

# Binational Conservation Strategy for Darwin's Frogs

Chile - Argentina 2018 - 2028



Summary in English



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This document is a summary of the original conservation strategy book which was published in Spanish and is available [here](#)

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# Acronyms and abbreviations

<b>AIFN</b>	Agrupación de Ingenieros Forestales por el Bosque Nativo (Chile)
<b>APN</b>	Administración de Parques Nacionales (Argentina)
<b>ASG</b>	IUCN scc Amphibian Specialist Group
<b>ASP</b>	Área Silvestre Protegida
<b>Bd</b>	<i>Batrachochytrium dendrobatidis</i>
<b>CONAF</b>	Corporación Nacional Forestal (Chile)
<b>CONICET</b>	Consejo Nacional de Investigaciones Científicas y Técnicas (Argentina)
<b>CONICYT</b>	Corporación Nacional de Ciencia y Tecnología (Chile)
<b>ECRD</b>	Estrategia Binacional de Conservación de las Ranitas de Darwin
<b>FHH</b>	Fundación Huilo Huilo (Chile)
<b>MADS</b>	Ministerio de Ambiente y Desarrollo Sustentable (Argentina)
<b>MERI</b>	Fundación MERI (Chile)
<b>MMA</b>	Ministerio del Medio Ambiente (Chile)
<b>NN</b>	Agrupación Nahuelbuta Natural (Chile)
<b>NGO</b>	Non-profit organization
<b>ORD</b>	ONG Ranita de Darwin (Chile)
<b>PT</b>	Parque Tantauco (Chile)
<b>RCE</b>	Reglamento de Clasificación de Especies (Chile)
<b>RECOGE</b>	Recuperación, Conservación y Gestión de Especies (Planes)
<b>RECH</b>	Asociación Red Chilena de Herpetología (Chile)
<b>SAG</b>	Servicio Agrícola Ganadero (Chile)
<b>SEIA</b>	Sistema de Evaluación de Impacto Ambiental (Chile)
<b>SNASPE</b>	Sistema Nacional de Áreas Protegidas del Estado (Chile)
<b>SSC</b>	Species Survival Commission
<b>TAR</b>	Taller de Actores Relevantes
<b>TNC</b>	The Nature Conservancy
<b>UACH</b>	Universidad Austral de Chile
<b>UCh</b>	Universidad de Chile
<b>UDEC</b>	Universidad de Concepción (Chile)
<b>UICN</b>	Unión Internacional para la Conservación de la Naturaleza (IUCN in English)
<b>UNAB</b>	Universidad Andrés Bello (Chile)
<b>UNCO</b>	Universidad Nacional del Comahue (Argentina)
<b>ZOO LEIPZIG</b>	Leipzig Zoo (Alemania)
<b>ZOO NACIONAL</b>	National Zoo (Chile)

# Partners



Universidad de Concepción



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# Vision

Darwin's frogs, unique in the world for their reproductive peculiarity, are conserved and valued as an emblem for the protection of the native forests of southern Chile and Argentina.



# Executive summary

Darwin's frogs *Rhinoderma darwinii* and *Rhinoderma rufum* are the only known species of amphibians in which males brood their offspring in their vocal sacs. We propose these frogs as flagship species for the conservation of the Austral temperate forests of Chile and Argentina. This recommendation forms part of the vision of the Binational Conservation Strategy for Darwin's Frogs, which was launched in 2018.

The strategy is a conservation initiative led by the IUCN SSC Amphibian Specialist Group, which in 2017 convened 30 governmental, non-profit and private organizations from Chile, Argentina and elsewhere.

Darwin's frogs are iconic examples of the global amphibian conservation crisis: *R. rufum* is categorized as Critically Endangered (Possibly Extinct) on the IUCN Red List, and *R. darwinii* as Endangered.

Here we articulate the conservation planning process that led to the development of the conservation strategy for these species and present its main findings and recommendations.

Using an evidence-based approach, the Binational Conservation Strategy for Darwin's Frogs contains a comprehensive status review of *Rhinoderma* spp., including critical threat analyses, and proposes 39 prioritized conservation actions. Its goals are that by 2028, key information gaps on *Rhinoderma* spp. will be filled, the main threats to these species will be reduced, and financial, legal and societal support will have been achieved.

The strategy is a multi-disciplinary, transnational endeavour aimed at ensuring the long-term viability of these unique frogs and their particular habitat.



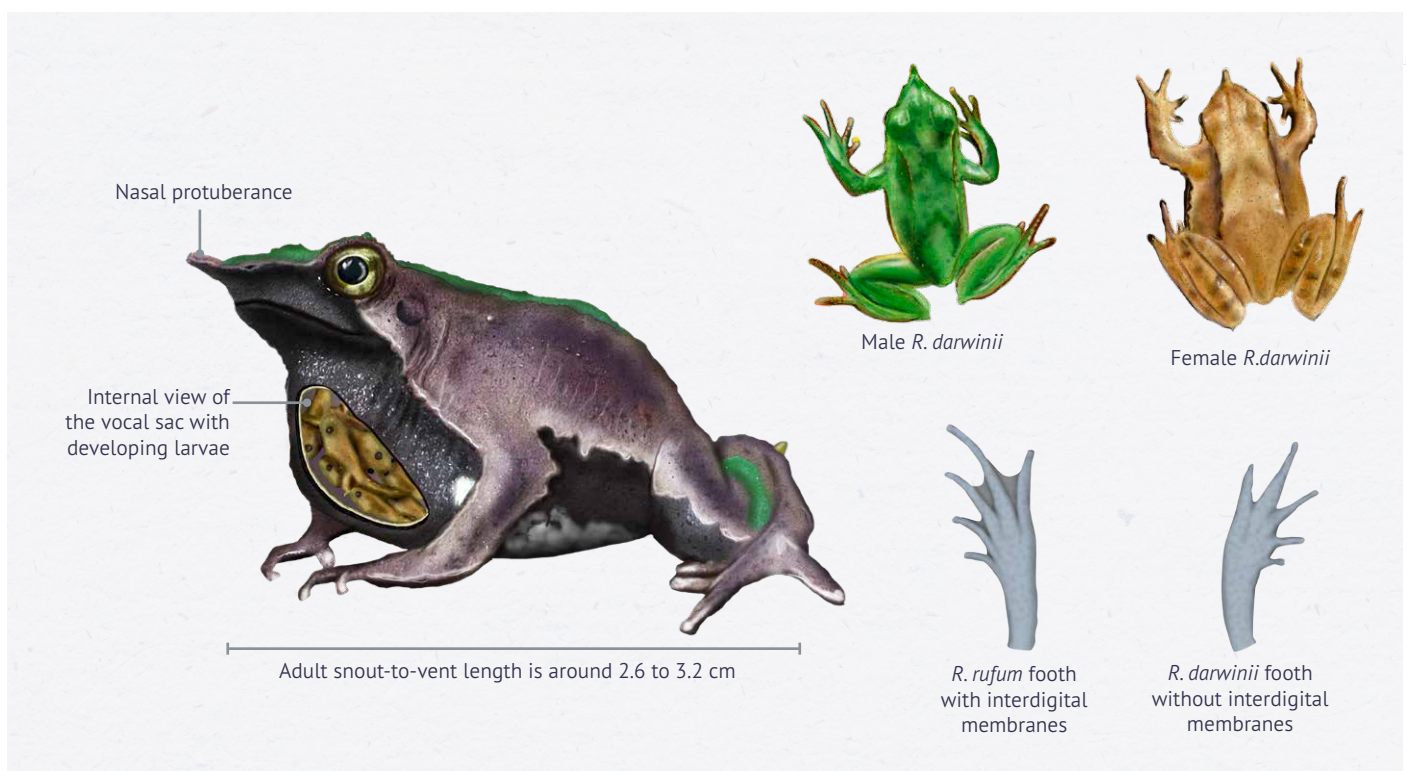
**A conservation strategy  
for Darwin's frogs**



# Introduction

Halting biodiversity loss depends largely on developing effective conservation policies and planning (Johnson et al., 2017). Evidence-based, inclusive, participatory conservation strategies are recommended when specific actions are needed to save species from extinction (IUCN, 2017). Key species can act as umbrellas or flagships, transforming species-level conservation plans into ecosystem-wide benefits (Superina et al., 2018).

The northern and the southern Darwin's frog (*Rhinoderma rufum* and *Rhinoderma darwinii*) are named after Charles Darwin, who was the first to collect *R. darwinii*, in 1834. These species are the only known amphibians in which the males brood their offspring within their vocal sacs (FIG. 1). In *R. rufum* the later larval stages develop in water, whereas in *R. darwinii* the entire larval development, lasting up to 8 weeks and including metamorphosis, takes place within the male's vocal sac (Formas et al., 1975; Formas, 2013). Endemic to the Austral temperate forests of South America, both species are highly threatened as a result of dramatic population declines, particularly during the last 4 decades (Crump & Veloso, 2005; Bourke et al., 2012; Soto-Azat et al., 2013a). The habitat of Darwin's frogs is an ecoregion characterized by a high degree of endemism and is thus of high conservation priority (Myers et al., 2000). *Rhinoderma rufum* has not been recorded since 1981 and remaining populations of *R. darwinii* are small and isolated (Soto-Azat et al., 2013a; IUCN, 2019). Darwin's frogs are found only in native forest (generally old-growth), and *R. darwinii* abundance has been positively correlated with the structural complexity of its forest habitat (Valenzuela- Sánchez et al., 2019a). Although habitat loss is a threat, population declines and extirpations have also been documented within protected areas and undisturbed ecosystems (Crump & Veloso, 2005; Soto-Azat et al., 2013a).



