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Measuring conservation priorities: A simple tool for conservation planning in poorly sampled areas

Karina Atkinson [a,*], Paul Smith [a,b]

[a] Fundación Para La Tierra, Mariscal Estigarribia 321 c/Teniente Capurro, Pilar, Departamento Ñeembucú, Paraguay
[b] FAUNA Paraguay, Carmen de Lara Castro 422, Barrio San Roque, Encarnación, Paraguay

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ABSTRACT

Global conservation resources are limited and as a result donors and funders are forced to make difficult decisions as to which areas are in most urgent need of support. Biodiversity can play a key role in these choices, but many other factors must be considered. In order to assist with such decisions we present a simple index that can be employed by non-scientists in poorly sampled countries, using the reptile fauna of 55 protected and two unprotected areas of Paraguay as a case study. This index can be applied at multiple taxonomic and geographic levels to minimize biases generated by uneven sampling. We offer words of caution on unsupported claims of high biodiversity, and highlight how the use of inaccurate terminology, although well-intentioned, can be detrimental to national or local conservation efforts. Results show that the top two areas of conservation priority in Paraguay are currently unprotected, and current investment of resources is ineffective and insufficient for long term protection of Paraguay's globally and nationally threatened reptiles.

1. Introduction

The catastrophic effects of habitat loss are well publicized, including loss of cultural and bio-diversity, climate change and desertification, and long term damage to biological systems. All of these have as yet poorly understood knock on effects for human populations (Brooks et al., 2002; Farig, 1997). This is especially true in largely unstudied regions where we lack data to infer outcomes (Oliver et al., 2015). While conservation best practices are still being debated, consolidation of protected areas remains one of the simplest and most effective means of preventing habitat destruction and biodiversity loss (Butchart et al., 2012; Laurance et al., 2012), and may be one of the few options available in areas where resources (both economic and human) are scarce (Karp et al., 2015). However deciding what areas should be protected involves weighing up a number of factors, such as land availability and tenure (Nolte, Agrawall, & Barreto, 2013), local culture and politics (Naughton-Treves, Holland, & Brandon, 2005), and of course comparative biological value (Lopoukhine, 2008; Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000). Biodiversity levels are one of the principal factors used to estimate the biological value of an area (Barlow, Gardner, Louzada, & Peres, 2010; Humphries, Williams, & Vane-Wright, 1995), but what constitutes "high biodiversity"? And how might decision-makers assess it when the data is deficient or lacking?

High biodiversity is a term that is frequently used by authors of inventory studies wishing to stress the significance of their results (Grime, 1997). Authors are aware that the more "biodiverse" a locality appears, the greater its perceived contribution to global biodiversity, and consequently the greater the likelihood that it will receive attention from conservation-planners (Grime, 1997). However the employment of the term "high biodiversity" and the more hyperbolic "mega-diversity", whilst understood as concepts even by non-specialists, does not follow any formal guidelines (Kaennel, 1998), even though it can greatly influence decision-makers, many of whom may lack formal biological training of their own. Working under the assumption that all biologists and conservation planners desire an effective and efficient protected area system, there is a collective need for transparency and responsibility by all involved, at all stages of the process, in order to ensure that limited available funds are invested where they are most needed (Lockwood, 2010; Oksanen & Kumpula, 2013).

In reality the identification of priority sites for conservation in poorly-studied areas is a complex process requiring more data than is typically available. Conservation planners may not always be qualified to evaluate whether geographical, ecological and taxonomic factors are adequately reflected in inventory results. Such results can sometimes be

* Corresponding author.
E-mail address: karina@paralatierra.org (K. Atkinson).

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misleading, being dependent on a variety of factors such as sampling techniques, field effort and even researcher experience (Coddington, Agnarsson, Miller, Kuntner, & Hormiga, 2009; Hortal, Jiménez Valverde, Gómez, Lobo, & Baselga, 2008; Milberg, Bergstedt, Fridman, Odell, & Westerberg, 2008). Authors of such studies have a responsibility to sincerely evaluate the comparative value of their results on both the local and global scales, and reflect on whether their results truly indicate high biodiversity and if that alone is sufficient for the declaration of a protected area (Bonn & Gaston, 2005; Eken et al., 2004).

The herpetofauna of Paraguay remains poorly known (Atkinson, Smith, Dickens, & Lee-Zuck, 2018; Cacciali, Buongermini, & Köhler, 2019; Cacciali, Cabral, & Yanosky, 2015; Smith, 2012; Smith, Cacciali, Atkinson, Pheasey, & Motte, 2012; Smith, Scott, Pheasey, & Atkinson, 2013). Though there has been an increase in field effort over the last decade, many recent Paraguayan herpetological publications are inventory based, present new distributional records (Atkinson et al. 2018; Atkinson, Smith, & Sarvary, 2017; Caccialli, Scott, Aquino Ortiz, Smith, 2016; Smith et al., 2014;) or describe new species (Cabral & Cacciali 2015, Cacciali, Cabral, Ferreira, & Kohler, 2016; Caccialli, Lotzkat, Gamble, & Kohler, 2018; Cacciali, Martinez, & Kohler, 2017; Cacciali, Morando, Avila, & Kohler, 2018; Cacciali, Morando et al., 2017; Carvalho, 2016) demonstrating that herpetological studies in the country remain in their infancy.

Conservation analysis tools have been created using a wide range of metrics and statistics (Ferrier, Manion, Elith, & Richardson, 2007), as well as those specific to species and or locations (Herrera, 2017), but these frequently require statistical knowledge, advanced computer programs or near complete datasets (Helmann & Fowler, 1999; Walther & Moore, 2005). In poorly studied areas the human and economic resources required both to generate and analyze the necessary data are often unavailable. Consequently, for conservation planning to be effective simpler tools need to be developed that can be understood and employed by people who may lack formal biological training (Knight & Cowling, 2010). Here we propose a simple index for comparing the conservation value of protected or unprotected areas which can be employed by non-scientists in places where complete datasets are lacking. This tool permits conclusions to be drawn with limited data or basic low level sampling, can be applied globally or locally, and at any taxonomic level.

2. Methods

2.1. Study area

Paraguay is split into two distinct regions, the Chaco west of the Paraguay River and the more humid Oriental region to the east (Gorham, 1973). The Oriental region sits at the interface of three of the worlds most globally threatened eco-regions, Cerrado, Atlantic Forest, and Mesopotamian Grasslands (Guyra Paraguay, 2005; Hayes, 1995). The Atlantic Forest, is a semi-deciduous forest which stretches from northeastern Brazil into eastern Paraguay, and northeastern Argentina (Neves et al., 2017). In the northern Oriental region it forms a mosaic with the Cerrado, a bushy and largely dry savanna which extends from central Brazil into eastern Bolivia and Paraguay (Eiten, 1972; 1978). To the south it forms a similar mosaic with the Mesopotamian Grasslands, which shares many superficial similarities with the Cerrado but is subject to regular seasonal flooding. All three habitats are under extreme pressure from expanding agriculture throughout their range (Nuñez, 2012; Smith, Atkinson, Brouard, & Pheasey, 2016).

