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Vulnerability of Philippine Amphibians to Climate Change

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There are currently recognized 107 species of Philippine amphibians. In addition, several possible new species await formal taxonomic description. Most of them occupy microhabitats in moist or wet tropical rainforests. Based primarily on their known reproductive modes and microhabitats (including altitudinal distributions), the vulnerability of each amphibian species was assessed. The results of our assessment indicate that 26 species (24.30%) are Highly Vulnerable, 48 species (44.86%) are Moderately Vulnerable, 27 species (25.23%) are Vulnerable, and 6 species (5.61%) are Least Vulnerable to climate change. However, this preliminary assessment is tentative and requires verification through field studies using other sets of indicators. Additionally, virtually all new species currently awaiting description are known from forested mountain habitats. These species are deemed disproportionately susceptible to climate change. Thus, the percentages of vulnerable taxa are expected to climb sharply with ongoing taxonomic and ecological studies.

Key Words: amphibians, climate change, montane, moisture–dependent, Philippines, vulnerability

INTRODUCTION

Amphibian population declines were recorded in the western United States, Puerto Rico, and northwestern Australia in the 1970s. More records of severe declines occurred in Costa Rica, Ecuador, and Venezuela in the 1980s. Initially, these reports were met with skepticism by herpetologists, who suspected these declines were normal variations of natural populations. But later in the 1990s and early 2000s, the declines became more widespread and more severe and were considered beyond the probability of chance events. These reports finally convinced “most herpetologists that amphibian declines are nonrandom unidirectional events” (Stuart et al. 2004).

A flood of studies in the late 1990s and the decade of the 2000s have further confirmed amphibian population declines from more geographic areas (Alford & Richards 1999; Daszak 1999; Pounds et al. 1999; Stuart et al. 2008; Röhr & Raffel 2010). These declines were largely attributed to the well known human–induced causes of exploitation and habitat destruction (Brook et al. 2003; Gallant et al. 2007), but some of them implicated climate changes as direct or indirect causes as well as other unexplained factors causing the so–called enigmatic declines (Stuart et al. 2004; Puschendorf et al. 2008). Some enigmatic declines (Stuart et al. 2004) are believed to be caused by a pathogenic fungus *Batrachochytrium dendrobatidis* responsible for a cutaneous disease (chytridiomycosis) in frogs. The disease was first discovered in Costa Rica and Panama in 1998 (Berger et al. 1998; Daszak et al. 2003) and is now reported to have infected more than 100 species in 14 families in five continents (Daszak & Cunningham 2003; Skerratt et al. 2007; Cunningham & Daszak 2008), resulting in

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population declines and even species extinctions in some areas. In the Philippines, the fungus has been reported to the Wildlife Society of the Philippines (R. M. Brown et al. unpublished data) on Luzon and Mindanao islands, but not from other areas of the country. No population declines due to *B. dendrobatidis* outbreaks have thus far been reported from the Philippines.

Known causes of amphibian population declines are habitat fragmentation and destruction, over-exploitation, disease outbreaks, and climate change (Stuart et al. 2004). There is evidence for the link of global amphibian population declines and species extinctions to climate change during the decade of the 2000s. Pithiyagoda et al. (2008) reported that of the 103 frog species in Sri Lanka, 19 have been considered extinct, and most of these were restricted to high elevations of 1,800 meters where average annual temperature increased by 1.3°C and average annual precipitation increased by ~20% during the period 1869 to 1995. The impacts of climate change are complex and become more detrimental to amphibian populations when acting in synergy with diseases like chytridiomycosis (Puschendorf et al. 2008).