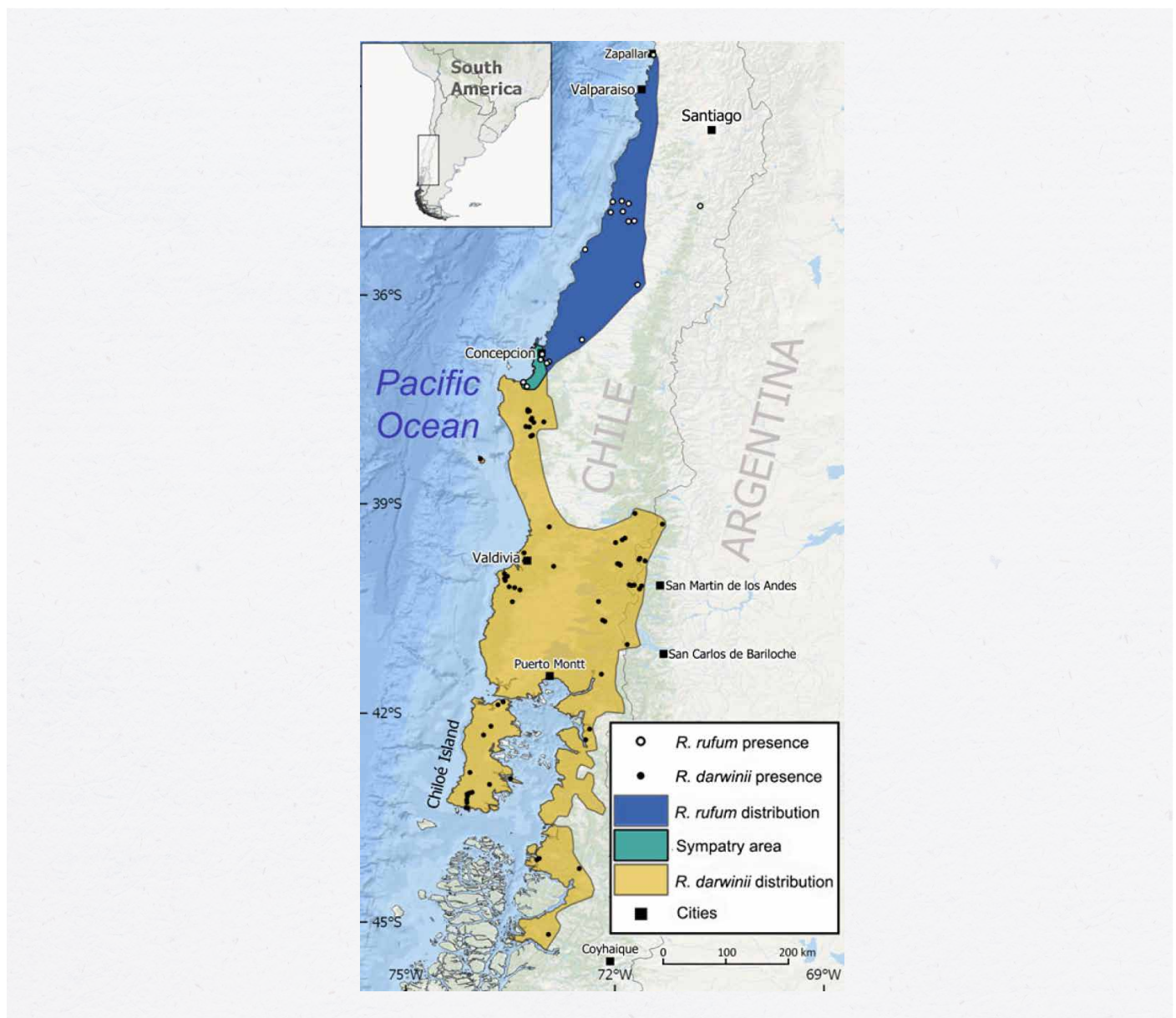
**FIGURE 1:** Darwin's frog (*Rhinoderma darwinii*) morphology. Note that although dorsal colouration is not a sexually dimorphic trait, in northern populations brown and green colourations are more prevalent in females and males, respectively.

Recently, there has been growing concern about Darwin's frogs, evidenced by several independent and uncoordinated research and conservation efforts. The majority (75%) of all publications on Darwin's frogs indexed in the Web of Science were published during 2010–2019, when a number of *in situ* and *ex situ* conservation projects were established for *R. darwinii*. Thus, we identified an opportunity for collaboration to provide efficient and cost-effective conservation outcomes for these unique and highly threatened frogs. In 2017 the Chilean section of the IUCN SSC Amphibian Specialist Group convened stakeholders to develop a conservation plan for Darwin's frogs, and as a result the Binational Conservation Strategy for Darwin's Frogs was launched in 2018. Here we summarize the process of the strategy's development, present its main findings and recommendations and discuss the major challenges and opportunities of implementation. We conclude by presenting the conservation strategy goals, objectives, and actions, including a prioritisation table.



# Study area and methods

The Austral temperate forests, which include the habitat of Darwin's frogs (32–47 °S), cover > 20 million ha, mainly in Chile but also in Argentina (4.6 and 16.0 million ha for *R. rufum* and *R. darwinii*, respectively; IUCN, 2019). *Rhinoderma rufum* is endemic to the coastal range of Chile at 0–500 m altitude (Bourke et al., 2012; Soto-Azat et al., 2013a; Cuevas, 2014). *Rhinoderma darwinii* is found in both the coastal range of Chile (including Mocha Island and the Chiloé Archipelago) and the Andes of Chile and Argentina (Soto-Azat et al., 2013a) at 0–1,340 m altitude (Úbeda & Pastore, 2015). Historical distributions of *Rhinoderma* spp. are shown in FIG. 2.



**FIGURE 2:** Distribution of Darwin's frogs in Chile and Argentina. Historical distribution of *Rhinoderma rufum*, *Rhinoderma darwinii* and the area of sympatry around Concepción. Localities with known current presence of *R. darwinii* are shown in solid dots. No population of *R. rufum* is currently known, but historical localities are shown in open dots. There is one unusual historical record for *R. rufum* in the Chilean foothills of the Andes (Barros, 1918).

## Conservation assessment

In July 2015, 19 Chilean herpetologists met at Universidad Andres Bello in Santiago to update the IUCN Red List assessment of Chilean amphibians (Soto-Azat et al., 2015). This work highlighted the urgent need for conservation planning for Darwin's frogs. Re-assessments of *R. darwinii* and *R. rufum* followed the IUCN Red List methodology: literature and data searches, assessments by experts and external review.

## Development of the strategy

Development of the Binational Conservation Strategy for Darwin's Frogs was facilitated by an Amphibian Specialist Group co-chair, a programme officer and a thematic group chair and followed IUCN guidelines for species conservation planning (IUCN, 2017). Initially, a 1-day symposium in September 2017 convened 292 participants interested in the conservation of Darwin's frogs. Here, 27 national and international speakers presented advances on *Rhinoderma* spp. research and conservation, and discussed IUCN guidelines for effective conservation planning (IUCN, 2017). Subsequently, 30 stakeholders that had been selected for their expertise, influence, and representation of relevant organizations, attended a 3-day conservation strategy workshop where we:

- (1) formulated the strategy's vision,
- (2) defined the strategy's time frame,
- (3) discussed the current status of Darwin's frogs,
- (4) assessed the challenges, barriers and threats to their conservation,
- (5) established working groups,
- (6) developed conservation goals, objectives and actions,
- (7) prioritized objectives and actions
- (8) elected the coordination structure.

Also, we formed four working groups based on identified conservation needs:

- (1) habitat loss,
- (2) captive breeding, research and climate change,
- (3) policy and education
- (4) diseases and invasive species

Following a SMART (Specific, Measurable, Achievable, Realistic and Time-bound) approach, each working group proposed goals, objectives and actions, which were later discussed, validated and prioritized by all workshop participants. After the workshop, a draft of the strategy was distributed among participants and others involved in the development of the strategy, for comment and approval.



# Results

## Conservation assessment

*Rhinoderma rufum* is categorized as Critically Endangered (Possibly Extinct) based on criterion D because its population size is estimated to be < 50 mature individuals (IUCN, 2019). The species has not been recorded since 1981 despite intense searches across its historical range (Busse, 2002; Bourke et al., 2012; Soto-Azat et al., 2013a; Cuevas, 2014). *Rhinoderma darwinii* is categorized as Endangered following criteria B2ab(iii) (IUCN, 2019) because:

- (1) Its current area of occupancy is estimated to be 224 km<sup>2</sup> (500 km<sup>2</sup> threshold; B2).
- (2) Extant populations are small and isolated (a).
- (3) The extent and quality of its remaining habitat continues to decline (b(iii); Crump & Veloso, 2005; Soto-Azat et al., 2013a; Uribe-Rivera et al., 2017; Bourke et al., 2018).