Western Paraguay is broadly comprised of the Dry Chaco in its western half and the Humid Chaco in the floodplain of the Paraguay River. The northeastern Chaco represents the southwestern extension of the Pantanal ecoregion and an introgression of the Cerrado region known locally as the Cerrados del Chaco (Mereles et al., 2013). The Dry Chaco is largely composed of arid thorn forest, and is currently suffering some of the highest levels of deforestation on the planet (Baumann et al., 2017; Caballero, Palacios, Arevalos, Rodas, & Yanosky, 2014). The Humid Chaco is an area of aseasonally flooded palm savanna becoming interspersed with gallery forest and swamp as it intergrades with the Pantanal region to the north (Guyra Paraguay, 2005; Hayes, 1995).

2.2. Measuring conservation priority index

We illustrate the comparative utility of the index, using the distribution of Paraguayan reptiles as an example, comparing 57 localities from which species lists of varying levels of completeness are available, including 55 protected and two unprotected areas (Fig. 1). In order to rank localities according to their conservation priority we developed a simple weighted score index (CPI) and applied it illustratively to Paraguayan reptiles. The index identifies priority areas for conservation by taking into account a spectrum of contributing factors, and can be applied to any taxa in any country or region. It is not entirely reliant on sampling effort, and places only limited emphasis on lengths of species lists. It is also flexible enough to adapt to new data and changing realities, including increased sampling, thus can be quickly and easily updated as new data becomes available, reflecting the rapidly changing world we live in. Crucially it provides a proportional measure of the potential conservation importance of a given area which allows for direct comparison between localities.

The proposed weighting of the CPI is based on factors likely to contribute to greater conservation value, giving greater emphasis to potential biodiversity contributors (such as habitat type and area), threat status and endemism, and less to contributors of more limited conservation value (such as species lists). The weighting of the index can be altered by conservation-planners according to priorities in the area that they work, but we propose that the weighting used here is a good general approach that is broadly applicable at all scales.

Each locality is scored according to the point system summarised in Table 1.

Number of ecoregions: 5 pts each. In this case Atlantic Forest, Cerrado, Pantanal, Mesopotamian Grasslands, Humid Chaco, Dry Chaco.

Total area: 1pt $<$ 1,000 ha; 2 pts 1,001–5,000 ha; 3 pts 5,001–10,000 ha; 4 pts 10,001–50,000 ha; 5 pts 50,001–100,000 ha; 6 pts $>$ 100,001 ha.

Biodiversity: Percentage of total documented fauna in the area being compared. In this case 190 species of reptiles known in Paraguay (Atkinson et al., 2018; Atkinson et al., 2017; Cabral & Cacciali, 2015; Caccialli, Lotzkat, et al., 2018; Cacciali, Martinez, et al., 2017; Cacciali, Morando, et al., 2018; Cacciali, Morando et al., 2017; Caccialli, Scott, et al., 2016; Carvalho, 2016).

Endemism: 2 pts for each habitat endemic species; 5 pts for each country endemic species. Habitat endemism follows FAUNA Paraguay (Smith, 2018).

Global Threat: 5pts for each Critically endangered species; 4 pts Endangered; 3 pts Vulnerable; 2 pts Near Threatened; 1pt Data Deficient; 0 pts Least Concern/Not evaluated. Global threat statuses based on IUCN (2019).

National Threat: 5pts for each Critically endangered species; 4 pts Endangered; 3 pts Vulnerable; 2 pts Near Threatened; 1pt Data Deficient; 0 pts Least Concern/Not evaluated. National threat statuses are taken from Motte et al. (2009) including updates by Cacciali, Cabral, et al. (2015).

Coverage: 2 pts for a species unique to the locality; 2 pts for a species not covered in the protected area system (applicable only to non-protected areas).

Unless stated above the data analysed was taken from Cacciali, Cabral, et al. (2015) and the index was applied to all of the protected areas in that publication, with the addition of two well-sampled unprotected areas, Rancho Laguna Blanca (RLB) based on Atkinson et al. (2017), Atkinson et al. (2018), and Smith et al. (2016), and Primavera based on (Cacciali et al., 2016), as well as incorporating the additional data reported for Reserva Natural Bosque Mbaracayú by Cacciali, Bauer,

