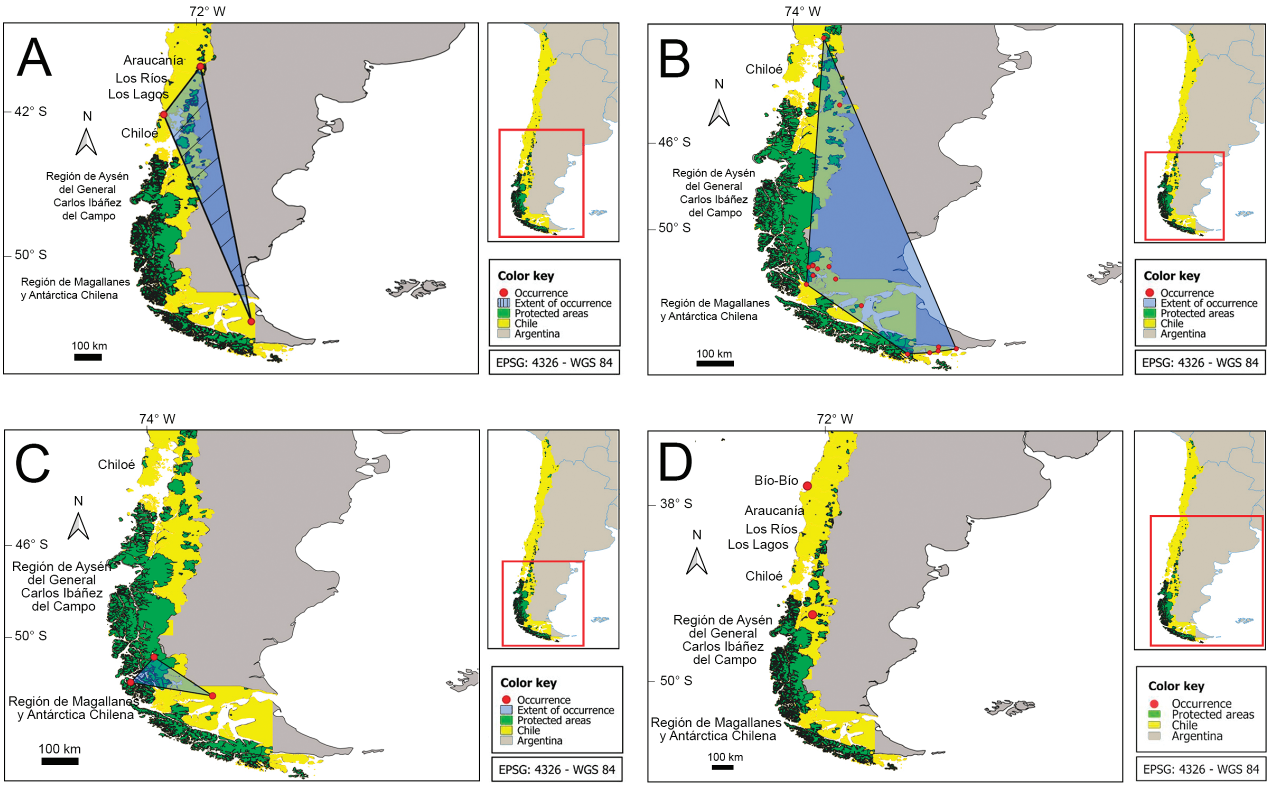

Figure 2. Distribution and occurrences of the Chilean micro-snails of the genus *Stephadiscus*, including protected areas. **A** *Stephadiscus celinae* **B** *Stephadiscus lyratus* **C** *Stephadiscus rumbolli* **D** *Stephadiscus stuardoi*. The maps were created using GeoCAT and QGIS software (Maps: G.A. Collado).

Table 1. Distributional parameters and conservation status for Chilean species of the genera *Stephacharopa* and *Stephadiscus*, based on IUCN and NatureServe guidelines. Abbreviations: AOO, area of occupancy; CR, Critically Endangered; D2, Vulnerable; EN, Endangered; EOO, extent of occurrence; LC, Least Concern; N1, Critically Imperiled; N2, Imperiled; N3, Vulnerable; NS, NatureServe; O, occurrences; OPA, occurrences in protected areas; Vu, Vulnerable. *Values of EOO should be changed to make them equal to AOO (IUNC 2019).