Only *R. darwinii* has been kept and bred in captivity.

## A conservation strategy

Under the vision ‘Darwin’s frogs, unique in the world for their reproductive peculiarity, are conserved and valued as an emblem for the protection of the native forests of southern Chile and Argentina’, the Binational Conservation Strategy for Darwin’s Frogs was launched in October 2018. The strategy is divided into two main components: a status review of *Rhinoderma* spp., and the conservation strategy itself, comprising a threat assessment (FIG. 3) and a list of prioritized conservation actions.

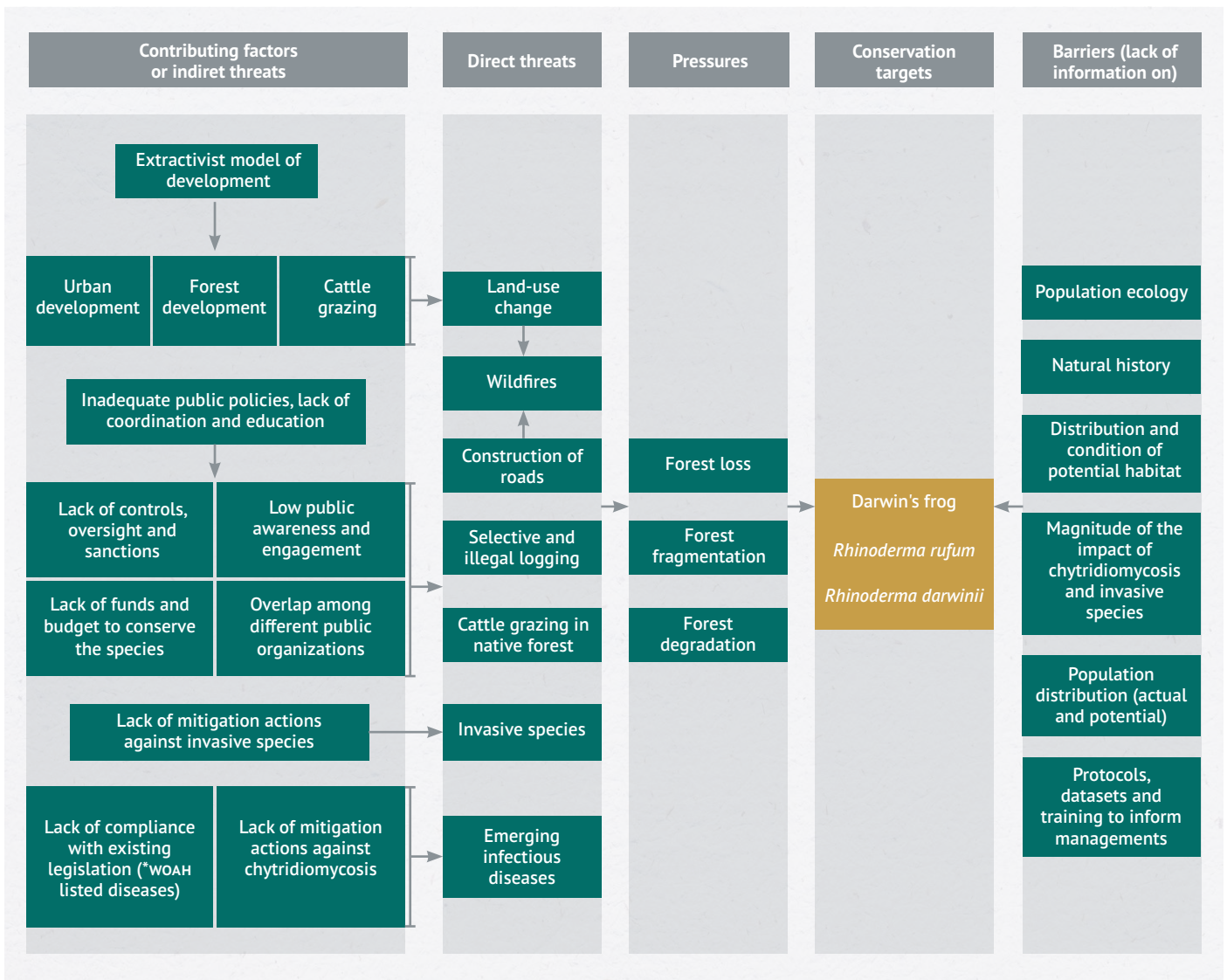
The strategy aims to achieve the following goals by 2028:

- (1) Obtain key information on the biology, management and status of *Rhinoderma* populations.
- (2) Reduce the main threats to Darwin’s frogs.
- (3) Provide the financial, legal and societal support needed for the proposed conservation actions.

To this end, the strategy contains 39 actions, grouped under 12 objectives. Each conservation action lists responsible stakeholders, deadlines, indicators, potential collaborators and funding sources. The strategy (IUCN ASG–Chile, 2018) has been distributed among relevant authorities, conservation organizations, local communities and the general public.

## Website

The full Binational Conservation Strategy for Darwin’s Frogs can be downloaded from the strategy’s website (see full reference in IUCN ASG–Chile, 2018). This website provides information on *Rhinoderma* biology and conservation along with relevant literature and other resources. The strategy is intended to be a dynamic and adaptive document, and the website will help with the coordination of identified actions.



**FIGURE 3:** Conceptual model showing a threat assessment for Darwin's frogs (*R. rufum* and *R. darwini*). We identified direct and indirect threats, barriers, contributing factors and pressures, and plotted their interactions with each other and within the binational conservation strategy. \*WOAH =World Organisation for Animal Health.

## Darwin's Frog Alliance

A key outcome of the conservation planning process was the creation of the Darwin's Frog Alliance, a network of 47 individuals, representing 30 institutions and a diverse array of stakeholders (from academia, government, zoological institutions, local communities, NGOs and the private sector) to enhance collaboration for the conservation of Darwin's frogs. The Alliance is led by members of the Amphibian Specialist Group, and endorsed by the Chilean and Argentinian Ministries of Environment.

## Threat assessment

The status review supported previous claims that the decline of Darwin's frogs has been largely driven by habitat loss, chytridiomycosis and climate change (Bourke et al., 2010, 2012, 2018; Soto-Azat et al., 2013a, 2013b; Uribe-Rivera et al., 2017; Valenzuela-Sánchez et al., 2017). Here we provide a brief synthesis of this review.

## Status of populations

Using species distribution modelling, Bourke et al. (2012) identified areas with potential remnant *R. rufum* populations, providing guidance for future efforts to rediscover this species. Soto-Azat et al. (2013a) dated its extinction to 1982 (95% CI: 1980–2000) using historical sightings. In contrast, *R. darwinii* is found in small and isolated populations (Soto-Azat et al., 2013a; Valenzuela-Sánchez et al., 2015). During the development of the strategy, we identified 56 extant populations in Chile and 10 in Argentina (Fig. 1). In Chile, *R. darwinii* has recently disappeared from, or drastically declined in, many localities where it was abundant only decades ago (Crump & Veloso, 2005; Soto-Azat et al., 2013a). The size of extant populations is c. 10–145 reproductive individuals (Crump, 2002; Soto-Azat et al., 2013a; Valenzuela-Sánchez et al., 2014, 2017, 2019a). In Argentina, the species has been less studied but, based on museum collections, it was probably much more abundant in the past (Úbeda & Pastore, 2015).

## Habitat loss

The original habitats of *R. rufum*, the Coastal Mediterranean and Maulino deciduous forests (32–36 °S), have been almost completely replaced by exotic pine and eucalypt plantations and agriculture, with < 7% of Maulino forest remaining (Smith-Ramírez, 2004; Echeverría et al., 2006). The Valdivian temperate rainforest (36–47 °S) is the typical habitat of *R. darwinii*. To the north, the situation for *R. darwinii* is similar to that for *R. rufum*, but further south the native forest becomes more continuous as the coverage of protected areas increases, thus providing more suitable habitat for the species.

## Amphibian chytridiomycosis

Caused by the fungus *Batrachochytrium dendrobatidis*, this emerging disease is known for its catastrophic and ongoing impacts on amphibian populations worldwide (Scheele et al., 2019). This pathogen has been identified from museum specimens of wild Chilean amphibians collected since the 1970s (Soto-Azat et al., 2013b). This coincides with the documented onset of South American amphibian declines (Scheele et al., 2019). Surveys in Chile have demonstrated that *B. dendrobatidis* is infecting *R. darwinii* in the wild (Bourke et al., 2010), with evidence of lethal chytridiomycosis (Soto-Azat et al., 2013b), which leads to extirpation of infected populations (Valenzuela-Sánchez et al., 2017).