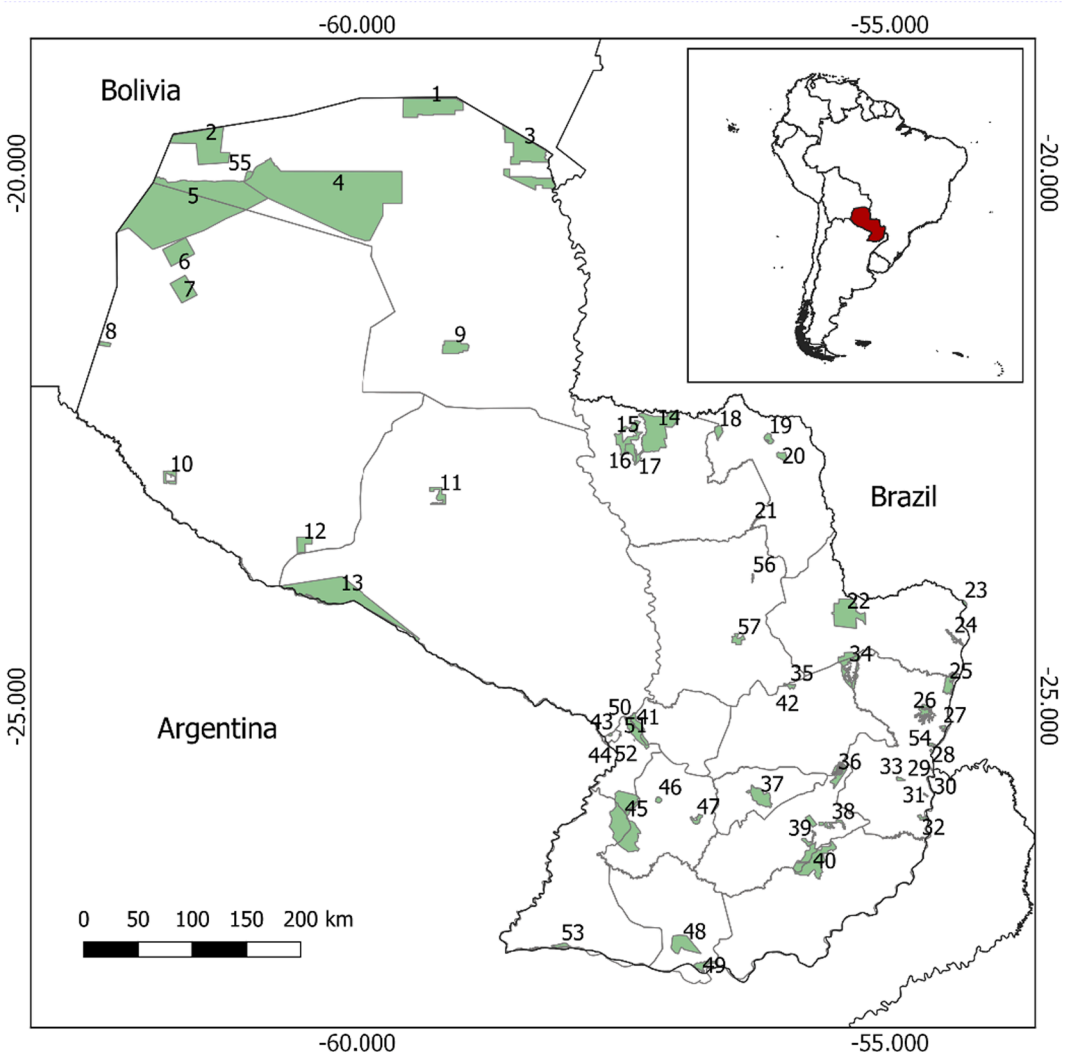

Fig. 1. Department map of Paraguay. All 57 protected and unprotected areas referenced in this paper. 1: Monumento Natural Cerro Chovoreca; 2: Reserva Natural Cerro Cabrera / Timane; 3: Parque Nacional Río Negro; 4: Parque Nacional Defensores del Chaco; 5: Parque Nacional Médanos del Chaco; 6: Reserva Natural Ñú Guazú; 7: Parque Nacional Teniente Enciso; 8: Reserva Natural Cañada del Carmen; 9: Reserva Natural Yaguarete Porã; 10: Reserva Natural Palmar Quemado; 11: Estancia Salazar; 12: Reserva Natural Toro Mocho; 13: Parque Nacional Tinfunqué; 14: Parque Nacional Paso Bravo; 15: Reserva Natural Tagatiyá Mi; 16: Parque Nacional San Luis; 17: Reserva Natural Cerrados del Tagatiyá; 18: Parque Nacional Bella Vista; 19: Reserva Natural Arroyo Blanco; 20: Parque Nacional Cerro Corá; 21: Reserva Natural Ka'i Ragüe; 22: Reserva Natural del Bosque Mbaracayu; 23: Refugio Biologico Binacional Mbaracayú; 24: Reserva Natural Carapá; 25: Reserva Ecologica Limoy; 26: Reserva EcologicaItabó; 27: Reserva Natural Pikyry; 28: Reserva Natural Tati Yupi; 29: Reserva Natural Maharishi; 30: Monumento Cientifico Moisés Bertoni; 31: Reserva Natural Tabucay; 32: Reserva para Parque Nacional Ñacunday; 33: Reserva Nacional Kuri'y; 34: Reserva Natural Morombi; 35: Reserva Ecologica Capiibary; 36: Reserva Natural Ypeti; 37: Reserva de Recursos Manejados Yvyturuzú; 38: Parque Nacional Caazapá; 39: Reserva Natural Tapytá; 40: Parque Nacional San Rafael; 41: Parque Nacional Lago Ypacaraí; 42: Paisaje Protegido Cerro 2 de Oro; 43: Reserva Ecologica Banco San Miguel / Bahía de Asunción; 44: Reserva Nacional Cerro Lambaré; 45: Parque Nacional Lago Ypoá; 46: Monumento Nacional Macizo Acahay; 47: Parque Nacional Ybycuí; 48: Refugio de Vida Silvestre Yabebyry; 49: Reserva Natural Yacyreta; 50: Reserva de Recursos Manejados Ñu Guazú; 51: Monumento Nacional Cerro Chororí; 52: Monumento Natural Cerro Koi; 53: Isla Carrizal; 54: Reserva Nacional Saltos del Guairá; 55: Reserva Natural Lote 1; 56: Rancho Laguna Blanca; 57: Primavera.

& Martinez (2015). Two species of unconfirmed identity, *Tropidurus* sp. and *Thamnodynastes* sp., were not included. A comparative ranking table of priority areas for conservation was then produced by applying the CPI to the 57 localities included in this study, to determine an Index Rank (Table 2).

3. Results

3.1. Biodiversity ranking (BR)

The top ten localities based on the CPI are compared with the top ten most species rich localities which we refer to as the Biodiversity Rank (BR) (Table 3).

The top five highest ranked localities for biodiversity are Rancho Laguna Blanca, Primavera, Reserva Ecológica Banco San Miguel/ Bahía de Asunción, Reserva Natural Bosque Mbaracayu, and Reserva Natural Yacyretá. The top two localities are currently unprotected. Reserva Ecológica Banco San Miguel/ Bahía de Asunción figures as the most biodiverse protected area in Paraguay under this ranking, however it has recently been subject to heavy modification with the construction of the Costanera de Asunción (promenade).

3.2. Conservation priority index (CPI) ranking

The top five highest ranked localities on the CPI are Rancho Laguna Blanca, Primavera, Parque Nacional Cerro Corá, Reserva Natural Bosque Mbaracayú, Parque Nacional Defensores del Chaco. The top two localities are both unprotected. Parque Nacional Cerro Corá figures as the

Table 1
CPI scoring system for comparing the conservation priority of poorly sampled protected and unprotected areas.

Criteria	Number of points					
	1	2	3	4	5	6
No. of Ecoregions					per ecoregion	
Total Area (ha)	<1,000	1,001–5,000	5,001–10,000	10,001–50,000	50,001–100,000	>100,001
Biodiversity						
Endemism		Habitat Endemic			Country Endemic	
Global Threat	Data Deficient	Near Threatened	Vulnerable	Endangered	Critically Endangered	
National Threat	Data Deficient	Near Threatened	Vulnerable	Endangered	Critically Endangered	
Coverage		Per species unique to locality and/or not covered in protected area system				

highest priority protected area under this ranking. The contribution of each of the indicators to the top ten CPI localities is shown in Fig. 2.