Species	O	OPA	EOO (km²)	AOO (km²)	IUCN			NS
					B1 (EOO)	B2 (AOO)	D	
Stephacharopa								
S. calderaensis	6	1	4,674	16	Vu B1ab(iii)	Vu B2ab(iii)	–	N2
S. distincta	3	0	7,795	12	Vu B1ab(iii)	EN B2ab(iii)	D2	N2
S. paposensis	1	0	4*	4	CR B1ab(iii)	CR B2ab(iii)	D2	N1
S. testalba	5	1	65	20	EN B1ab(iii)	EN B2ab(iii)	D2	N2
Stephadiscus								
S. celinae	3	1	170,807	12	LC	EN B2ab(iii)	D2	N2
S. lyratus	17	7	285,317	64	LC	LC	–	N3
S. rumbolli	3	2	16,800	12	Vu B1ab(iii)	EN B2ab(iii)	D2	N2
S. stuardoi	2	1	8*	8	CR B1ab(iii)	CR B2ab(iii)	D2	N1

Threats

In Chile, the species studied are threatened by urbanisation, habitat loss, habitat alteration, pollution, extreme temperatures, droughts, storms, floods, tsunamis, volcanism, climate change, soil erosion, landslides, earthquakes, tourism and recreational activities, forest fires, highways and roads, livestock, mining, hydroelectric plants and invasive species (Suppl. material 1). Considering the number of occurrences and threats, *Stephacharopa distincta*, *Stephacharopa paposensis*, *Stephacharopa testalba*, *Stephadiscus celinae*, *Stephadiscus rumbolli* and *Stephadiscus stuardoi* also meet the conditions for Vulnerable D2 status since they have five locations or fewer (Table 1) and several plausible threats (Suppl. material 1).

Potential ranges

The mapping of the occurrences of *Stephacharopa* on the protected areas indicates that only one population of *Stephacharopa calderaensis* and *Stephacharopa testalba* fell within a protected area, the Pan de Azúcar National Park and Parque Botánico Hualpén, respectively. In *Stephadiscus*, of the 17 occurrences of *Stephadiscus lyratus*, seven are found within protected areas. Each of the three remaining species included at least one population within a protected area (Table 1).

Species distribution models were performed on all species, except for *Stephacharopa paposensis* and *Stephadiscus stuardoi* because they have few occurrences (one and two, respectively). All models performed in MaxEnt gave AUC values greater than 0.9 in five cases and 0.7 in one (Suppl. material 3). Results from the analysis showed a gain in coverage with respect to the current range in all modelled species, covering a greater number of protected areas, which was remarkable in *Stephacharopa distincta*, *Stephacharopa testalba* and *Stephadiscus celinae* (Fig. 3). The variables that contributed the most information to the mod-