## Climate change

Because of its specific habitat requirements (Valenzuela-Sánchez et al., 2019a), slow life-history strategy (Valenzuela-Sánchez et al., 2017) and dispersal limitations (Valenzuela Sánchez et al., 2014, 2019b), *Rhinoderma* spp. are expected to be particularly susceptible to climate change (Soto-Azat et al., 2013a). Using a dispersal-constrained species distribution model, Uribe-Rivera et al. (2017) estimated that during 1970–2010, climate change led to a reduction of suitable habitat for this species by 23–40%. Bourke et al. (2018) predicted an expansion of climatically suitable areas for *R. darwinii* by 2080, especially in the south of its range. However, unless assisted by translocations, *R. darwinii* would not naturally colonize most of the emerging suitable areas (Uribe-Rivera et al., 2017). Incorporating dispersal limitations analyses of climate change projections for 2050 and 2080 show reductions of 33–56% in the potential distribution of *R. darwinii* (FIG. 4, Uribe-Rivera et al., 2017).



## Other threats

Collection of wild *Rhinoderma* spp., mainly for hobbyists and museums, was common in the past (J.C. Ortiz, pers. obs., 1988; Soto-Azat et al., 2013a). Other threats and barriers include livestock farming in forest habitats, non-compliance with current legislation, and lack of public awareness and engagement (FIG. 4).

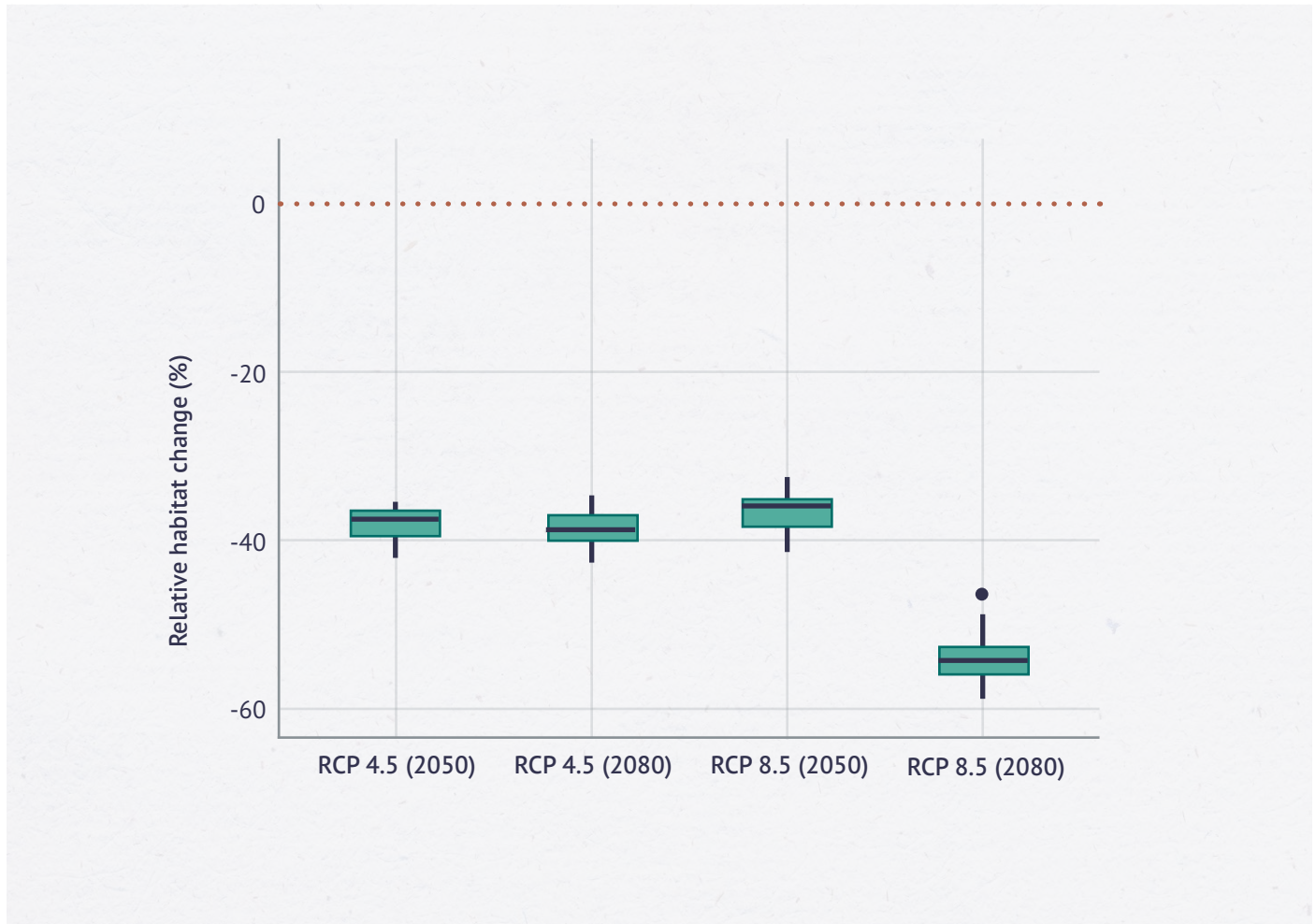


FIGURE 4: Boxplot (median, 25th, and 75th percentiles) of relative changes in the extent of potential habitat (suitable and accessible) of *R. darwini*, projected to two temporal windows (2050 and 2080) and two climate change scenarios (Relative Concentration Pathway 4.5 and 8.5; IPCC, 2014). The dashed line represents a scenario of no change compared to the present situation.

## Ongoing conservation

Although there are 30 protected areas (28 in Chile and two in Argentina) within the range of *R. darwini*, none protect any of the historical sites of *R. rufum*. Since 2009, three *in situ* conservation projects have been implemented for *R. darwini*: in Huilo Huilo, Tantauco and Melimoyu private parks. Currently, there are two independent *ex situ* conservation projects for *R. darwini*: one led by Universidad de Concepción in conjunction with Zoo Leipzig, Germany (since 2009), and another by the National Zoo of Chile (since 2010). There are also several education initiatives focused on Darwin's frogs: one at the National Zoo of Chile (visited by > 860,000 people in 2018), a Darwin's frog education centre in Huilo Huilo (> 100,000 visitors in 2018), and an education programme run by NGO Ranita de Darwin, which has reached > 15,000 people in local communities within the range of *Rhinoderma* spp.



# Discussion

Multi-pronged strategies that combine research, management, education and policy are required to achieve successful species conservation (Superina et al., 2018). The Binational Conservation Strategy for Darwin's Frogs is a multi-sectoral, participatory effort and follows an evidence based process to achieve the long-term conservation of Darwin's frogs. Additionally, this strategy promotes these species as non-traditional flagships for the conservation of the Austral temperate forest, which has been identified as one of the world's 25 biodiversity hotspots (Myers et al., 2000).

## Conservation challenges

### Habitat protection

The coastal range of central Chile has the greatest terrestrial species richness in the country, but almost entirely lacks protection and has experienced a rapid loss of biodiversity (Smith-Ramírez, 2004), especially since the 1970s (Echeverría et al., 2006). If *R. rufum* is rediscovered, it will be challenging to guarantee its immediate *in situ* protection, considering that it may occur on private land. In contrast, protected areas have allowed the persistence of *R. darwini*. In Chile, 93% of known populations (52 out of 56; FIG. 2) are within areas with some level of protection, mostly private parks (43%). Although < 5% of the range of *R. darwini* lies in Argentina, all known populations (10) in this country are in two large and contiguous national parks: Lanín and Nahuel Huapi (Úbeda & Pastore, 2015). Private reserves (which cover 1.5 million ha in central and southern Chile) are key for the conservation of Darwin's frogs. Similarly, a partnership with the forestry sector can boost the protection of Darwin's frog habitat. Forestal Arauco is the largest forestry company in South America (owning 1.4 million ha in Chile and Argentina) and a participating member of the Binational Conservation Strategy for Darwin's Frogs. Most of their land is planted with exotic pines and eucalypts, but > 110,000 ha of native forests are protected as conservation areas, five of which currently protect populations of *R. darwini* (Arauco, 2017). Improving the conservation status of Darwin's frogs depends on increasing the area and connectivity of its habitat (Soto-Azat et al., 2013a). The traditional approach to achieving this would be to create or expand protected areas (Smith-Ramírez, 2004), but a novel initiative is being implemented in southern Chile. In collaboration with local landowners and regional government, NGO Ranita de Darwin promotes amphibian conservation by voluntary agreements (Ranita de Darwin, 2020a) to encourage planting of native forest, habitat management and monitoring of the Darwin's frog population by landowners (Santangeli et al., 2016).

### Managing wildfires

Wildfires are considered an emerging threat to Darwin's frogs. During 2017 and 2018, central and southern Chile experienced the largest wildfires in recent history; > 500,000 ha were burnt in 2017, 20% of which involved native forest (CONAF, 2017). Climate change projections predict a trend of increasing damage by wildfires (Urrutia-Jalabert et al., 2018). Fire prevention or rapid containment is a key aspect of future conservation management plans for *Rhinoderma* spp.

## Reintroductions

There are plans to reintroduce *R. darwinii* individuals from captive breeding projects to areas from which they have been extirpated, or to use them for population reinforcement. Translocation success will depend on evidence-based management of the threats that led to the extirpations or declines at the release sites (IUCN, 2013; Molina-Burgos et al., 2018).