3.3. Differences between the CPI and BR

The two unprotected localities, Rancho Laguna Blanca and Primavera, are highest ranked both in the CPI and the BR, suggesting that two of the most important areas for the conservation of reptiles are currently outside the protected area system. Parque Nacional Cerro Cora (+3 places higher), Reserva Natural del Bosque Mbaracayú (+3) and Reserva Natural Tatí Yupí (+4) are shown to be of significantly greater conservation priority for reptiles when the CPI is applied, compared to when the BR alone is considered. Reserva Ecológica Banco San Miguel/ Bahía de Asunción (-7) and Reserva de Recursos Manejados Yvyturuzú (-6) both showed significant decreases in their CPI rankings when compared with their BR. Reserva Ecológica Banco San Miguel/ Bahía de Asunción which has the third longest species list does not figure in the top ten of the CPI, suggesting that the supposed biodiversity of this locality is likely an artefact of greater observer effort, itself a direct result of proximity to the capital city.

While most of the top ten CPI localities also have significant BRs, the high CPI rankings of Rancho Laguna Blanca, Primavera, Reserva Natural Tatí Yupí, and Parque Nacional Cerro Corá reflect high levels of endemism and high numbers of threatened species. Parque Nacional Defensores del Chaco and Parque Nacional Río Negro score highly because of the large areas these parks cover. The presence of multiple eco-regions boost the Rancho Laguna Blanca, Reserva Natural del Bosque Mbaracayú, Parque Nacional Río Negro, Parque Nacional San Rafael and Reserva Ecológica Banco San Miguel/ Bahía de Asunción CPI scores.

4. Discussion

4.1. CPI

Based on the CPI rankings, the top two localities (reptile conservation priorities) are currently unprotected. Perhaps the most well-documented locality in the country is Rancho Laguna Blanca (classified as "Reserva Natural" from 2010 to 2015), in San Pedro department, northeastern Paraguay. RLB is a small property of 1124 ha, comprising a mosaic of Cerrado and Atlantic Forest habitat. The results of a five year, year-round reptile inventory of this reserve documented 57 species (Smith et al., 2016). Though this inventory was declared nearly complete, remarkably-five more species were subsequently recorded at this locality in the months following publication (Atkinson et al., 2018, Atkinson et al., 2017) bringing the total to 62 species, almost a third of all of Paraguay's reptile species. The bulk of the site list for Primavera, San Pedro department is based on a collection made by Eric J. Phillips and is housed in the British Museum. A total of 53 reptile species are contained within this collection of over 350 specimens (Cacciali, Scott, et al., 2016). Both of these localities are considerably more diverse in raw species numbers than that reported for other Paraguayan localities (McDiarmid & Foster, 1987; Motte & Nuñez, 2002; Motte et al. 2015; Nuñez, 2012; Scott & Lovett, 1975). While Rancho Laguna Blanca (23°48' S, 056°17'W) and Primavera (S24°36′ W56°44′) have the highest BR, their proportionately greater CPI scores are strongly influenced by lack of protected area status, number of eco-regions present, and high levels of endemism and threatened species (Cacciali, Scott, et al., 2016; Carvalho, 2016). However "high biodiversity" was also claimed for several protected Paraguayan localities with much lower species lists (Cacciali, Bauer, et al., 2015: 35 species; Nuñez, 2012: 27 species,), creating a dilemma for conservation planners, grant givers, and decision-makers.

Parque Nacional Cerro Corá (23°48' S, 056°17'W) lists 35 species, outside of the top five in the BR, but has high numbers of endemic and threatened species, making it the highest priority protected area in the country. There is no published inventory for this park. This conservation

Table 2
Conservation Priority Index scores as applied to Paraguayan protected areas with the addition of the two unprotected areas (marked *) dealt with in this publication. Results are ranked according to index score with a second rank based solely on known biodiversity.

Locality No.	Locality Name	Dept.	Ecoreg.	Total Area	Biodiv.	End.	Glob. Threat	Nat. Threat	Cov.	CPI	CPI Rank	Biodiv. Rank
1	Monumento Natural Cerro Chovoreca	Alto Paraguay	5	6	0	0	0	0	0	11	37=	40=
2	Reserva Natural Cerro Cabrera / Timane	Alto Paraguay	5	6	0	0	0	0	0	11	37=	40=
3	Parque Nacional Río Negro	Alto Paraguay	10	6	16.8	2	2	10	0	46.8	7	7
4	Parque Nacional Defensores del Chaco	Alto Paraguay	5	6	20.5	10	5	3	4	53.5	5	4
5	Parque Nacional Médanos del Chaco	Boquerón/ Alto Paraguay	5	6	4.2	0	0	0	2	17.2	23=	20=
6	Reserva Natural Ñú Guazú	Boquerón	5	5	0.5	0	0	0	0	10.5	39	35=
7	Parque Nacional Teniente Enciso	Boquerón	5	4	13.2	11	3	3	0	39.2	10	11
8	Reserva Natural Cañada del Carmen	Boquerón	5	2	0	0	0	0	0	7	46=	40=
9	Reserva Natural Yaguarete Porã	Alto Paraguay	5	5	0	0	0	0	0	10	41	40=
10	Reserva Natural Palmar Quemado	Boquerón	5	3	0.5	0	0	0	0	8.5	42	35=
11	Estancia Salazar	Presidente Hayes	5	4	5.3	0	4	1	0	19.3	18=	15=
12	Reserva Natural Toro Mocho	Boquerón	5	4	1.6	0	0	1	0	11.6	32=	29=
13	Parque Nacional Tinfunqué	Presidene Hayes	5	6	5.3	0	3	0	0	19.3	18=	15=
14	Parque Nacional Paso Bravo	Concepción	5	6	3.7	0	0	2	2	18.7	20	23
15	Reservaa Natural Tagatiyá Mi	Concepción	5	4	4.2	0	0	4	0	17.2	23=	17=
16	Parque Nacional San Luis	Concepción	5	4	1.6	7	0	3	0	20.6	17	32=
17	Reserva Natural Cerrados del Tagatiyá	Concepción	5	3	0.5	7	0	0	0	15.5	26	40=
18	Parque Nacional Bella Vista	Amambay	5	3	0	0	0	0	0	8	43=	40=
19	Reserva Natural Arroyo Blanco	Amambay	10	3	0.5	0	0	0	0	13.5	30	35=
20	Parque Nacional Cerro Corá	Amambay	5	3	18.4	14	3	21	4	68.4	3	6
21	Reserva Natural Ka'i Ragüe	Amambay	5	2	1.1	0	0	3	0	11.1	36	29=
22	Reserva Natural del Bosque Mbaracayu	Canindeyú	10	5	18.4	4	2	19	0	58.4	4	8
23	Refugio Biologico Binacional Mbaracayú	Canindeyú	10	2	1.1	0	0	0	0	13.1	31	32=
24	Reserva Natural Carapá	Canindeyú	5	2	0	0	0	0	0	7	46=	40=
25	Reserva Ecologica Limoy	Alto Paraná	5	3	3.7	4	0	8	0	23.7	15=	24=
26	Reserva Ecologica Itabó	Alto Paraná	5	3	2.6	2	0	6	0	18.6	21	24=
27	Reserva Natural Pikyry	Alto Paraná	5	2	6.3	8	0	16	0	37.3	12	14
28	Reserva Natural Tati Yupi	Alto Paraná	5	2	7.9	8	0	18	0	40.9	9	13
29	Reserva Natural Maharishi	Alto Paraná	5	1	4.7	4	0	9	0	23.7	15=	17=
30	Monumento Cientifico Moisés Bertoni	Alto Paraná	5	1	0	0	0	0	0	6	52=	40=
31	Reserva Natural Tabucay	Alto Paraná	5	1	0	0	0	0	0	6	52=	40=
32	Reserva para Parque Nacional Ñacunday	Alto Paraná	5	2	0	0	0	0	0	7	46=	40=
33	Reserva Nacional Kuri'y	Alto Paraná	5	2	0	0	0	0	0	7	46=	40=
34	Reserva Natural Morombi	Caaguazú and Canindeyú	10	4	1.1	0	0	0	0	15.1	27	32=
35	Reserva Ecologica Capiibary	San Pedro	5	2	0	0	0	0	0	7	46=	40=
36	Reserva Natural Ypeti	Caazapa	10	4	0.5	0	0	0	0	14.5	28	25=
37	Reserva de Recursos Manejados Yvyturuzú	Guaira	5	4	5.3	2	0	2	0	18.3	22	17=
38	Parque Nacional Caazapá	Caazapá	5	4	2.6	0	0	0	0	11.6	42=	28
39	Reserva Natural Tapytá	Caazapá	5	2	0.5	0	0	0	0	7.5	45	25=
40	Parque Nacional San Rafael	Caazapá and Itapúa	10	5	14.7	8	0	6	2	45.7	8	9
41	Parque Nacional Lago Ypacaraí	Cordillera and Central	5	4	4.2	0	0	1	0	14.2	29	20=
42	Paisaje Protegido Cerro 2 de Oro	San Pedro	5	1	0	0	0	0	0	6	52=	40=
43	Reserva Ecologica Banco San Miguel / Bahía de Asunción	Central	10	1	20.5	2	0	5	0	38.5	11	3
44	Reserva Nacional Cerro Lambaré	Central	5	1	4.2	0	0	0	0	10.2	40	20=
45	Parque Nacional Lago Ypoá	Central, Paraguari and Ñeembucú	5	5	1.6	0	0	0	0	11.6	32=	29=
46	Monumento Nacional Macizo Acahay	Paraguarí	5	2	3.7	5	0	0	0	15.7	25	26=
47	Parque Nacional Ybycuí	Paraguarí	5	2	11.6	12	1	2	2	35.6	13	12
48	Refugio de Vida Silvestre Yabebyry	Misiones	5	4	2.6	0	0	0	0	11.6	32=	26=

