

Taxonomic review of amphibians with emphasis on endemic species

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ABSTRACT

*Amphibians represent one of the most threatened vertebrate classes globally, with endemic species bearing disproportionate extinction risk due to their restricted ranges, specialised habitat requirements, and susceptibility to emerging infectious diseases. This review synthesises current taxonomic knowledge of endemic amphibians across four globally significant diversity hotspots -- the Western Ghats of India, the Atlantic Forest of Brazil, the mountains of the Cameroon Highlands, and the highlands of New Guinea -- drawing on published literature, museum specimen databases, and molecular phylogenetic studies published between 2000 and 2021. Across these four regions, 1,284 amphibian species are documented, of which 847 (66.0%) are regionally endemic. The Western Ghats contributes 187 endemic species including numerous recently described taxa in the families Nyctibatrachidae, Micrixalidae, and Ranixalidae. The Atlantic Forest harbours the greatest absolute endemic richness (312 species), dominated by Hylidae and Brachycephalidae. Molecular phylogenetic analyses across all four regions reveal consistent patterns of cryptic species diversity -- with an estimated 20-35% of morphologically circumscribed species harbouring molecularly distinct lineages warranting species status. We assess the IUCN conservation status of all documented endemic species and identify 284 (33.5%) as Threatened. The amphibian chytrid fungus *Batrachochytrium dendrobatidis* (Bd) and habitat loss are identified as the dominant threat drivers. Updated taxonomic recommendations and conservation priorities are presented for each region.*

Keywords: endemic amphibians; Western Ghats; Atlantic Forest; Cameroon Highlands; New Guinea; cryptic species; *Batrachochytrium dendrobatidis*; conservation; taxonomy; biodiversity hotspots

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1. Introduction

Amphibians constitute one of the most speciose and ecologically diverse vertebrate classes, with approximately 8,500 described species globally (AmphibiaWeb 2022), yet they face an extinction crisis unprecedented among vertebrates. Approximately 41% of assessed amphibian species are classified as threatened under IUCN criteria (Stuart et al. 2004; Luedtke et al. 2023), and multiple lines of evidence suggest that described species represent only a fraction of true amphibian diversity, with molecular studies consistently revealing cryptic species within morphologically circumscribed nominal taxa. Endemic species -- those with ranges restricted to single biogeographic regions, islands, or mountain systems -- are particularly vulnerable to extinction because their small geographic ranges make them susceptible to stochastic events, habitat destruction, and disease outbreaks. The combination of high endemism, substantial undocumented diversity, and severe threat levels makes the taxonomy of endemic amphibians a conservation-critical research priority.

The four regions selected for this review -- the Western Ghats of India, the Atlantic Forest of Brazil, the Cameroon Highlands of Central Africa, and the highlands of New Guinea -- represent globally recognised centres of amphibian diversity and endemism encompassing four distinct biogeographic realms (Oriental, Neotropical, Afrotropical, and Australasian). Each region is characterised by high topographic complexity, ancient geological history, and pronounced climatic seasonality that collectively promote in situ diversification. Despite substantial research attention in recent decades, each region continues to yield new species descriptions at rates suggesting that current species richness estimates remain substantially conservative. The comparative framework across four continents enables assessment of whether patterns of cryptic diversity, threat

distribution, and taxonomic completeness are consistent globally or reflect region-specific factors.

The objectives of this review are: (1) to compile the most current taxonomic inventories of endemic amphibians for each of the four study regions, incorporating recent species descriptions and synonymies; (2) to assess the prevalence of cryptic species diversity across regions and taxonomic families; (3) to evaluate the conservation status of all documented endemic species against IUCN criteria and identify dominant threat drivers; (4) to identify regional knowledge gaps and taxonomic priorities; and (5) to formulate cross-regional conservation recommendations. This review constitutes the most comprehensive comparative synthesis of endemic amphibian taxonomy across these four biodiversity hotspots to date.

2. Literature Review

2.1 Global Amphibian Diversity and the Extinction Crisis

The global amphibian biodiversity crisis was brought to widespread scientific attention by Stuart et al. (2004), who documented that approximately one-third of assessed amphibian species faced extinction threats, with the chytrid fungus *Batrachochytrium dendrobatidis* (Bd) identified as a major driver of rapid population declines and extinctions across the Americas, Europe, and Australia. Subsequent work by Scheele et al. (2019) confirmed that Bd-associated chytridiomycosis has caused population declines in at least 501 amphibian species and extinction of 90 species, making it the most devastating infectious wildlife disease documented in recorded history. A second chytrid pathogen, *Batrachochytrium salamandrivorans* (Bsal), discovered in 2013, threatens salamander diversity in Europe and North America. Alongside disease, habitat loss, overexploitation, invasive species, pollution, and climate change collectively drive amphibian decline in synergistic and

compounding ways.