Philippine Amphibian Fauna

Philippine amphibians consist of 107 species (3 caecilians and 104 frogs and toads) as listed in Table 1 based on various sources (Inger 1954; Alcala & Brown 1998, 1999; Brown et al. 2000; Diesmos et al. 2004, 2006; Siler et al. 2007, 2009b, 2010; Brown et al. 2009). About 85% of them inhabit forested areas. Endemism of Philippine amphibians is high, ca 78.5%, but is likely to increase to about 80% when more new species are described formally, following the lineage species concept (Brown et al. 2008). This high species richness and high endemism are due to a combination of factors that favored speciation in the past, including fluctuating sea levels that created habitats with equable climatic conditions and complex geologic (tectonic) events favoring creation of many microhabitats and promoting geographic barriers to population mixing (Heaney 1985; Sodhi et al. 2004; Brown & Diesmos 2009).The Philippines has been identified as one of the four Southeast Asian hotspots among the 25 Global Conservation hotspot areas characterized by high endemism and, at the same time, are experiencing rapid habitat destruction and high extinction rates (Mittermeier et al. 1999; Woodruff 2010; Bickford et al. 2010). Recent assessment of the conservation status of Philippine amphibians by the IUCN has identified one species as Critically Endangered, 18 species as Endangered, and 29 species as Vulnerable (Stuart et al. 2008). Because so many Philippine species are considered "Data Deficient" (and thus, cannot be assessed due to a lack of basic natural history data), more detailed studies may reveal more threatened species.

Climate Change Projection for the Philippines

Climate change predictions are based on reconstructions of global temperatures in the past with the use of proxies. There is agreement in several published studies that global temperature has risen over the past 400 years, although temperatures were below average in 1600 (see Wegman et al. undated Report to the U.S. Congress).

Yusuf & Francisco (2009) have identified the Philippines along with Indonesia (Sumatra, Java, West Papua) and Malaysia (Sabah) as among the most vulnerable countries in Southeast Asia, based on the high exposure frequencies of droughts, cyclonic storms, landslides, and floods, all of which are believed to be driven by changes in temperature and precipitation. For the Philippines, the occurrence of destructive typhoons during the past three years tends to give credence to these projections.

The Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) has made the following projections in climate change patterns for 2020 and 2050, which could impact Philippine amphibians (Hilario et al. Observed Trends and Climate Change Scenarios for the Philippines, unpublished; The Philippine Strategy for Climate Change and Adaptation): The projected rise in mean annual temperature is between 0.9 ºC to 1.4 ºC for 2020 and 1.7 ºC to 2.4 ºC by 2050 based on a fine–scale model, *Providing Regional Climates for Impact Studies* (PRECIS). The dry months of March to May will become drier and the wet months of June through November will become wetter. Reduction in rainfall in most parts of Mindanao for all seasons is predicted. Stronger southwest monsoon winds are also projected on Luzon and Visayas. Areas with increasing elevation in slope gradients are more vulnerable to excessive rains, landslides, and flashfloods than gently sloping areas at lower elevations. The most inherently sensitive areas due to topography are in central and northern Luzon, Mindanao, and parts of Mindoro, Negros and Panay Islands, which are coincidentally areas of high endemism for amphibians (Brown & Alcala 1970) and mammals (Heaney & Roberts 2009).

MATERIALS AND METHODS

To assess the vulnerability of the 107 species of Philippine amphibians to the potential effects of climate change, we developed five criteria and a semi-quantitative 5-point scoring system, adopted from Obura & Grimsdith (2009) who studied climate change vulnerability studies on sensitive ecosystems. Based primarily on available data (published or unpublished), we scored each amphibian species according to its status, altitudinal distribution, reproductive mode, habitat, and relative rarity, which are fairly well known for Philippine amphibians (Alcala 1962; Alcala & Brown 1982; Brown & Alcala 1961, 1983; Alcala & Brown 1998, 1999; Diesmos & Brown 2011).Table 1 describes these criteria in detail.

There are five criteria with a maximum possible score of 5 and a total possible score of 25 for each species. The 107 amphibian species were then sorted from highest (24) to lowest (4) scores. Groups were then created based on score values, by subtracting the minimum score (4) from the maximum score (24) and dividing by four. Each Group has a score range of 5. Group 1 (scores 19 to 24) is classified as Highly Vulnerable; Group 2 (13 to 18) as Moderately Vulnerable; Group 3 (7 to 12) as Vulnerable; and Group 4 (6 and below) as Least Vulnerable.

Table 1. Criteria for assessing vulnerability of Philippine amphibians to climate change.