(*continued on next page*)

Table 2 (*continued*)

Locality No.	Locality Name	Dept.	Ecoreg.	Total Area	Biodiv.	End.	Glob. Threat	Nat. Threat	Cov.	CPI	CPI Rank	Biodiv. Rank
49	Reserva Natural Yacyreta	Itapua and Misiones	5	3	17.9	4	0	17	4	50.9	6	5
50	Reserva de Recursos Manejados Ñu Guazú	Central	5	1	13.2	2	0	3	0	24.2	14	10
51	Monumento Nacional Cerro Chororí	Central	5	1	0	0	0	0	0	6	52=	40=
52	Monumento Natural Cerro Koi	Central	5	1	0	0	0	0	0	6	52=	40=
53	Isla Carrizal	Ñeembucú	5	2	0	0	0	0	0	7	46=	40=
54	Reserva Nacional Saltos del Guairá	Canindeyú	5	1	0	0	0	0	0	6	52=	40=
55	Reserva Natural Lote 1	Alto Paraguay	5	3	0	0	0	0	0	8	43=	40=
56	Rancho Laguna Blanca*	San Pedro	10	1	32.6	22	8	47	30	151	1	1
57	Primavera*	San Pedro	5	3	27.9	7	0	23	10	75.9	2	2

Table 3
Localities ranked in the top ten for both CPI and Biodiversity Rank, and the difference between the two.

Location	CPI	Index Rank	Biodiversity Rank	Difference
Rancho Laguna Blanca	150.6	1	1	0
Primavera	75.9	2	2	0
Parque Nacional Cerro Corá	68.4	3	6	+3
Reserva Natural Bosque Mbaracayú	58.4	4	4	0
Parque Nacional Defensores del Chaco	53.5	5	8	+3
Reserva Natural Yacyretá	50.9	6	5	−1
Parque Nacional Río Negro	46.8	7	7	0
Parque Nacional San Rafael	45.7	8	9	+1
Reserva Natural Tatí Yupí	40.9	9	13	+4
Parque Nacional Teniente Enciso	39.2	10	11	+1
Reserva Ecológica Banco San Miguel / Bahía de Asunción	38.2	11	3	−8
Reserva de Recursos Manejados Yvyturuzú	24.6	16	10	−6

priority is not reflected in its BR. Parque Nacional Defensores del Chaco (23°48' S, 056°17'W) ranks fourth in both the CPI ranking and the BR. It is one of the largest parks in Paraguay, and contains several globally threatened species, as well species not found elsewhere in Paraguay. Reserva Natural del Bosque Mbaracayú (S24°04′ W55°20′) is not in the top five locations in terms of BR, but due to its size, the number of eco-regions comprised within its boundaries and the number of threatened species recorded, it merits high priority status. The reserve is located approximately 100 km east of Rancho Laguna Blanca, and is composed of comparable habitat types, though it is 13 times the size. Cacciali, Bauer, et al. (2015) describe Reserva Natural del Bosque Mbaracayú as an area with "a high richness of herpetofauna", but document just 35 reptile species as present. While it would seem reasonable to assume that the real diversity is much greater (the total list is just over half of that of Rancho Laguna Blanca), this is actually one of the most well-sampled sites in the country.