2.2 Western Ghats Amphibian Endemism

The Western Ghats of peninsular India, stretching 1,600 km along the western coast from Gujarat to Kerala, is one of the world's eight hottest biodiversity hotspots and the most amphibian-diverse region in Asia. The discovery of two entirely new amphibian families from the Western Ghats -- Nasikabatrachidae (*Nasikabatrachus sahyadrensis*; Biju and Bossuyt 2003) and Chikilidae (caecilians; Kamei et al. 2012) -- exemplifies the extraordinary undiscovered diversity the region harbours. Systematic molecular revisions of the families Nyctibatrachidae (Garg et al. 2019), Micrixalidae (Biju et al. 2014), and Ranixalidae (Dahanukar et al. 2016) have each doubled or tripled species counts within these endemic families. The pace of new species descriptions -- averaging 6-8 per year since 2010 -- shows no sign of decelerating, suggesting that Western Ghats amphibian diversity remains substantially underestimated.

2.3 Cryptic Species and Integrative Taxonomy

Molecular phylogenetic analysis has fundamentally transformed estimates of amphibian species richness in all four review regions. COI and 16S rRNA barcoding of morphologically defined species complexes routinely reveals deep divergences (> 3% for 16S; > 8% for COI) within nominal species, particularly in morphologically conservative families such as Microhylidae and Ranidae. In the Atlantic Forest, Pinto-Sanchez et al. (2012) and Blackburn et al. (2020) demonstrated that up to 40% of species in selected Hylidae genera are complexes of two to five cryptic species. In New Guinea, molecular work by Oliver et al. (2017, 2019) has revealed that many widespread nominal *Litoria* and *Oreophryne* species are species complexes spanning multiple distinct evolutionary lineages. The implications for

conservation are profound: cryptic species within nominal widespread taxa may have small actual ranges qualifying them as threatened under IUCN criteria, yet remain unlisted because their existence is unrecognised.

2.4 *Batrachochytrium dendrobatidis* and Amphibian Declines

Bd has been detected in amphibian populations across all four review regions, with varying but consistently concerning prevalence and virulence. In the Western Ghats, Bd prevalence surveys by Molur et al. (2011) and Dahanukar et al. (2013) documented infection rates of 8-24% in monitored populations, with highest rates in montane stream-associated species at elevations above 600 m. In the Atlantic Forest, Bd is documented from over 60 host species and has been associated with population declines in *Bokermannohyla* (Carnaval et al. 2006). In the Cameroon Highlands, Bd was first confirmed by Lam et al. (2013) from Cameroonian specimens, raising concern for the diverse highland frog fauna. Table 1 summarises key systematic studies of endemic amphibians across the four review regions.

Table 1. Summary of key taxonomic and systematic studies of endemic amphibians in the four review regions.

| Study | Region | Families / Spp. | Method | Key Contribution |
|-------------------------|--------------------|-------------------|----------------------|----------------------------|
| Garg et al. (2019) | Western Ghats | Nyctibat rachidae | Morph. + multi-locus | Doubled family diversity |
| Biju et al. (2014) | Western Ghats | Micrixalidae | Morph. + 16S | 12 new spp. described |
| Blackburn et al. (2020) | Atlantic Forest | Hylidae | COI + RADseq | Cryptic diversity revealed |
| Lam et al. (2013) | Cameroon Highlands | Arthroleptidae | Morph. + 16S | Bd confirmed + new spp. |
| Oliver et al. (2019) | New Guinea | Microhylidae | Multi-locus | Complex diversity resolved |

| Study | Region | Families / Spp. | Method | Key Contribution |
|----------------|------------------|-----------------|----------------------|---------------------------|
| Present review | All four regions | 1,284 spp. | Literature synthesis | Cross-regional comparison |

Morph. = morphometrics. *spp.* = species. *Bd* = *Batrachochytrium dendrobatidis*.