Criteria	Description	Score	Remarks
Status	Alien species	1	Alien, invasive species are expected to adapt to a wide range of environmental conditions
	Non-endemic	2	Widespread distribution in and out of the Philippines
	Endemic to Philippines; widespread	3	Distributed throughout the archipelago
	Endemic to Philippines; found in 3-5 islands	4	Refers to species found in one or two Pleistocene Aggregate Island Complexes (PAICs)
	Endemic to 1-2 islands only	5	Population with restricted range.
Elevation	Wide-range (lowland to montane)	1	Species in this group are expected to undergo altitudinal shift
	Restricted to lowland (ca. 500m and below)	2	Lowland areas are expected to be less impacted by reduced precipitation
	Lower limit: ca. 500m	3	Reduced moisture with increasing altitudes
	ca.1000 masl	4	
	ca. 2000masl	5	
Habitat	Non-forest (including near human habitations)	1	Species in this criteria are expected to tolerate degraded habitats
	Karst (caves, limestone)	2	Karsts/limestone habitats retain more moisture than non-karst areas
	Forest streams/ponds, tree holes	3	Arranged according to moisture levels
	Forest (ground, leaf litter)	4	
	Forest (mainly arboreal)	5	
Reproduction	Conventional tadpole (eggs laid in ditches and ponds near human habitations)	1	Tadpoles are expected to tolerate poor water quality in degraded habitats
	Conventional tadpole (eggs laid in forest ponds, streams)	2	Tadpoles are sensitive to sedimentation and removal by flood
	Eggs laid in foamy mass above water	3	Probably adaptable to reduced water-level
	Direct development (laid on ground and leaf litter)	4	Forest ground litters retain more moisture
	Direct development (laid on aerial vegetation and leaf axils)	5	Sensitive to reduced moisture
Rarity	Common	1	Rare species are expected to be affected by population declines compared to the common species
	Intermediate between common and uncommon)	2	
	Uncommon	3	
	Intermediate betw-een uncommon and rare	4	
	Rare	5	

RESULTS

The results are presented in Table 2. Out of the 107 species, 26 species (24.3%) are Highly Vulnerable, 48 species (44%) are Moderately Vulnerable, 27 species (25.2%) are Vulnerable and 6 species (5.6%) are Least Vulnerable to climate change. Seventy-four species (69%) are considered Highly Vulnerable and Moderately Vulnerable and are mostly direct developers (42 species including *Platymantis, Philautus* and *Oreophryne*), arboreal (30 species) and distributed in high altitude (>1000m) forest habitats (13 species). The Highly to Moderately Vulnerable Groups contained 74 species, with 29 species having a conservation status of Critically Endangered and Endangered in Stuart (2004 Table 2).

Table 2. Climate change vulnerability scores for Philippine amphibians per criteria in Table 1.

		Status					Elevation					Habitat					Reproduction					Rarity					
Species	**Family**	Alien species	Non-endemic	Endemic to Phil; widespread	Endemic to Phil; found in 3-5 islands	Endemic to 1-2 islands	Wide-range (lowland to montane)	Restricted to lowland (ca. 500m and below)	Lower limit ca. 500m	Lower limit ca.1000 masl	Lower limit ca. 2000masl	Non-forest (near human habitations)	Karst (caves, limestone)	Forest streams/ponds, tree holes	Forest (ground, leaf litter)	Forest (mainly arboreal)	Conventional tadpole (eggs laid in ditches)	Conventional tadpole (eggs laid in forest ponds, streams)	Eggs laid in foamy mass above water	Direct (eggs laid on ground, leaf litter)	Direct (eggs laid on aerial vegetation and leaf axils)	Common	Intermediate (common to uncommon)	Uncommon	Intermediate(uncommon to rare)	Rare	TOTAL SCORE
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Group 1: Highly Vulnerable																											
Platymantis subterrestris	Ceratobatrachidae					5				4						5					5					5	24
Philautus worcesteri	Rhacophoridae					5				4						5					5					5	24
Philautus surrufus	Rhacophoridae					5				4						5					5					5	24
Platymantis panayensis	Ceratobatrachidae					5			3							5					5					5	23
Platymantis banahao	Ceratobatrachidae					5			3							5					5					5	23
Platymantis cornutus	Ceratobatrachidae					5			3							5					5					5	23
Platymantis negrosensis	Ceratobatrachidae					5			3							5					5					5	23
Oreophryne annulata	Microhylidae					5					5					5					5			3			23
Platymantis luzonensis	Ceratobatrachidae					5			3							5					5				4		22
Platymantis taylori	Ceratobatrachidae					5		2								5					5					5	22
Philautus poecilus	Rhacophoridae					5				4						5					5			3			22
Oreophryne nana	Microhylidae					5			3							5					5			3			21
Pelophryne albotaenia	Bufonidae					5				4						5		2								5	21
Philautus schmackeri	Rhacophoridae					5	1									5					5					5	21
Platymantis rabori	Ceratobatrachidae				4		1									5					5					5	20
Platymantis naomiae	Ceratobatrachidae					5				4					4					4				3			20
Philautus leitensis	Rhacophoridae				4		1									5					5					5	20
Platymantis montanus	Ceratobatrachidae					5				4						5					5	1					20
Platymantis isarog	Ceratobatrachidae					5				4						5					5	1					20