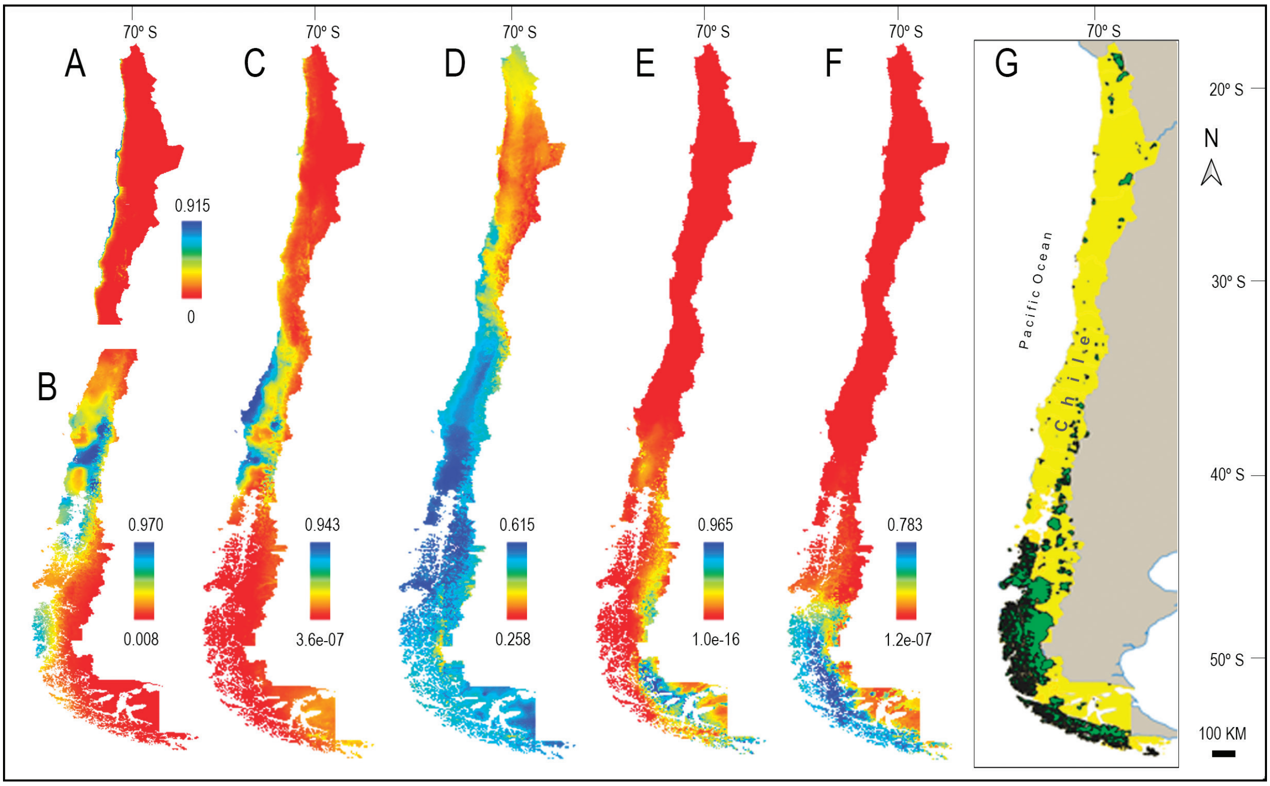

Figure 3. Potential distribution and species habitats of the genera *Stephacharopa* and *Stephadiscus* in Chile according to the modelling performed in Maxent. **A** *Stephacharopa calderaensis* **B** *Stephacharopa distincta* **C** *Stephacharopa testalba* **D** *Stephadiscus celinae* **E** *Stephadiscus lyratus* **F** *Stephadiscus rumbolli* **G** map showing Chilean territory (yellow) and protected areas (dark green). The maps were created using ArcGIS software (Maps: G.A. Collado).

els in *Stephacharopa calderaensis*, *Stephacharopa distincta* and *Stephacharopa testalba* were temperature annual range (bio7), precipitation of the coldest quarter (bio19) and precipitation of driest month (bio14), respectively, while in *Stephadiscus celinae*, *Stephadiscus lyratus* and *Stephadiscus rumbolli*, it was solar radiation. The contribution of all variables per species is shown in Suppl. material 3.

Discussion

Considering the IUCN sub-criterion B2 (AOO), which frequently classifies species in more serious conservation categories than sub-criterion B1 (EOO) and that it should be the final conservation category assigned according to the IUCN, two species were classified as Critically Endangered (CR), four Endangered (EN), one Vulnerable (Vu) and one Least Concern (LC). Under NatureServe, the assessment was rather equivalent to this one, ranking the same first two species as Critically Imperiled (N1), five Imperiled (N2) and one Vulnerable (N3). On the other hand, based on the IUCN D2 sub-criterion, six species were listed as Vulnerable (D2) given the low number of populations and the plausible threats that were identified.

Within the genus *Stephacharopa*, *S. paposensis* is the most at-risk species of the four evaluated since it was listed as Critically Endangered (CR) by the IUCN and Critically Imperiled (N1) by NatureServe. This snail is restricted to its type locality, Quebrada Paposo, an area that presents several and serious threats (Suppl. material 1). High contamination by garbage and debris has been observed in this ravine, as well as earth movements resulting from road works. The disappearance of a population of freshwater snails from a small spring in the area was previously reported (Collado 2012). A similar situation occurs for *Stephadiscus stuardoi*, but in this case, its presence has been reported from two localities separated by hundreds of kilometres. Both localities present several threats, which makes the future of the species uncertain. We avoid labelling species with few occurrences as Data Deficient (DD) by treating them as highly endemic species circumscribed to one or a few localities, as recommended by the IUCN (2019). Besides, classifying a species as Data Deficient (DD) practically nullifies any possibility of management.