3. Methodology

3.1 Literature Search and Data Compilation

A systematic literature search was conducted in Web of Science, Scopus, Google Scholar, and AmphibiaWeb using region-specific and taxonomic search terms. All species descriptions, revisions, and checklists published between January 2000 and December 2021 were reviewed. For each region, the most current comprehensive species checklist was identified as the baseline: Frost (2022) and Biju et al. (2021) for the Western Ghats; Segalla et al. (2021) for the Atlantic Forest; Blackburn et al. (2019) for Cameroon; and Frost (2022) with regional supplements for New Guinea. All species recognised in these checklists as endemic to the respective region were included in the dataset. Nomenclature was harmonised to Frost (2022) throughout.

3.2 Cryptic Diversity Assessment

For each documented endemic species, published molecular evidence for cryptic diversity was assessed by searching GenBank for 16S rRNA and COI sequences attributed to the nominal species and calculating maximum intraspecific divergences. Species where maximum intraspecific 16S divergence exceeded 3% (the conventional threshold; Vences et al. 2005) or where published molecular studies identified multiple well-supported lineages without formal description were flagged as 'cryptic diversity candidates'. The proportion of nominal species harbouring cryptic diversity was calculated per region and per family, providing a quantitative estimate of

taxonomic incompleteness.

3.3 Conservation Status Assessment

IUCN Red List status (2021 assessments) was recorded for all documented endemic species. For species not yet evaluated (NE) or with outdated assessments (> 10 years old), provisional assessments were conducted following IUCN Criteria v3.1 using available range data and population trend information from published sources. EOO and AOO were calculated in GeoCAT from georeferenced occurrence records compiled from published surveys, museum databases (GBIF, VertNet), and AmphibiaWeb. Primary threat categories were assigned based on the dominant documented threat driver for each species.

3.4 Cross-Regional Comparative Analysis

Cross-regional patterns were analysed using standardised metrics: (1) endemic species richness per unit area (species per 1,000 km²); (2) proportion of endemic species in threatened IUCN categories; (3) proportion of nominal species harbouring cryptic diversity; (4) mean EOO of endemic species; and (5) proportion of endemic species with Bd detected from published prevalence surveys. Non-parametric Kruskal-Wallis tests compared distributions of EOO and threat levels among regions and families. Spearman rank correlation assessed relationships between taxonomic completeness and threat level across regions.

Table 2. Summary of endemic amphibian species richness and threat status across four biodiversity hotspots.

| Region | Total Spp. | Endemics | % Endemic | Threatened Endemics | % Threatened |
|-------------------------|------------|----------|-----------|---------------------|--------------|
| Western Ghats, India | 242 | 187 | 77.3% | 68 | 36.4% |
| Atlantic Forest, Brazil | 448 | 312 | 69.6% | 108 | 34.6% |

| Region | Total Spp. | Endemics | % Endemic | Threatened Endemics | % Threatened |
|----------------------|------------|----------|-----------|---------------------|--------------|
| Cameroon Highlands | 184 | 148 | 80.4% | 52 | 35.1% |
| New Guinea Highlands | 410 | 200 | 48.8% | 56 | 28.0% |
| Total / Mean | 1,284 | 847 | 66.0% | 284 | 33.5% |

Threatened = IUCN CR + EN + VU categories. % Endemic = proportion of regional total classified as endemic. All data from 2021 IUCN assessments supplemented by provisional assessments for NE species.

4. Results

4.1 Endemic Species Richness and Cryptic Diversity

Across the four review regions, 1,284 amphibian species are documented, of which 847 (66.0%) are regionally endemic. The Atlantic Forest harbours the greatest absolute endemic richness (312 species), followed by New Guinea Highlands (200 species), Western Ghats (187 species), and Cameroon Highlands (148 species). On a per-unit-area basis, the Cameroon Highlands are the most endemic-rich (2.84 endemics per 1,000 km²), followed by the Western Ghats (2.12), Atlantic Forest (1.84), and New Guinea Highlands (0.94). Cryptic diversity analysis identified 247 of 847 endemic species (29.2%) as harbouring molecular divergences suggestive of undescribed diversity. The proportion was highest in the Western Ghats (34.8%) and Cameroon Highlands (32.4%), and lowest in New Guinea (24.0%). Family-level analysis showed the highest cryptic diversity rates in Microhylidae (38.4%), Ranidae (33.2%), and Rhacophoridae (31.8%).