## Policy and public engagement

The Chilean Ministry of Environment administers the legal instrument of Recovery, Conservation and Management (RECOGE) Plans to execute research, protection and conservation programmes for threatened species. The Ministry has been part of the development of the Binational Conservation Strategy for Darwin's Frogs since its inception; inclusion of RECOGE criteria in the strategy will facilitate its adoption. In Argentina, where *R. darwinii* is present only in two national parks, the National Park Administration is responsible for implementing the strategy. Once signed by the environment authorities of both countries, the strategy will facilitate interdisciplinary and international working amongst public agencies. Another area in which both countries can take action involves animal health departments, with the enforcement of amphibian import regulations and the implementation of biosecurity protocols aimed at limiting the spread of *B. dendrobatidis* (and other invasive species) both at national and local levels (Valenzuela-Sánchez et al., 2018; Bacigalupe et al., 2019). Official recognition of the strategy is also relevant for establishing nation-wide conservation education programmes. Improving the public's knowledge of and attitudes towards Darwin's frogs will be critical to achieve the strategy's objectives (Márquez-García et al., 2018).

## Future research

Studies on population trends and threats to *R. darwinii* in Argentina are lacking and little is known about the genetic diversity of *Rhinoderma*. There have been no genetic studies of *R. rufum* and limited information is available for *R. darwinii* (Crump & Veloso, 2005). A characterization of the genetic structure of *Rhinoderma* spp. across their range would inform *in situ* management and assessment of potential reintroductions using captive-bred animals (IUCN, 2013).

Other critical investigations include improving our understanding of two known major threats: amphibian chytridiomycosis and climate change (Soto-Azat et al., 2013b; Uribe-Rivera et al., 2017). For *R. darwinii*, research is underway to assess mitigation actions addressing infections with *B. dendrobatidis* (Ranita de Darwin, 2020b). Besides phenotypic plasticity, amphibians have two options to deal with climate change: evolutionary adaptation and dispersal (Uribe-Rivera et al., 2017). No information exists concerning evolutionary or phenotypic responses to rapid and ongoing climate change (IPCC, 2014); studies addressing this issue will allow us to predict, and potentially mitigate, the impacts of climate change on *Rhinoderma*.



# Conclusions

The Binational Conservation Strategy for Darwin's Frogs is the first conservation strategy exclusively dedicated to amphibians at the species level in both Chile and Argentina. It provides an informative case study of a comprehensive programme for iconic, yet under-appreciated, fauna and an example of how small ectothermic animals can become flagship species for conservation, a role usually assigned to larger charismatic mammals. The development of the strategy is a constructive example of stakeholders, including local communities and industry, working together to generate a robust instrument to combat the amphibian extinction crisis. This multi-disciplinary conservation planning initiative is an effort to coordinate existing work in Chile and Argentina and to catalyse further conservation actions based on scientific evidence. Successful implementation of the strategy will help to ensure the long-term viability of these unique frogs and, by extension, of their habitat, the Austral temperate forest.





**Goals, objectives,  
and actions**

## Goal 1

By the year 2028 all the key information on diverse aspects of the biology and the current status of the populations of the genus *Rhinoderma* is available, such that:

- Environmental factors that allow predicting Darwin's frogs occurrence are well understood. This will facilitate the finding of new populations as well identification of potential reintroduction sites.
- The population dynamics of Darwin's frogs are well understood. We understand the effects of climate change and chytridiomycosis on these dynamics.
- The taxonomic status of *R. rufum* is determined and the genetic diversity of the populations of both species of Darwin's frogs is known.
- There are protocols, databases, and training programmes in place to assist *in situ* and *ex situ* management of Darwin's frogs.

## Goal 2

By the year 2028 all the main threats to Darwin's frogs have been reduced, including:

- The habitats of Darwin's frogs have been protected effectively across all the priority sites with confirmed presence of Darwin's frogs. Population at these sites are self-sustaining.
- Ecological restoration of the habitat of Darwin's frogs has started (threats associated with habitat degradation have been controlled) in sites with degraded habitat. In sites with recent local extinction of Darwin's frogs, re-introduction of captive breed individuals has started after a threat assessment considering genetic factors, environmental stressors, and biosecurity and ethical aspects.
- Invasive species that could have a negative impact on Darwin's frogs are controlled (e.g. chytrid fungus, wild boars) in a way that no longer represent a threat to the known populations of these species.

## Goal 3

By the year 2028 this conservation strategy has all the necessary legal and financial support, including support from key stakeholders and the public:

- This conservation strategy is legally recognized in Chile by the elaboration and approval of a "Plan de Recuperación, Conservación y Gestión de Especies" (Minister of the Environment, Government of Chile).
- This conservation strategy has all the financial and human resources to ensure its long-term implementation.
- This conservation strategy has been incorporated into the operational planning of at least four key actors from different sectors (e.g. public organisms in charge of managing state protected areas, Ministerio del Medio Ambiente (Chile), Ministerio de Ambiente y Desarrollo Sustentable (Argentina), forestry companies, conservation organizations).
- This conservation strategy is communicated to the public using an specific education and outreach programme.

# Goal 1

By the year 2028 all the key information on diverse aspects of the biology and the current status of the populations of the genus *Rhinoderma* is available

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
Obj. 1.1	Identify areas with high probability of occurrence of <i>Rhinoderma</i> populations, considering the impact of climate change, chytrid fungus infection, and invasive species on species presence					
1.1.1	Construct species distribution models or refine existing models, considering bioclimatic variables and land use, to determine current areas with high probability of occurrence of <i>Rhinoderma</i> populations	ORD	October 2018 - July 2019	Maps with habitat suitability for each species are published	CONAF, DGA	ORD
1.1.2	Construct species distribution models, considering bioclimatic variables and land use, to explore the impact of projected climate change scenarios on <i>Rhinoderma</i> distributions	ORD, UNAB and Bioforest	October 2018 - July 2019	Maps with habitat suitability for each species, projected into the future (2050 and 2080) are published	CONAF, DGA	ORD
1.1.3	Determine low- and high-risk areas for the presence of chytrid infections in <i>Rhinoderma</i> populations to prioritise areas where disease mitigation is required	ORD, UACH, UNAB	October 2018 - July 2019	Maps with high- and low-risk areas for chytrid fungus infections in <i>Rhinoderma</i> are published	CONAF, DGA	FONDECYT post-doc N°3180107, UACH y potentially ZOO LEIPZIG, UNAB, ORD
1.1.4	Survey at least 30 new localities for <i>R. rufum</i> , and at least 20 new localities for <i>R. darwinii</i> in Chile and 10 in Argentina, ideally informed by species distribution models, to attempt to find new populations of these species and improve knowledge about their current distribution	UCH, ORD, UNAB, UDEC, ZOO NACIONAL, APN	November 2018 - December 2021	New populations are detected and published	Bioforest, CMPC, NN, UNCO, RECH, SAG, CONAF, MMA, FHH, Forestal Arauco S.A., TNC, MADS	Potentially NGOs, public agencies, FONDECYT, and other conservation grants



N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
1.1.5	Determine the level of habitat degradation in sites with presence of <i>Rhinoderma</i> species	Academia, ONGS	First semester 2019 - second semester 2020	Report about the habitat quality of monitored sites published	AIFBN, CMPC, Arauco, public services (MMA, SAG, CONAF, APN, DGA, MADS), academia, ORD, consultants	Potentially NGOs, public agencies, FONDECYT, and other conservation grants
1.1.6	Conduct a literature search, complemented with field studies, to identify invasive species that might represent a threat to <i>Rhinoderma</i>	UDEC, APN	2018 - 2020	Database and scientific publication	ORD, SAG, CONAF, academia, FHH, MERI, PT, TNC, other private protected areas	Potentially NGOs, public agencies, FONDECYT, and other conservation grants
1.1.7	Strengthen citizen science programmes in order to find new <i>Rhinoderma</i> populations	ORD, UCH, ZOO NACIONAL, UDEC	October 2018 - December 2020	At least one platform is operational as of December 2018, and remains operational until 2028	NN, RECH, SAG, CONAF, MMA, APN, UNCO, MADS	Potentially NGOs, public agencies, FONDECYT, and other conservation grants
<b>Obj. 1.2</b>	<b>Launch or strengthen <i>Rhinoderma</i>-focused population monitoring programmes, aiming to fully understand the population dynamics of these species to inform in situ management</b>					
1.2.1	Implement long-term monitoring programmes, including epidemiological vigilance of chytrid fungus infections, at least in 20 populations of <i>R. darwinii</i> (distributed evenly across the species distribution) and in all detected populations of <i>R. rufum</i>	ORD, UNAB, UDEC, Bioforest, APN, CONAF, UNCO, NN, ZOO NACIONAL	2019 - 2023	Programmes are established by 2019. Data generated is published periodically (e.g. every 3-5 years) to provide necessary information for management	SAG, MMA, Arauco, CMPC, FHH, MERI, PT, TNC, other private protected areas and forestry companies, MADS	ORD and potentially ZOO LEIPZIG, NGOs, public agencies, FONDECYT, researchers, and other conservation grants
1.2.2	Study the metapopulation dynamics of <i>R. darwinii</i> (capture-recapture and genetics), to understand how dispersal processes operate in this species, evaluate the role of sympatric species as reservoirs or vectors of <i>B. dendrobatidis</i> and evaluate how habitat fragmentation may	ORD, UACH, UNAB	August 2018 - February 2021	Scientific article is published and recommendations applied to the management of the species are delivered through the website of the strategy and related organizations	FHH, CONAF, SAG, MERI, PT, TNC, ZSL, other private protected areas	FONDECYT postdoc N°3180107, and potentially FHH, ZOO LEIPZIG, UNAB and ORD