4.2. *Biodiversity ranking*

The highest biodiversity ranked protected locality, Reserva Ecológica Banco San Miguel/ Bahía de Asunción, is only ranked tenth in the CPI. Under BR the Reserva Ecológica Banco San Miguel/ Bahía de

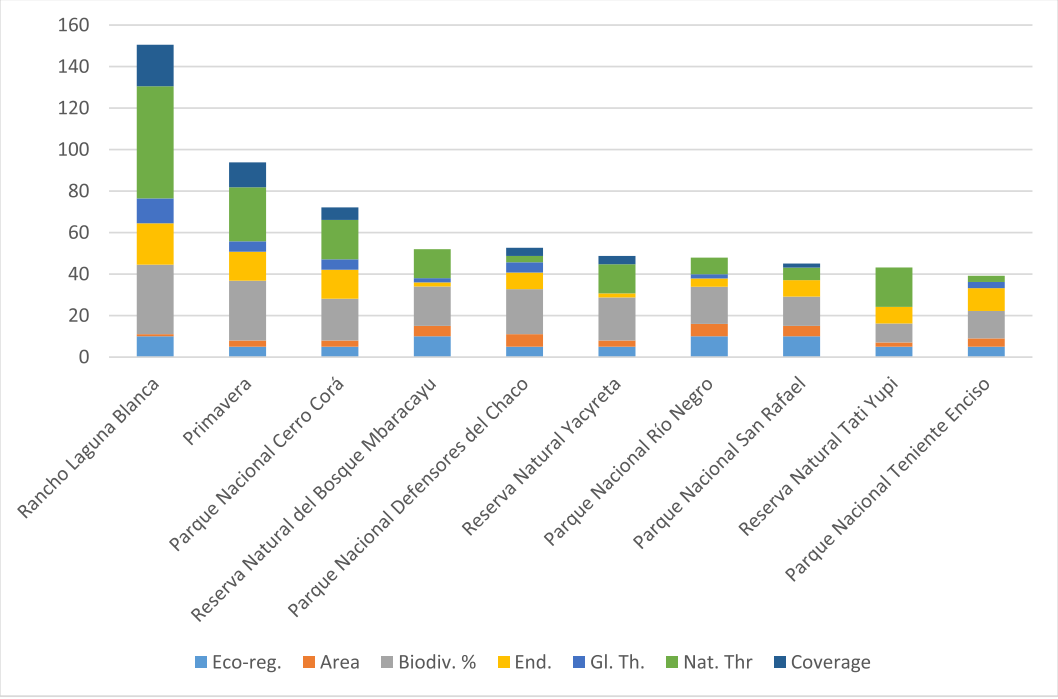

Fig. 2. The contribution of each criterion to the ten highest rated CPI locations.

Asunción could conceivably have been understood to be the highest conservation priority in the country. In fact the species list for this locality is largely derived from old records, and the high number of species recorded is an artefact of continued and regular sampling related to its accessibility, being located adjacent to the capital city. On the other hand 18 localities lack a reptile list at all, making it impossible to assess their conservation value for reptiles under BR. The Reserva de Recursos Manejados Yvyturuzú ranks tenth in the BR but scores much lower when CPI is applied, and is thus of lower national priority for the conservation of reptiles than previously understood. On the other hand, based on BR alone, Reserva Natural Tatí Yupí would not be in the top ten national conservation priorities, greatly underestimating its true value.

4.3. Identifying priority areas for conservation

The results emphasise how poorly we currently understand the priority areas for the conservation of reptiles in Paraguay and how deficient the current protected area system is for reptile conservation, with two areas of the highest priority for reptile conservation lying outside of the protected area system. In an analysis of the effectiveness of the Paraguayan protected area system for reptile conservation, Cacciali, Cabral, et al. (2015) noted that 90.1 % of species had been documented within 55 protected areas, meaning that almost 10 % of species did not enjoy any legal protection. As a result of additional inventory work that number has since risen, and 18.5 % of species are now known to occur outside of the protected area system. With just over 80 % of species protected, this coverage may seem adequate, but it should be noted that amongst the 18.5 % suffering no protection are three nationally (*Phalotris nigrilatus*, *Philodryas agassizii* and *Rhachidelus brazili*) and one globally (*Philodryas livida*) threatened species, as well as seven Paraguayan endemic species (*Homonota marthae*, *Homonota rupicola*, *Tropidurus lagunablanca*, *Ophiodes luciae, Colobosaura kraepelini, Phyllopezus heuteri,* and *Phalotris normanscotti)*. Many of these species have not yet had their conservation status assessed, but are likely deserving of globally threatened status. In addition, the fact that published herpetofaunal data for 18 protected areas are not available highlights the shortcomings of the BR approach to conservation in a country where undersampling and sampling bias is rife.

4.4. The responsibility of inventory authors

The maximum number of species documented at any one Paraguayan locality is 62 at Rancho Laguna Blanca (Atkinson et al., 2018, Atkinson et al., 2017; Smith et al., 2016), however this number alone does not necessarily reflect conservation priority, as on the one hand it provides no information on the conservation status of the species and on the other it may simply reflect more sustained sampling. Though potentially high biodiversity may be inferred for many localities based on the heterogeneity of habitats, large areas covered and limited sampling, in the highly competitive world of conservation funding such inferences do not outweigh verifiable data.

Declaring that incomplete inventories represent “high biodiversity” when the numbers involved are small, may seem superficially like an effective way to emphasise the need for protection, but could in fact have the opposite of the desired effect by inferring low overall biodiversity for the country or region when compared with better sampled sites. Well-intentioned but ultimately unsupported and inaccurate claims may thus be detrimental to conservation efforts and the allocation of scarce conservation resources, particularly if neighbouring countries or regions with similar habitats are more thoroughly sampled.

Though tempting, the use of the term “high biodiversity” to infer conservation priority is something that should be resisted unless it can be demonstrated to be true. The scale (local, national, regional, global, habitat level etc.) at which the high biodiversity is being claimed should be made clear and the affirmation should be supported with an honest analysis of the completeness of the results. Numbers that are merely higher than other published inventories should not be assumed to represent conservation priority unless the inventories which are being compared against are sustained and thereby provide a true reflection of the actual biodiversity. Clearly these criteria are met rarely in a country like Paraguay where the sampling effort has been so limited that a small protected area adjacent to the capital city had, until recently, been held to be the most biodiverse location for reptiles in the country. Caution is thus required in interpreting the distribution data of Paraguayan reptiles (and presumably other taxa as well) and even more care is required when defining conservation priorities.

4.5. The CPI as a tool

Whilst techniques such as species accumulation curves are a useful tool for illustrating the completeness of inventories, they are constrained by the effectiveness and diversity of methods used, and the overall area sampled, as well as the efforts of those employing them. Species-area curves and rarefaction curves require more complete datasets in order to compare biodiversity between localities (Gotelli & Colwell, 2001) with incomplete datasets leading to inaccurate assumptions (Gray, Ungland & Lambshead, 2004). Modelling may also be used to help determine priorities, but as well as requiring the use of complex or expensive computer programs, these methods are not universally applicable and are also only as reliable as the data available (Rodríguez, Brotons, Bustamante & Seoane, 2007).