As Chile comprises a long territory from north to south, with different climatic and hydrographic conditions, to which are added variations in the density of human population and urban development, not all species are exposed to the same threats. *Stephacharopa calderaensis* and *Stephacharopa paposensis* are the only northern taxa. In the xeric environments of Atacama Desert, with little urban development, these species are threatened by floods and droughts, mining, climate change, habitat loss, pollution and soil landslides, amongst other factors (Collado 2012; Burgos 2015; present study). *Stephacharopa distincta*, *Stephacharopa testalba*, *Stephadiscus celinae* and *Stephadiscus stuardoi* occupy the centre-south area of the country, with a Mediterranean climate and mesomorphic characteristics and where the largest number of people and cities of the country are concentrated. These species are threatened by urbanisation, habitat loss, forest fires, pollution, forestry activities, hydroelectric plants, roads, tourism and recreational activities, droughts and climate change (Araya 2016; Arnaboldi 2016; Subsecretaría de Turismo 2017; Díaz et al. 2018; Morales Flores 2019; Enríquez 2021; Robles 2021; present study). On the other hand, *Stephadiscus celinae* and *Stephadiscus rumbolli* are distributed in the austral region of Chile, where there is a humid, cold temperate climate with oceanic influence and hygromorphic characteristics. Species are affected by storms and floods, habitat alteration, tourism and recreational activities, pollution and invasive species (Martinic 2004; DAPMA 2009; Magallanes 2012; Graells et al. 2015; Valderrama et al. 2018; Arredondo et al. 2019; El Heraldo Austral 2019; GEF 2019; CONAF 2020; SONAMI 2021; present study).

The AUC results obtained in the species distribution models of the species analysed (greater than 0.9 and 0.7) indicate high reliability. The modelling results showed that the species have broader potential ranges, being useful for prioritising conservation actions. The analysis also revealed the climatic and environmental variables that influence the habitat of the species (Carvajal-Hernández et al. 2020), which contributes to the limited knowledge of these micro-snails. However, Pearson et al. (2007) have pointed out that the results of modelling in species with few occurrences should be interpreted as revealing geographic areas that present environmental conditions like those existing in current habitats, not necessarily indicating potential distributions.

Temperature is one of the most influential environmental predictors affecting the distribution of species (Austin and Meyers 1996) and it was the most important variable regarding the distribution of *Stephacharopa calderaensis*, *Stephacharopa distincta* and *Stephacharopa testalba*. Solar radiation is also an influential environmental variable affecting the habitat conditions in some species of plants and animals (Austin and Meyers 1996; Bennie et al. 2008), but not always. For example, the occurrence of the green toad, *Bufotes viridis* (Laurenti, 1768) was associated with a high level of solar radiation in the Middle East area, but it did not influence the distribution of the salamander *Salamandra infraimmaculata* Martens, 1885 in the same geographic area (Blank and Blaustein 2012).

Different measures have been proposed regarding conservation biology for some species of flora and fauna threatened with extinction. *Ex situ* conservation measures include translocation and breeding or culture of species outside the natural habitat, such as zoos, government and conservation institutions or natural parks (Bloxam et al. 1984; Tonge and Bloxam 1991; CBD 1992; Pearce-Kelly et al. 1997; Mace et al. 1998; Hadfield et al. 2004; IUCN/SSC 2014). Likewise, different *in situ* conservation measures have been proposed, including the installation of environmental interpretation trails, the creation of micro-reserves, the creation/extension of protected areas and the eradication of invasive species (Berkmüller and Savasdiasara 1981; CBD 1992; Balmford et al. 1995; IUCN 2002; Laguna et al. 2004; Anonymous 2005; Kadis et al. 2013; Trias-Blasi et al. 2017). For the species with few occurrence records (*Stephacharopa paposensis*, *Stephadiscus stuardoi* and *Stephacharopa distincta*, *Stephadiscus celinae* and *Stephadiscus rumbolli*), we propose to establish short-term *ex situ* conservation measures, such as breeding of specimens in captivity due to the high risk of extinction. In land snails, there are several examples that were successful after implementing these types of actions (Bloxam et al. 1984; Tonge and Bloxam 1991; Pearce-Kelly et al. 1997; Mace et al.1998; Hadfield et al. 2004). At the same time, the creation of micro-reserves around the type localities would also be a priority measure concerning their proven effectiveness (Laguna et al. 2004; Kadis et al. 2013; Trias-Blasi et al. 2017). However, this measure is more difficult to implement, considering landowners, personnel costs, infrastructure, logistics etc. With due precautions, specimen translocations can also be carried out, which have given positive results in different taxa (Balmford et al. 1995; Berger-Tal et al. 2020).