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
	impact the persistence of these metapopulations					
1.2.3	Identify factors that increase the risk of Bd infection in Darwin's frogs and how climate change could modify this risk	ORD, UACH, UNAB, UDEC	2018 - 2028	Scientific articles published	CONAF, SAG, DGA, FHH, MERI, PT, TNC, ZSL, others	UACH, UNAB and potentially FONDECYT, ZOO LEIPZIG, ORD
<b>Obj. 1.3 Define the taxonomic status of <i>R. rufum</i> and define Evolutionarily Significant Units (ESU) for <i>R. darwinii</i></b>						
1.3.1	Define the taxonomic status of <i>R. rufum</i> and define Evolutionarily Significant Units (ESU) for <i>R. darwinii</i>	UCH, UNAB, UDEC	August 2018 - December 2019	Scientific articles published	National and international museums, ORD	Potentially NGOs, public agencies, researchers, and other conservation grants
1.3.2	Obtain morphological data and samples for genetic analysis of the genus <i>Rhinoderma</i> (priority given to museum samples)	UCH, UNAB, UDEC	March 2018 - December 2019	Scientific articles published	Cardiff University (United Kingdom), FHH, MERI, PT, APN, TNC	Potentially NGOs, public agencies, researchers and other funds for conservation
<b>Obj. 1.4 Compile and communicate (using databases, protocols, and training resources) all relevant information regarding geographic distribution, ecology, behaviour, and population status of <i>Rhinoderma</i>, in order to inform in situ and ex situ management</b>						
1.4.1	Implement a online platform of geographical records of <i>Rhinoderma</i> populations (e.g. mandatory for publicly funded institutions or individual to upload relevant data)	MMA, APN	2019 online platform, 2020 - 2028 data is updated annually	Online platform available and updated annually with all the information collected	CONAF, Academia, ORD, SEIA	Potentially MMA, APN and other public agencies
1.4.2	Collate information from public and private organisms about sites with <i>Rhinoderma</i> presence and its habitat quality	MMA, ORD, APN	2018 - 2019	Cartography of the level of habitat degradation in sites with the presence of Darwin's frogs	AIFBN, private (forestry), public agencies (SAG, CONAF, DGA), academia, NGOs, consultants	Potentially MMA, ORD, APN

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
1.4.3	Elaborate (ideally during a workshop) a population monitoring protocol for <i>Rhinoderma</i> feasible to be applied by both researchers and conservation practitioners (e.g. park rangers)	ORD, UNAB, UDEC, Bioforest, NN, ZOO NACIONAL, UNCO, UCH, UACH, APN	October 2018 - March 2019	Document published on strategy website by November 2018 and regularly updated as necessary	SAG, CONAF, MMA, MADS	ORD and potentially ZOO LEIPZIG, academia, NGOs and other public agencies
1.4.4	Deliver training and capacity building to researchers and conservation practitioners conducting <i>Rhinoderma</i> population monitoring	ORD, APN, academia	2019 - 2020	Staff trained in all areas of interest	CONAF, forestry companies	Potentially public and private funds (MMA training programs, CONAF, forestry companies)
1.4.5	Elaborate a protocol (ideally during a workshop) about <i>ex situ</i> management and conservation re-introductions of <i>Rhinoderma</i>	UDEC, ZOO NACIONAL, UCH, ORD	October 2018 - March 2019	Document published on strategy website and regularly updated as necessary	SAG, CONAF, MMA, APN, MADS	Potentially UDEC, ZOO NACIONAL, NGOs
1.4.6	Develop a protocol (ideally during a workshop) with a response plan if a population of <i>R. rufum</i> is found	ORD, UDEC, UNAB, ZOO NACIONAL, UCH	October 2018 - March 2019	Document published on strategy website and regularly updated as necessary	SAG, CONAF, MMA	ORD, UDEC, UNAB, ZOO NACIONAL, UCH
1.4.7	Determine the mating system on <i>Rhinoderma</i> through genetic methods for inferring paternity to inform <i>ex situ</i> management	UCH	November 2018 - December 2020	Findings published (e.g. scientific article) and informing <i>ex situ</i> management	ORD, Cardiff university (United Kingdom), UNAB, UDEC, ZOO NACIONAL	Potentially UCH and other conservation grants and research

## Goal 2 By the year 2028 all the main threats to Darwin's frogs have been reduced

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
<b>Obj. 2.1 Increase the level of protection of sites with <i>Rhinoderma</i> presence</b>						
2.1.1	Prioritise sites with presence of <i>R. rufum</i> and <i>R. darwinii</i> (in the latter only those sites located across the coastal range between Concepción and Valdivia) for the creation of public and private protected areas	CONAF, MMA	January 2020 (in the case of <i>R. rufum</i> , populations of the species must be previously identified)	Proposals for the creation of at least one protected area per species	AIFBN, academia, ORD, NN, CMPC	Potentially public and/or private funds for land acquisition to create protected area
2.1.2	Promote the use of conservation easements (Derecho Real de Conservación) to protect <i>Rhinoderma</i> populations in private land	MMA, CONAF	January 2019	By 2028, at least five properties with presence of <i>Rhinoderma</i> populations have a conservation easement	AIFBN, academia, ORD, NN	Potentially MMA, CONAF and other funds for conservation
<b>Obj. 2.2 Restore degraded <i>Rhinoderma</i> habitat</b>						
2.2.1	Prioritise sites with presence of Darwin's frogs for habitat restoration	Academia and NGOs	First semester of 2021.	Prioritisation list available to inform habitat restoration	Private (forestry companies), CMPC, Arauco, public agencies (MMA, SAG, CONAF, APN, MADS), AIFBN	Potentially NGOs, public agencies, and other conservation grants
2.2.2	Design and implement <i>Rhinoderma</i> -focused and community-friendly habitat restoration in priority sites	MMA (besides ASP), CONAF y APN (en ASP), forestry companies	Second semester 2021 - 2028	By 2028, habitat restoration successfully implemented in at least five priority sites	ORD, CMPC, Arauco, AIFBN, Academia, NGOs, MADS	Potentially public and private funds available (CONAF, MMA and forestry restoration programs)

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
<b>Obj. 2.3 Eliminate <i>B. dendrobatidis</i> as a threat for Darwin's frogs</b>						
2.3.1	Test the effectiveness of different methods (e.g. exclusion of reservoir host using fences, in situ antifungal treatment) to either prevent chytrid fungus infections or reduce infection prevalence in <i>Rhinoderma</i> populations	ORD, UACH, UNAB	2018 - 2021	Findings published (e.g. scientific article, management guidelines) and effectively informing <i>Rhinoderma</i> conservation management	FHH, CONAF, SAG, MERI, PT, TNC, other private protected areas	Proyect FONDECYT postdoc N° 3180107, and potentially ZOO LEIPZIG, UNAB, ORD
2.3.2	Explore the suitability and effectiveness of <i>Rhinoderma</i> translocations from chytrid-positive sites (after proper antifungal treatment) to chytrid-free areas	ORD, UACH, UNAB	2021-2028	Findings published (e.g. scientific article, management guidelines) and effectively informing <i>Rhinoderma</i> conservation management	CONAF, SAG, APN, UDEC, ZOO NACIONAL, CONICYT, CONICET, Fundación Huilo Huilo, Fundación MERI, Parque Tantauco, TNC	Potentially UNAB, FONDECYT, ZOO LEIPZIG, ORD
2.3.3	Develop and reinforce biosecurity protocols for researchers, park rangers, tourists, etc.	UNAB, ORD, SAG, CONAF, UACH, RECH	Protocols available by 2019 and implemented from 2020 to 2028	Protocols available on streategy website. Research permits (e.g. SAG, CONAF, APN) require specific measures to reduce the risk of chytrid spread or infections	SAG, CONICYT, CONICET, FHH, MERI, PT, TNC, other private protected areas	Potentially UNAB, FONDECYT, ZOO LEIPZIG, ORD
2.3.4	Evaluate the incorporation of chytrid fungus and Ranavirus as notifiable diseases in Chile, as recommended by WOA (i.e. listed infections in the Aquatic Code)	SAG	2018	If incorporated, passive surveillance in place and inclusion of infections in WOA reports	UNAB, ORD, UACH	SAG
2.3.5	Awareness campaign about the negative impacts of chytridiomycosis directed to policymakers and the public to reduce the spread of this pathogen	MMA, CONAF, APN	Awareness campaign designed and launched by 2019 and active until 2028	Information material distributed in protected areas, schools, and social media. Meetings with policymakers.	SAG, Academia, FHH, MERI, PT, TNC, other private protected areas, MADS	Potentially MMA, SAG, CONAF, ORD, APN, ZOO LEIPZIG and other conservation grants