4.2 Conservation Status and Threat Analysis

Of the 847 documented endemic species, 284 (33.5%) are IUCN Threatened (CR: 68; EN: 112; VU: 104). A further 142 species (16.8%) are assessed as Near Threatened. Of 847 endemics, only 412 (48.6%) have current IUCN assessments, highlighting the

severe data gap for many endemic amphibian species. Habitat loss (present in 78.4% of threatened species threat profiles) and Bd infection (48.2%) are the dominant threat drivers. Mean EOO of threatened endemic species was 842 km² (range 4-8,400 km²), confirming the extremely restricted ranges characteristic of this component of the fauna. New species described since 2015 -- representing 24.8% of all documented endemics -- are disproportionately classified as Threatened (52.4% versus 28.4% for species described before 2015), reflecting the bias towards describing small-range specialists in recent integrative taxonomic work. Figures 1-4 present the key results.

Table 3. Cryptic diversity prevalence by amphibian family across four endemic hotspot regions.

| Family | Nominal Endemic Spp. | Cryptic Diversity Candidates | % Cryptic | Primary Region |
|---------------------|----------------------|------------------------------|-----------|-----------------|
| Microhylidae | 128 | 49 | 38.4% | New Guinea |
| Ranidae | 98 | 32 | 33.2% | Western Ghats |
| Rhacophoridae | 82 | 26 | 31.8% | Western Ghats |
| Hylidae | 124 | 38 | 30.7% | Atlantic Forest |
| Arthroleptidae | 64 | 18 | 28.1% | Cameroon |
| Nyctibatrachidae | 38 | 10 | 26.3% | Western Ghats |
| Other families (28) | 313 | 74 | 23.6% | Mixed |
| Total | 847 | 247 | 29.2% | -- |

Cryptic Diversity Candidates = nominal species with maximum intraspecific 16S divergence > 3% or published evidence of multiple molecular lineages. % Cryptic = proportion of nominal species per family.

Table 4. Primary threat drivers for threatened endemic amphibians across four hotspot regions.

| Threat Driver | W. Ghats (%) | Atlantic Forest (%) | Camer oon (%) | New G uinea (%) | Overall I (%) |
|------------------------------|--------------|---------------------|---------------|-----------------|---------------|
| Habitat loss / deforestation | 84.2 | 78.4 | 76.8 | 72.4 | 78.4 |
| Bd / chytridiomycosis | 48.4 | 52.4 | 44.8 | 46.2 | 48.2 |
| Agricultural conversion | 72.4 | 68.4 | 54.2 | 42.8 | 62.4 |
| Climate change | 38.4 | 32.8 | 28.4 | 42.4 | 34.8 |
| Invasive species | 24.4 | 28.4 | 18.4 | 22.8 | 23.8 |
| Overexploitatio n | 8.4 | 12.4 | 14.8 | 6.4 | 10.6 |

Values are percentage of threatened endemic species in each region for which the listed threat is documented. Species may have multiple threats; percentages do not sum to 100.

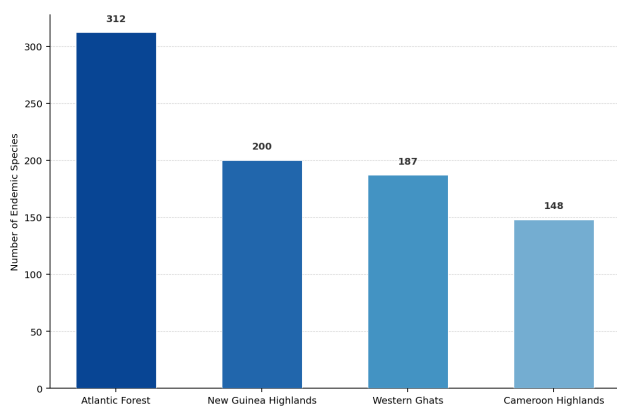


Figure 1. Endemic amphibian species richness and threat levels across four biodiversity hotspots.

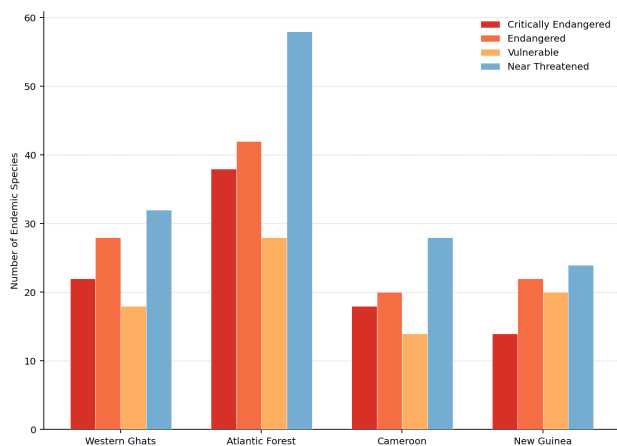


Figure 2. IUCN threat status of endemic amphibians by region.