The weighted indicators employed in the CPI address the multifactorial nature of conservation decisions (Dinerstein & Wikramanayake, 1993; Sisk, Launer, Switky & Ehrlich, 1994; Knight & Cowling, 2007). Under this method a locality is ranked according to its documented value for conservation. This is independent of sampling bias to a significant degree, and especially beneficial for poorly-sampled localities where species of conservation interest have been documented. Such an approach is novel and effective in countries such as Paraguay where the fauna is greatly understudied, allowing poorly-sampled localities to be more effectively compared with well-sampled localities, determining a more honest biodiversity value, and highlighting conservation priorities. This tool can be applied to any site in the world at any taxonomic level, potentially assisting policy makers and funders to more effectively prioritise resources for conservation.

Using this tool, a hypothetical locality that was home to a single, critically-endangered, restricted range endemic and no other species would score as highly as a similarly-sized locality at which 22 species of least concern had been recorded. In this way the conservation priority is identified even given the lack of a species list. Using only the simplest of data that should be readily available to all conservation planners, it is an easy way of identifying conservation priorities at all scales with easy application across taxa.

5. Conclusions

Assessment of conservation priorities for individual taxonomic groups is a more complex equation than simply identifying well inventoried areas. Identification of conservation priority needs to also take into account the current level of protection of species present within the protected area system, global and national conservation status of the species present, national and eco-region endemism and total land areas. These measurable variables need be considered alongside practical issues that are more difficult to quantify such as local threats, available funds, on the ground support, and potential for long term success. CPI is a simple way of illustrating numerically the contribution of localities to conservation in order for such priorities to be quickly and easily identified, and it can be easily expanded for comparisons at all geographic and taxonomic levels.

The true contribution of each of these protected areas to overall biodiversity conservation would of course require the employment of the CPI across taxa, but the flexible nature of the CPI demonstrates its

utility for non-scientist conservation planners working at different taxonomic and geographic scales, and in a constantly changing environment. With a rapid rate of habitat loss throughout Paraguay, including the deforestation of the Atlantic Forest and Chaco (Huang et al., 2007; Huang et al., 2009; Kuemmerle et al., 2017; Nori et al., 2016; Yanosky, 2013), the conversion to agriculture of the Cerrado (Carvalho, Júnior & Ferreira, 2009; Françoso et al., 2015), and draining of the Mesopotamian Grasslands and Pantanal (Bilenca & Miñarro, 2004; Da Silva & Girard, 2004; Gottgens et al., 2001; Harris et al., 2005) coupled with limited resources available for conservation (Wilson, McBride, Bode, & Possingham, 2006), it is imperative that accurate conservation priorities be established, so that informed decisions can be made. True conservation priority areas of Paraguay must be identified and protected as a matter of urgency, a situation that is unfortunately true for a much of the globe in the 21st century (Lopoukhine et al. 2012).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Paraguayan reptile species list with data used to calculate CPI score taken from Cacciali, Bauer, et al. (2015), Cacciali, Cabral, et al. (2015), Smith et al. (2016), Caccialli, Scott, et al. (2016), Atkinson et al. (2017), and Atkinson et al. (2018.).

Species	Endemic	Nationally threatened	Globally threatened	Locality specific
TESTUDINES				
Testudinidae				
Chelonoidis carbonaria		LC	NA	
Chelonoidis chilensis		LC	VU	
Kinosternidae				
Kinosternon scorpioides		LC	NA	
Chelidae				
Acanthochelys macrocephala		DD	NT	
Acanthochelys pallidipectoris		DD	EN	
Mesoclemmys vanderhaegei		LC	NT	
Phrynops geoffroanus		NA	NA	
Phrynops hilarii		DD	NA	
Phrynops williamsi		VU	NA	
Hydromedusa tectifera	AF	DD	NA	
SQUAMATA-SAURIA				
Dactyloidae				
Norops meridionalis	CE	EN	NA	
Iguanidae				
Iguana iguana		DD	NA	
Leiosauridae				
Anisolepis longicauda	PY	DD	NA	
Liolaemidae				
Liolaemus azarai	MG	VU	NA	Yacyreta
Liolaemus chacoensis		DD	LC	
Polychrotidae				
Polychrus acutirostris		LC	NA	
Tropiduridae				
Stenocercus caducus		LC	NA	
Tropidurus etheridgei		LC	NA	
Tropidurus guarani	PY	LC	NA	
Tropidurus spinulosus		LC	LC	
Tropidurus torquatus		LC	LC	
Tropidurus lagunablanca	CE, PY	CR	CR	Rancho Laguna Blanca
Tropidurus sp.				
Tropidurus tarara	CE, PY	LC	LC	
Tropidurus teyumirim	PY, AF	DD	DD	Parque Nacional Ybycuí
Gekkonidae				
Hemidactylus mabouia		NA	LC	
Lygodactylus wetzeli		LC	LC	
Phyllodactylidae				
Homonota borellii		NA	LC	Parque Nacional Defensores del Chaco
Homonota horrida	CD	LC	LC	
Homonota marthae	PY, CD	NA	DD	
Homonota rupicola	PY	NA	NA	Formaciones Cordillera de los Altos
Homonota septentrionalis	PY, CD	NA	NA	
Phyllopezus heuteri	PY	NA	NA	