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
<b>Obj. 2.4 Eradicate or control invasive species that are threats for Darwin's frogs (for example, wild boars)</b>						
2.4.1	Design and implement programmes for the control of invasive species identified as threats to Darwin's frogs	Academia, SAG, CONAF, APN	Programmes developed by 2019 and implemented from 2020 to 2028	Programmes implemented. Findings published (e.g. research articles, management guidelines) to inform management	FHH, CONAF, SAG, MERI, PT, TNC, other private protected areas	Proyect FONDECYT postdoct N° 3180107, and potentially ZOO LEIPZIG, UNAB, ORD

# Goal 3

By the year 2028 this conservation strategy has all the necessary legal and financial support, including support from key stakeholders and the public

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
<b>Obj. 3.1</b> Validate the conservation strategy according to Chilean law under the Planes de Recuperación, Conservación y Gestión de Especies (RECOGE) framework						
3.1.1	Submit a RECOGE plan proposal to the Ministerio del Medio Ambiente de Chile following the abbreviated pathway	ECRD participants	First semester 2019	MMA resolution to start the abbreviated procedure of the RECOGE Plan for Darwin's frogs	MMA	MMA, ORD, UNAB and potentially ZOO LEIPZIG
3.1.2	Elaborate the RECOGE Plan for Darwin's frogs in coordination with the MMA Planning Committee	Plan Development Group (core group), in coordination with the Department of Species Conservation of the MMA	Second semester 2019	RECOGE plan for Darwin's frogs officially published	ECRD participants	Potentially ZOO LEIPZIG, ORD, MMA, and other conservation grants
<b>Obj. 3.2</b> Secure funding for implementing all the actions of this conservation strategy						
3.2.1	Define a budget with estimated costs for each action of this conservation strategy	Interim Governance Committee, ORD, UNAB	Second semester 2018	Budget available and used for fundraising purposes	MMA, CONAF, APN, SAG, NGOs and academia, MADS	Interim Governance Committee, ORD, UNAB
3.2.2	Apply for grants to implement the conservation strategy actions	According to distribution of tasks in the strategy	2018-2028	Documents proving application	MMA, CONAF, APN, SAG, NGOs and academia, MADS	Potentially NGOs, public agencies and researchers
<b>Obj. 3.3</b> Incorporate this conservation strategy in the operational planning of at least four key stakeholder organisations						
3.3.1	Create a regulatory framework to make sure that all relevant organisations and individuals share geographical records and other	CONAF, SAG and APN (research and collection permits),	Second semester 2018 - first semester 2019	As of 2019, public agencies in charge of granting research permits and wildlife licences have	Academia, NGOs, forestry companies, MADS	Potentially CONAF, SAG, MMA

N°	Actions	Responsible institutions	Timescale	Indicators	Potential collaborators	Funding
	relevant data into the Darwin's frogs online database	MMA (SEIA)		implemented this regulatory framework to allow compulsory data sharing		
3.3.2	Identify national, regional, and local key stakeholders (including forestry companies) and incorporate the conservation strategy actions into their operational planning	Interim Governance Committee, ORD, UNAB, AIFBN	Second semester 2018 - first semester 2019	Agreements signed to demonstrate the incorporation of actions into operational plans	Regional directorates of public agencies, NGOs, academia, Forestal Arauco	Interim Governance Committee, ORD, UNAB, AIFBN
3.3.3	Incorporate as partners of this conservation strategy to all the forestry companies holding a FSC (Forest Stewardship Council) certification	Bioforest, Interim Governance Committee, ORD	October 2018 - December 2020	All forestry companies certified in the Forest Stewardship Council are incorporated into the ECRD	Forest Stewardship Council Chile, CMPC	Funds from forestry companies and Forest Stewardship Council Chile
3.3.4	Increase awareness among high-level decision makers about the importance of implementing the actions of this conservation strategy	Interim Governance Committee, AIFBN, ORD	Second semester 2018 - second semester 2019	Number of meetings held with high-level decision makers	Academia, privates and public agencies	Interim Governance Committee, AIFBN, ORD

#### Obj. 3.4 Develop and implement an *Rhinoderma*-focused environmental education programme

3.4.1	Design and implement a <i>Rhinoderma</i> -focused education programme for different audiences and prioritised according to conservation needs	ZOO NACIONAL	Programme designed by 2019; programme activities implemented from 2020 to 2028	Program designed and implemented (includes the creation of a manual for teachers).	ORD, AIFBN, UNAB, FHH, MERI, PT, privates, CONAF, APN, RECH, MADS, MMA, Ministerio de Educación	Potentially NGOs, public agencies, and other conservation grants
3.4.2	Strategic communication of this conservation strategy to the public and relevant stakeholders	Interim Governance Committee, ORD, NGOs	First quarter 2019	Number of communication activities and products. Conservation strategy website developed and maintained.	Academy and public agencies (e.g. MMA, municipalities, Municipal Environmental Certification System), MADS	Potentially ORD and ZOO LEIPZIG





# Prioritisation table

**U:** urgent

**I:** important

**O:** opportunistic

Objectives	U	I	O	Total	U+I	Ranking*
2.2 Restore degraded <i>Rhinoderma</i> habitat	8	10	1	19	18	1
2.1 Increase the level of protection of sites with <i>Rhinoderma</i> presence	6	11	8	25	17	2
1.3 Define the taxonomic status of <i>R. rufum</i> and define Evolutionarily Significant Units (ESU) for <i>R. darwinii</i>	9	3	1	13	12	3
1.1 Identify areas with high probability of occurrence of <i>Rhinoderma</i> populations, considering the impact of climate change, chytrid fungus infection, and invasive species on species presence	9	1	0	10	10	4
1.2 Launch or strengthen <i>Rhinoderma</i> -focused population monitoring programmes, aiming to fully understand the population dynamics of these species to inform <i>in situ</i> management	9	1	15	25	10	5
2.3 Eliminate chytridiomycosis as a threat for Darwin's frogs	1	8	0	9	9	6
3.2 Secure funding for implementing all the actions of this conservation strategy	5	4	0	9	9	7
3.3 Incorporate this conservation strategy in the operational planning of at least four key stakeholder organisations	0	7	8	15	7	8
2.4 Eradicate or control invasive species that are threats for Darwin's frogs (for example, wild boars)	3	0	2	5	3	9
3.4 Develop and implement an <i>Rhinoderma</i> -focused environmental education programme	3	0	4	7	3	10
3.1 Validate the conservation strategy according to Chilean law under the Planes de Recuperación, Conservación y Gestión de Especies (RECOGE) framework	1	1	4	6	2	11
1.4 Compile and communicate (using databases, protocols, and training resources) all relevant information regarding geographic distribution, ecology, behaviour, and population status of <i>Rhinoderma</i> , in order to inform <i>in situ</i> and <i>ex situ</i> management	0	0	17	17	0	12

\* The ranking is based only on the sum of Urgent (U) + Important (I), understanding that the objectives considered as Opportunistic (O) can be achieved without additional effort and do not indicate importance or urgency.



# References

- ARAUCO (2017) 2017 Sustainability Report. Forestal Arauco, Santiago, <https://www.arauco.cl/chile/sostenibilidad/reportes-de-sostenibilidad/> [accessed 26 February 2020].
- BACIGALUPE, L.D., VÁSQUEZ, I.A., ESTAY, S.A., VALENZUELASÁNCHEZ, A., ALVARADO-RYBAK, M., PEÑAFIEL-RICAURTE, A. ET AL. (2019) The amphibian-killing fungus in a biodiversity hotspot: identifying and validating high-risk areas and refugia. *Ecosphere*, 10, eo2724.
- BARROS, R. (1918) Notas sobre el 'sapito vaquero' (*Rhinoderma darwini* Dum. & Bibron). *Revista Chilena de Historia Natural*, 22, 71–75.
- BOURKE, J., ULMER, P., MUTSCHMANN, F., BUSSE, K., WERNING, H. & BÖHME, W. (2010) *Batrachochytrium dendrobatidis* in Darwin's frog (*Rhinoderma darwini*), Chile. *Diseases of Aquatic Organisms*, 92, 217–221.
- BOURKE, J., BUSSE, K. & BÖHME, W. (2012) Searching for a lost frog (*Rhinoderma rufum*): identification of the most promising areas for future surveys and possible reasons of its enigmatic decline. *North-Western Journal of Zoology*, 8, 99–106.
- BOURKE, J., BUSSE, K. & BÖHME, W. (2018) Potential effects of climate change on the distribution of the Endangered Darwin's frog. *North-Western Journal of Zoology*, 14, 165–170.
- BUSSE, K. (2002) Darwin's frogs in danger; *Rhinoderma*, are there any *Rhinoderma rufum* left in Chile? *Reptilia*, 25, 63–67.
- CONAF (CORPORACIÓN NACIONAL FORESTAL) (2017) Análisis de la Afectación y Severidad de los Incendios Forestales Ocurredos en Enero y Febrero de 2017 sobre los Usos de Suelo y los Ecosistemas Naturales Presentes entre las Regiones de Coquimbo y Los Ríos de Chile. Informe Técnico, Santiago, Chile.
- CRUMP, M.L. (2002) Natural history of Darwin's frog *Rhinoderma darwini*. *Herpetological Natural History*, 9, 21–31.
- CRUMP, M.L. & VELOSO, A. (2005) El aporte de observaciones de terreno y del análisis genético para la conservación de *Rhinoderma darwini* en Chile. In *Historia, Biodiversidad y Ecología de los Bosques Costeros de Chile* (eds C. Smith-Ramírez, J.J. Armesto & C. Valdovinos), pp. 452–455. Editorial Universitaria, Santiago, Chile.
- CUEVAS, C.C. (2014) Native forest loss impacts on anuran diversity: with focus on *Rhinoderma rufum* (Philippi 1902) (*Rhinodermatidae*) in coastal range, south-central Chile. *Gestión Ambiental*, 27, 1–18.
- ECHEVERRÍA, C., COOMES, D., SALAS, J., REY-BENAYAS, J.M., LARA, A. & NEWTON, A. (2006) Rapid deforestation and fragmentation of Chilean Temperate Forests. *Biological Conservation*, 130, 481–494.
- FORMAS, J.R. (2013) External morphology, chondrocranium, hyobranchial skeleton, and external and internal oral features of *Rhinoderma rufum* (Anura, *Rhinodermatidae*). *Zootaxa*, 3641, 395–400.
- FORMAS, J.R., PUGÍN, E. & JORQUERA, B. (1975) La identidad del batracio chileno *Heminectes rufus* Philippi, 1902. *Physis Section C*, 89, 147–157.
- IPCC (2014) *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, eds R.K. Pachauri & L.A. Meyer). IPCC, Geneva, Switzerland.
- IUCN (2013) *Guidelines for Reintroductions and Other Conservation Translocations*. Version 1.0. IUCN Species Survival Commission, Gland, Switzerland. <https://portals.iucn.org/library/efiles/documents/2013-009.pdf> [accessed 28 August 2019].
- IUCN (2017) *Guidelines for Species Conservation Planning*. Version 1.0. IUCN, Gland, Switzerland. [portals.iucn.org/library/sites/library/files/documents/2017-065.pdf](https://portals.iucn.org/library/sites/library/files/documents/2017-065.pdf) [accessed 28 August 2019].