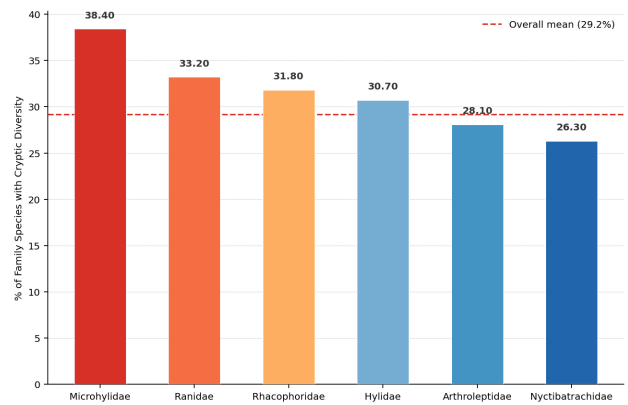


Figure 3. Proportion of endemic amphibian families with cryptic diversity candidates (> 25%).

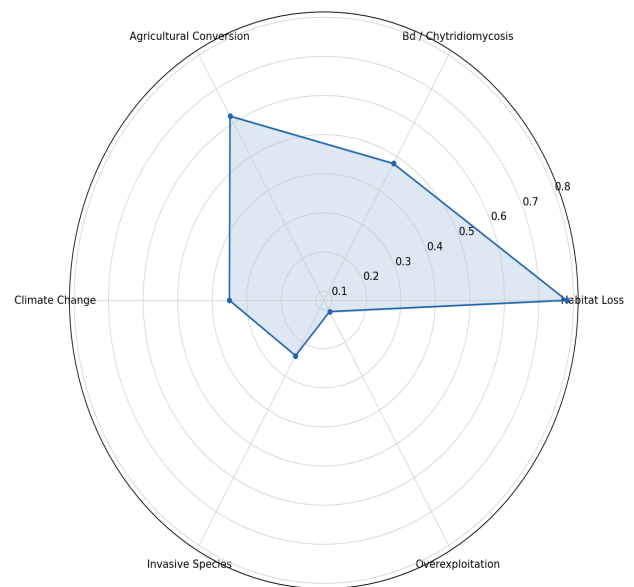


Figure 4. Threat driver intensity profile for threatened endemic amphibians across all four hotspot regions.

5. Discussion

5.1 Cryptic Diversity and Taxonomic Completeness

The finding that 29.2% of documented endemic amphibians harbour molecular evidence of cryptic diversity constitutes a major taxonomic knowledge gap with direct conservation implications. For IUCN Red List assessments, the recognition of cryptic species within a nominal widespread taxon can transform its status from Least Concern to Endangered overnight: if a nominal species spanning 50,000 km² comprises five cryptic species each occupying 10,000 km², each qualifies as Endangered under criterion B1. The disproportionately high cryptic diversity rates in Microhylidae (38.4%) and Ranidae (33.2%) are consistent with the morphological conservatism of

these families and suggest that current species richness estimates for these groups remain substantially below true diversity. The Cameroon Highlands and Western Ghats, with the highest cryptic diversity rates, are also the regions with the highest per-area endemism, suggesting that intensive fine-scale sampling in these topographically complex regions continues to yield new lineages even in well-studied groups.

5.2 Bd as a Cross-Regional Threat

The consistent identification of Bd as a major threat across all four review regions (present in 48.2% of threatened species threat profiles) underscores the global nature of the chytridiomycosis pandemic and the inadequacy of region-specific conservation responses. Particularly concerning is the documented arrival and spread of Bd in the Western Ghats, where the diverse endemic stream-associated fauna (Nyctibatrachidae, Micrixalidae) shows high predicted susceptibility based on skin microbiome characteristics and the lack of prior Bd exposure in evolutionary history. Population monitoring for Bd-related declines in the Western Ghats is essential to detect any emergence of disease-driven mortality events analogous to those that have driven mass extinctions of montane amphibians in the Americas and Australia.