Table 2 continued next page

Ansonia muelleri	Bufonidae	5	4	3	2	5	19
Pelophryne lighti	Bufonidae	5	4	5	2	3	19
Platymantis sierramadrensis	Ceratobatrachidae	5	2	5	5	2	19
Platymantis diesmosi	Ceratobatrachidae	5	4	4	4	2	19
Limnonectes diuatus	Dicroglossidae	5	4	3	2	5	19
Philautus acutirostris	Rhacophoridae	5	1	5	5	3	19
Platymantis indeprensus	Ceratobatrachidae	5	3	4	4	3	19
Group 2: Moderately Vulnerable							
Ansonia mcgregori	Bufonidae	5	3	3	2	5	18
Platymantis mimulus	Ceratobatrachidae	5	2	4	4	3	18
Platymantis polillensis	Ceratobatrachidae	5	1	5	5	2	18
Platymantis hazelae	Ceratobatrachidae	5	1	5	5	2	18
Platymantis guentheri	Ceratobatrachidae	4	1	5	5	3	18
Platymantis pseudodorsalis	Ceratobatrachidae	5	3	4	4	2	18
Limnonectes parvus	Dicroglossidae	5	3	3	2	5	18
Ingerana mariae	Dicroglossidae	5	3	3	2	5	18
Platymantis lawtoni	Ceratobatrachidae	5	2	4	4	2	17
Platymantis pygmaeus	Ceratobatrachidae	5	2	4	4	2	17
Platymantis cagayanensis	Ceratobatrachidae	5	2	4	4	2	17
Platymantis levigatus	Ceratobatrachidae	5	1	4	4	3	17
Barbourula busuangensis	Bombinatoridae	5	2	3	2	5	17
Rana (Hylarana) igorota	Ranidae	5	3	3	2	4	17
Rhacophorus appendiculatus	Rhacophoridae	2	2	5	3	5	17
Platymantis bayani	Ceratobatrachidae	5	3	2	4	2	16
Ichthyophis glandulosus	Ichthyophiidae	5	1	3	2	5	16
Ichthyophis mindanaoensis	Ichthyophiidae	5	1	3	2	5	16
Caudacaecilia weberi	Ichthyophiidae	5	1	3	2	5	16
Rana (Hylarana) tipanan	Ranidae	5	2	3	2	4	16
Philautus surdus	Rhacophoridae	4	1	5	5	1	16
Rhacophorus everetti	Rhacophoridae	2	1	5	5	3	16
Rhacophorus pardalis	Rhacophoridae	2	1	5	5	3	16
Rhacophorus bimaculatus	Rhacophoridae	2	3	5	3	3	16
Nyctixalus pictus	Rhacophoridae	2	2	4	3	4	16
Bufo philippinicus	Bufonidae	5	2	3	2	3	15
Platymantis spelaeus	Ceratobatrachidae	5	2	2	4	2	15
Platymantis paengi	Ceratobatrachidae	5	2	2	4	2	15
Platymantis biak	Ceratobatrachidae	5	2	2	4	2	15
Platymantis insulatus	Ceratobatrachidae	5	2	2	4	2	15
Kaloula rigida	Microhylidae	5	4	3	2	1	15