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Species	Endemic	Nationally threatened	Globally threatened	Locality specific
Phyllopezus przewalskii		LC	NA	
Gymnophthalmidae				
Bachia bresslaui	CE	VU	VU	Parque Nacional Cerro Cora
Cercosaura ocellata		VU	NA	
Cercosaura schreibersii		LC	LC	
Colobosaura kraepelini	PY	NA	NA	
Colobosaura modesta		DD	NA	
Micrablepharus maximiliani		DD	NA	
Vanzosaura rubricauda		DD	NA	
Teiidae				
Ameiva ameiva		LC	NA	
Ameivula abalosi		LC	LC	
*Ameivula n.*sp.		LC	NA	
Dracaena paraguayensis	PA	DD	NA	
Kentropyx viridistriga		LC	LC	
Salvator duseni		VU	NA	
Salvator merianae		LC	LC	
Salvator rufescens		LC	NA	
Teius oculatus		LC	NA	
Teius teyou		LC	LC	
Mabuyidae				
Aspronema dorsivittatum		LC	NA	
Copeoglossum nigropunctatum		DD	NA	
Manciola guaporicola		LC	NA	
Notomabuya frenata		LC	NA	
Anguidae				
Ophiodes fragilis		NA	NA	Parque Nacional Cerro Cora
Ophiodes intermedius		LC	LC	
Ophiodes luciae	PY, CH	NA		35Km NW of Antequera
Ophiodes striatus		NA	NA	
Ophiodes aff. striatus		NA	NA	
Amphisbaenidae				
Amphisbaena alba		LC	LC	
Amphisbaena albocingulata		NA	LC	
Amphisbaena angustifrons		DD	LC	
Amphisbaena bolivica		LC	LC	
Amphisbaena camura		LC	LC	
Amphisbaena darwini		NA	NA	
Amphisbaena leeseri		DD	NA	Rio Apa
Amphisbaena mertensii		LC	NA	
Amphisbaena prunicolor		DD	NA	
Amphisbaena roberti		DD	NA	
Amphisbaena steindachneri		DD	NA	
Leposternon microcephalum		DD	NA	
SQUAMATA-SERPENTES				
Boidae				
Boa constrictor		LC	NA	
Epicrates alvarezi	CD	LC	NA	
Epicrates crassus		VU	NA	
Eunectes murinus		CR	NA	
Eunectes notaeus		LC	NA	
Viperidae				
Bothrops alternatus		LC	NA	
Bothrops diporus		LC	NA	
Bothrops jararaca	AF	LC	NA	
Bothrops jararacussu	AF	CR	LC	
Bothrops moojeni		LC	NA	
Bothrops pauloensis		LC	NA	
Crotalus durissus		LC	LC	
Elapidae				
Micrurus altirostris		LC	NA	
Micrurus baliocoryphus		LC	LC	
Micrurus corallinus	AF	VU	NA	
Micrurus frontalis		LC	NA	
Micrurus lemniscatus		VU	NA	
Micrurus pyrrhocryptus		LC	LC	
Micrurus silviae	MG	NA	NA	Kanguery
Colubridae				
Chironius bicarinatus		NA	NA	
Chironius exolitus		NA		
Chironius flavolineatus		LC	NA	Parque Nacional Cerro Cora
Chironius maculoventris		NA	NA	
Chironius quadricarinatus		LC	NA	
Drymarchon corais		LC	NA	
Drymoluber brazili		VU	NA	
Leptophis ahaetulla		LC	NA	

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Species	Endemic	Nationally threatened	Globally threatened	Locality specific
Mastigodryas bifossatus		LC	NA	
Simophis rhinostoma		DD	NA	
Spilotes pullatus		LC	NA	
Tantilla melanocephala		DD	NA	
Dipsadidae				
Atractus paraguayensis		DD	NA	
Atractus reticulatus	AF	DD	NA	
Atractus thalesdelemai	MG	NA	NA	
Imantodes cenchoa		EN	NA	
Leptodeira annulata		LC	LC	
Dipsas bucephala		EN	LC	
Dipsas cisticeps		DD	LC	
Sibynomorphus lavillai	CD	DD	NA	Cerro León
Sibynomorphus mikanii	AF	EN	NA	
Sibynomorphus turgidus		LC	NA	
Sibynomorphus ventrimaculatus		LC	LC	
Psomophis genimaculatus		LC	NA	
Psomophis obtusus		LC	LC	
Apostolepis ambiniger		DD	NA	
Apostolepis assimilis		DD	NA	Itaipu
Apostolepis dimidiata		DD	NA	
Apostolepis intermedia		NA	NA	Rancho Laguna Blanca
Phalotris lemniscatus		LC	LC	
Phalotris matogrossensis		NA	NA	
Phalotris multipunctatus	CE	CR	NA	Rancho Laguna Blanca
Phalotris nigrilatus	HC, PY	VU	NA	
Phalotris normanscotti	CD, PY	NA	NA	
Phalotris tricolor		DD	LC	
Thamnodynastes chaquensis	CD	LC	NA	
Thamnodynastes hypoconia		LC	NA	
Thamnodynastes lanei		NA	NA	
Thamnodynastes strigatus		LC	LC	
Thamnodynastes sp.		NA	NA	
Tomodon dorsatus		NA	NA	
Tomodon ocellatus		NA	NA	
Taeniophallus occipitalis		LC	NA	
Boiruna maculata		LC	NA	
Clelia clelia		LC	NA	
Clelia plumbea		LC	NA	
Mussurana bicolor		LC	LC	
Mussurana quimi		VU	NA	Isla Yacyreta
Oxyrhopus guibei		LC	NA	
Oxyrhopus petolarius		VU	NA	
Oxyrhopus rhombifer		LC	NA	
Phimophis guerini		DD	NA	
Phimophis vittatus		DD	LC	
Pseudoboa nigra		DD	NA	
Rhachidelus brazili		CR	LC	
Philodryas aestiva		LC	NA	
Philodryas agassizii		EN	NA	
Philodryas baroni	CD	LC	NA	
Philodryas erlandei	CD	LC	NA	
Philodryas livida	CE	NA	VU	Rancho Laguna Blanca
Philodryas mattogrossensis		LC	NA	
Philodryas nattereri		NA	NA	Rancho Laguna Blanca
Philodryas olfersii		LC	NA	
Philodryas patagoniensis		LC	NA	
Philodryas psammophidea		LC	LC	
Helicops infrataeniatus		DD	NA	
Helicops leopardinus		LC	NA	
Hydrops caesurus		VU	LC	
Pseudoeryx plicatilis		DD	LC	
Hydrodynastes gigas		LC	NA	
Erythrolamprus aesculapii		LC	NA	
Erythrolamprus albertguentheri		LC	NA	
Erythrolamprus almadensis		LC	NA	
Erythrolamprus frenatus		DD	NA	
Erythrolamprus jaegeri		LC	LC	
Erythrolamprus miliaris		LC	NA	
Erythrolamprus poecilogyrus		LC	NA	
Erythrolamprus reginae		LC	NA	
Erythrolamprus sagittifer		LC	LC	
Erythrolamprus semiaureus		LC	NA	
Erythrolamprus typhlus		DD	NA	Horqueta, Concepcion
Lygophis anomalus		NA	NA	
Lygophis dilepis		LC	LC	

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Species	Endemic	Nationally threatened	Globally threatened	Locality specific
Lygophis flavifrenatus		LC	NA	
Lygophis meridionalis		LC	NA	
Lygophis paucidens	CE	NA	NA	Rancho Laguna Blanca
Xenodon dorbignyi		DD	NA	
Xenodon histricus		DD	NA	
Xenodon merremi		LC	NA	
Xenodon neuwiedii		DD	LC	
Xenodon pulcher	CD	LC	NA	
Xenopholis undulatus		DD	NA	
Anomalepididae				
Liotyphlops beui		DD	LC	
Liotyphlops ternetzii		DD	NA	
Leptotyphlopidae				
Epictia albipuncta		LC	NA	
Epictia vellardi		LC	NA	
Rena unguirostris		LC	NA	
Typhlopidae				
Amerotyphlops brongersmianus		DD	NA	
CROCODYLIA				
Alligatoridae				
Caiman latirostris		LC	LC	
Caiman yacare		LC	LC	
Paleosuchus palpebrosus		CR	LC	Rio Apa

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