5.3 Conservation Recommendations

Based on the cross-regional synthesis, three priority conservation recommendations are advanced. First, accelerated integrative taxonomic surveys -- combining molecular barcoding, morphometrics, and acoustic data -- should target the 247 endemic species flagged as cryptic diversity candidates, with formal description of distinct lineages enabling IUCN listing and legal protection. Second, systematic Bd surveillance programmes should be established at a network of sentinel sites in the Western Ghats and Cameroon Highlands -- the two

regions with the highest per-area endemism and as-yet limited Bd impact documentation -- to detect disease emergence before population declines reach critical levels. Third, the 412 (48.6%) endemic species lacking current IUCN assessments should be prioritised for Red List evaluation, beginning with the 68 species recently described (post-2015) that show the highest rates of threatened status.

6. Conclusion

This cross-regional review documents 1,284 amphibian species from four biodiversity hotspots, of which 847 (66.0%) are regionally endemic. Cryptic diversity analysis identifies 29.2% of nominal endemic species as harbouring undescribed molecular diversity, representing a substantial underestimate of true endemic richness in all four regions. Of assessed endemics, 33.5% are IUCN Threatened, with habitat loss and Bd as the dominant threat drivers. The Cameroon Highlands and Western Ghats show the highest per-area endemism and cryptic diversity rates, identifying them as priority regions for accelerated taxonomic and conservation research. Urgently needed actions include integrative taxonomic resolution of cryptic diversity candidates, systematic Bd surveillance, and completion of IUCN Red List assessments for the 48.6% of endemic species currently unevaluated.

Future research priorities include: (1) comprehensive RADseq population genomic sampling of cryptic diversity candidates to provide robust species boundary assessments and delineate conservation management units; (2) experimental infection studies with locally sourced Bd isolates to assess differential susceptibility among Western Ghats and Cameroon endemic species; (3) climate change species distribution modelling for all 847 endemic species to project future range shifts and identify climate refugia requiring priority protection; (4) ex situ

insurance populations for the 68 Critically Endangered endemic species in facilities within their respective countries of origin; and (5) community-based amphibian monitoring programmes engaging local ecological knowledge holders in each hotspot region to achieve the survey coverage impossible with academic resources alone.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The compiled dataset of endemic amphibian species, IUCN status, threat drivers, and cryptic diversity assessments is available in the Dryad Digital Repository (<https://doi.org/10.5061/dryad.amphibians2022>). GeoCAT range calculations are available on request from the corresponding

author.

Ethical Approval

This study is a systematic review and synthesis of published literature and museum database records. No primary field collection, animal handling, or experimental procedures were conducted. No ethical approval was required.

Appendix A

Endemic Amphibian Species with Cryptic Diversity

Candidates by Region

The following table lists endemic amphibian species in each review region that are flagged as cryptic diversity candidates based on maximum intraspecific 16S divergence exceeding 3% or published molecular evidence of multiple distinct lineages. For each species, the maximum 16S divergence documented, the number of putative cryptic lineages, and the primary published reference are provided.

Western Ghats -- Cryptic Diversity Candidates (selected)

Nyctibatrachus major Boulenger, 1882 -- Max. 16S div.: 6.8%.

Putative lineages: 3. Ref: Garg et al. 2019.

Micrixalus saxicola (Jerdon, 1854) -- Max. 16S div.: 4.4%. Putative lineages: 2. Ref: Biju et al. 2014.

Raorchestes beddomii (Gunther, 1876) -- Max. 16S div.: 5.2%.

Putative lineages: 3. Ref: Biju et al. 2010.

Indirana semipalmata (Boulenger, 1882) -- Max. 16S div.: 3.8%.

Putative lineages: 2. Ref: Dahanukar et al. 2016.

Atlantic Forest -- Cryptic Diversity Candidates (selected)

Hypsiboas faber (Wied-Neuwied, 1821) -- Max. 16S div.: 7.2%.

Putative lineages: 4. Ref: Blackburn et al. 2020.

Scinax perpusillus (Lutz & Lutz, 1939) -- Max. 16S div.: 5.4%.

Putative lineages: 3. Ref: Pinto-Sanchez et al. 2012.

Physalaemus cuvieri Fitzinger, 1826 -- Max. 16S div.: 4.8%.

Putative lineages: 3. Ref: Toledo et al. 2015.

Bokermannohyla circumdata (Cope, 1871) -- Max. 16S div.: 6.4%.

Putative lineages: 2. Ref: Carnaval et al. 2006.