- IUCN (2019) The IUCN Red List of Threatened Species. Version 2019-2. IUCN, Gland, Switzerland. [iucnredlist.org](http://iucnredlist.org) [accessed 28 August 2019].
- IUCN ASG-CHILE (2018) Estrategia Binacional de Conservación de la Ranitas de Darwin. IUCN SSC Amphibian Specialist Group- Chile, Santiago, Chile. [estrategiarhinoderma.org](http://estrategiarhinoderma.org) [accessed 28 August 2019].
- JOHNSON, C.N., BALMFORD, A., BROOK, B.W., BUETTEL, J.C., GALETTI, M., GUANCHUM, L. ET AL. (2017) Biodiversity losses and conservation responses in the Anthropocene. *Science*, 356, 270–275.
- MÁRQUEZ-GARCÍA, M., JACOBSON, S.K. & BARBOSA, O. (2018) Evaluating biodiversity workshops in Chile: are farmers responding with conservation action? *Environmental Education Research*, 24, 1669–1683.
- MOLINA-BURGOS, B.E., VALENZUELA-SÁNCHEZ, A., ALVARADORYBAK, M., KLARIAN, S. & SOTO-AZAT, C. (2018) Trophic ecology of the Endangered Darwin's frog inferred by stable isotopes. *Endangered Species Research*, 36, 269–278.
- MYERS, N., MITTERMEIER, R.A., MITTERMEIER, C.G., DA FONSECA, G.A.B. & KENT, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, 403, 853–858.
- RANITA DE DARWIN (2020a) Iniciativa de Conservación de Tierras para Anfibios. Organización No Gubernamental Ranita de Darwin, Santiago and Valdivia, Chile. [ranitadedarwin.org/conservaciondetierras](http://ranitadedarwin.org/conservaciondetierras) [accessed April 2020].
- RANITA DE DARWIN (2020b) Proyecto Emerge. Estudio Metapoblacional de Ranas del Bosque Templado Austral y Gestión Epidemiológica. Organización No Gubernamental Ranita de Darwin, Santiago and Valdivia, Chile. [ranitadedarwin.org/emerge](http://ranitadedarwin.org/emerge) [accessed April 2020].
- SANTANGELI, A., ARROYO, B., DICKS, L.V., HERZON, I., KUKKALA, A. S., SUTHERLAND, W.J. ET AL. (2016) Voluntary non-monetary approaches for implementing conservation. *Biological Conservation*, 197, 209–214.
- SCHEELE, B.C., PASMANS, F., BERGER, L., SKERRAT, L.F., MARTEL, A., BEUKEMA, W. ET AL. (2019) Amphibian fungal panzootic causes catastrophic and ongoing loss of biodiversity. *Science*, 363, 1459–1463.
- SMITH-RAMÍREZ, C. (2004) The Chilean coastal range: a vanishing center of biodiversity and endemism in South American temperate rainforests. *Biodiversity and Conservation*, 13, 373–393.
- SOTO-AZAT, C., VALENZUELA-SÁNCHEZ, A., COLLEN, B., ROWCLIFFE, J.M., VELOSO, A. & CUNNINGHAM, A.A. (2013a) The population decline and extinction of Darwin's frogs. *PLOS ONE*, 8, e66957.
- SOTO-AZAT, C., VALENZUELA-SÁNCHEZ, A., CLARKE, B.T., BUSSE, K., ORTIZ, J.C., BARRIENTOS, C. ET AL. (2013b) Is chytridiomycosis driving Darwin's frogs to extinction? *PLOS ONE*, 8, e79862.
- SOTO-AZAT, C., VALENZUELA-SÁNCHEZ, A., ORTIZ, J.C., DÍAZPÁEZ, H., CASTRO, C., CHARRIER, A. ET AL. (2015) ASG Chile leads update of the extinction risk of Chilean amphibians for the IUCN Red List of Threatened Species. *FrogLog*, 23, 6–7.
- SUPERINA, M., CORTÉS DUARTE, A. & TRUJILLO, F. (2018) Connecting research, management, education and policy for the conservation of armadillos in the Orinoco Llanos of Colombia. *Oryx*, 53, 17–26.
- ÚBEDA, C.A. & PASTORE, H. (2015) Distribución de *Rhinoderma darwinii* en Argentina (Anura, Rhinodermatidae), con Comentarios sobre su Estatus y Conservación. Resúmenes 6to Congreso Chileno de Anfibios y Reptiles, Red Chilena de Herpetología, Valdivia, Chile.
- URIBE-RIVERA, D.E., SOTO-AZAT, C., VALENZUELA-SÁNCHEZ, A., BIZAMA, G., SIMONETTI, J.A. & PLISCOFF, P. (2017) Dispersal and extrapolation on the accuracy of temporal predictions from distribution models for the Darwin's frog. *Ecological Applications*, 27, 1633–1645.
- URRUTIA-JALABERT, R., GONZÁLEZ, M.E., GONZÁLEZ-REYES, Á., LARA, A. & GARREAUD, R. (2018) Climate variability and forest fires in central and south-central Chile. *Ecosphere*, 9, e02171.
- VALENZUELA-SÁNCHEZ, A., HARDING, G., CUNNINGHAM, A.A., CHIRGWIN, C. & SOTO-AZAT, C. (2014) Home range and social analyses in a mouth brooding frog: testing the coexistence of paternal care and male territoriality. *Journal of Zoology*, 294, 215–223.

VALENZUELA-SÁNCHEZ, A., CUNNINGHAM, A.A. & SOTO-AZAT, C. (2015) Geographic body size variation in ectotherms: effects of seasonality on an anuran from the southern temperate forest. *Frontiers in Zoology*, 12, 37.

VALENZUELA-SÁNCHEZ, A., SCHMIDT, B.R., URIBE-RIVERA, D.E., COSTAS, F., CUNNINGHAM, A.A. & SOTO-AZAT, C. (2017) Cryptic disease-induced mortality may cause host extinction in an apparently stable host–parasite system. *Proceedings of the Royal Society B*, 284, 20171176.

VALENZUELA-SÁNCHEZ, A., O'HANLON, S.J., ALVARADO-RYBAK, M., URIBE-RIVERA, D.E., CUNNINGHAM, A.A., FISHER, M.C. ET AL. (2018) Genomic epidemiology of the emerging pathogen *Batrachochytrium dendrobatidis* from native and invasive amphibian species in Chile. *Transboundary and Emerging Diseases*, 65, 309–314.

VALENZUELA-SÁNCHEZ, A., SCHMIDT, B.R., PÉREZ, C., ALTAMIRANO, T., TOLEDO, V., PÉREZ, Í. ET AL. (2019a) Assessing habitat quality when forest attributes have opposing effects on abundance and detectability: a case study on Darwin's frogs. *Forest Ecology and Management*, 432, 942–948.

VALENZUELA-SÁNCHEZ, A., CAYUELA, H., SCHMIDT, B., CUNNINGHAM, A.A. & SOTO-AZAT, C. (2019b) Slow natal dispersal across a homogeneous landscape suggests the use of mixed movement behaviours in the Darwin's frog. *Animal Behaviour*, 150, 77–86.

**ESTRATEGIA BINACIONAL DE CONSERVACIÓN**



**Ranitas de Darwin**