For species with five to six populations (*Stephacharopa testalba*, *Stephacharopa calderaensis*), we recommend the creation of micro-reserves (Laguna et al. 2004; Kadis et al. 2013; Trias-Blasi et al. 2017) in at least one locality, as well as the installation of environmental interpretation trails. Although this last initiative has been somewhat questioned (Navrátil et al. 2016), the heart of the idea seems good enough, having been implemented successfully (Berkmüller and Savasdiasara 1981; Anonymous 2005). Translocations are also appropriate. For *Stephadiscus celinae*, an additional measure would be to extend the Chiloé National Park by a few kilometres to the north, incorporating the locality registered on the island. Immediate measures to conserve the species *Stephadiscus lyratus* seem not to be critical considering the 17 populations in which the species is subdivided in Chile. This species also has several occurrences within protected areas (Cuezzo et al. 2021; present study). However, much of its southernmost distribution range is also occupied by the invasive beaver *Castor canadensis* Kuhl, 1820 (Graells et al. 2015; Molina et al. 2018), which is very damaging in invaded ecosystems, so it is recommended to eradicate this species.

Biodiversity hotspots, endemism areas and species with restricted distribution are key concepts in biodiversity studies (Reid 1998). In addition, knowing the threat status of species is crucial in conservation biology (Kahraman et al. 2012). In the present study, we evaluated the conservation status of eight species of land micromolluscs from different genera, most of them resulting in a high risk of extinction for which we proposed several conservation measures. However, the lack of knowledge of the life cycle, ecological and reproductive aspects of many Chilean mollusc species, including those studied here, is an issue that should be considered in the short term.

Conclusions

In this study, one species of the genus *Stephacharopa* (*S. paposensis*) was listed as Critically Endangered (CR), two Endangered (EN) (*S. distincta*, *S. testalba*) and one Vulnerable (Vu) (*S. calderaensis*) using the IUCN standards. Under NatureServe, *S. paposensis* was ranked as Critically Imperiled (N1), while *S. calderaensis*, *S. distincta* and *S. testalba* as Imperiled (N2). Likewise, one species of the genus *Stephadiscus* (*S. stuardoi*) was listed as Critically Endangered (CR), two Endangered (EN) (*S. celinae*, *S. rumbolli*) and one Least Concern (LC) (*S. lyratus*) using the IUCN standards. Under NatureServe, *S. stuardoi* was ranked as Critically Imperiled (N1), *S. celinae*, and *S. rumbolli* as Imperiled (N2), while *S. lyratus* Vulnerable (N3). Species distribution analysis showed that all species modelled have wider habitat ranges. Prompt conservation actions regarding micro-snail species are necessary to apply in Chile considering the high extinction risk of endemic and native species analysed in this study.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: MAV, GAC, CTD. Formal analysis: GAC, NF. Investigation: GAC. Methodology: NF, GAC. Project administration: GAC. Software: GAC. Supervision: GAC. Validation: MAV, GAC, MAV, CTD. Visualization: MAV, GAC. Writing – original draft: GAC. Writing – review and editing: NF, CTD, GAC, MAV, MAV.

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

List of geographical coordinates and threats affecting species

Authors: Gonzalo A. Collado, Nataly Flores, Marcela A. Vidal, Cristian Torres-Díaz, Moisés A. Valladares

Data type: Geographical coordinates and threats (.xlsx file)

Link: https://doi.org/10.3897/natureconservation.53.100631.suppl1

Supplementary material 2

NatureServe assessment

Authors: Gonzalo A. Collado, Nataly Flores, Marcela A. Vidal, Cristian Torres-Díaz, Moisés A. Valladares

Data type: table (.docx file)

Explanation note: Input data of Chilean species for NatureServe assessment.

Link: https://doi.org/10.3897/natureconservation.53.100631.suppl2

Supplementary material 3

Species distribution models

Authors: Gonzalo A. Collado, Nataly Flores, Marcela A. Vidal, Cristian Torres-Díaz, Moisés A. Valladares

Data type: table (.docx file)

Explanation note: Relative contributions (in percentage) of the climate and environmental variables in species of *Stephacharopa* and *Stephadiscus* and model validation results.

Link: https://doi.org/10.3897/natureconservation.53.100631.suppl3