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Platymantis corrugatus	Ceratobatrachidae	3	1	4	4	2	14
Platymantis dorsalis	Ceratobatrachidae	3	1	4	4	2	14
Limnonectes woodworthi	Dicroglossidae	5	2	3	2	2	14
Occidozyga diminutiva	Dicroglossidae	4	2	3	2	3	14
Philautus longicrus	Rhacophoridae	2	1	5	5	1	14
Limnonectes ferneri	Dicroglossidae	5	2	3	2	1	13
Limnonectes micrixalus	Dicroglossidae	5	2	3	2	1	13
Limnonectes macrocephalus	Dicroglossidae	5	2	3	2	1	13
Leptobrachium lumadorum	Megophryidae	5	1	3	2	2	13
Leptobrachium mangyanorum	Megophryidae	5	1	3	2	2	13
Leptobrachium tagbanorum	Megophryidae	5	1	3	2	2	13
Kaloula kalingensis	Microhylidae	5	2	3	2	1	13
Kaloula kokachii	Microhylidae	5	2	3	2	1	13
Rana (Hylarana) luzonensis	Ranidae	5	2	3	2	1	13
Rana (Hylarana) mangyanum	Ranidae	5	2	3	2	1	13
Rana (Hylarana) melanomenta	Ranidae	5	2	3	2	1	13
Rana (Hylarana) everetti	Ranidae	4	1	3	2	3	13
Group 3: Vulnerable							
Limnonectes acanthi	Dicroglossidae	4	2	3	2	1	12
Limnonectes visayanus	Dicroglossidae	4	2	3	2	1	12
Limnonectes leytensis	Dicroglossidae	3	1	3	2	3	12
Limnonectes magnus	Dicroglossidae	5	1	3	2	1	12
Megophrys ligayae	Megophryidae	5	1	3	2	1	12
Kaloula walteri	Microhylidae	5	1	3	2	1	12
Rana (Hylarana) similis	Ranidae	4	2	3	2	1	12
Nyctixalus spinosus	Rhacophoridae	4	4	4	3	1	12
Pelophryne brevipes	Bufonidae	4	2	3	2	3	11
Rana (Hylarana) moellendorffi	Ranidae	4	1	3	2	1	11
Megophrys stejnegeri	Megophryidae	3	1	3	2	1	10
Kaloula baleata	Microhylidae	2	2	3	2	1	10
Rana (Sanguirana) sanguina	Ranidae	1	2	3	2	3	10
Fejervarya vittigera	Ranidae	3	1	3	2	1	10
Rana (Hylarana) grandocula	Ranidae	3	1	3	2	1	10
Limnonectes palavanensis	Dicroglossidae	2	1	3	2	1	9
Kaloula picta	Microhylidae	3	2	1	2	1	9
Staurois natator	Ranidae	2	1	3	2	1	9

Table 2 continued next page

Polypedates macrotis	Rhacophoridae	2	2	1	3	1	9
Chaperina fusca	Microhylidae	2	3	1	2	1	9
Kalophrynus pleurostigma	Microhylidae	2	1	3	2	1	9
Rana (Sylvirana) nicobariensis	Ranidae	2	1	3	2	1	9
Kaloula conjuncta	Microhylidae	3	2	1	1	1	8
Polypedates leucomystax	Rhacophoridae	2	1	1	3	1	8
Microhyla petrigena	Microhylidae	2	2	1	2	1	8
Rana albotuberculata	Ranidae	1	1	3	2	1	7
Fejervarya cancrivora	Ranidae	2	2	1	1	1	7
Group 4: Least Vulnerable							
Occidozyga laevis	Dicroglossidae	2	1	1	1	1	6
Kaloula pulchra	Microhylidae	1	2	1	2	1	6
Hoplobatrachus rugulosus	Ranidae	1	2	1	1	1	5
Rana (Lithobates) catesbeiana	Ranidae	1	2	1	1	1	5
Rana (Hylarana) erythraea	Ranidae	1	2	1	1	1	5
Bufo marinus (Rhinella marina)	Bufonidae	1	1	1	1	1	4

The results of our analysis are not directly comparable with the results of vulnerability assessments done in other countries which utilized long-term trends in amphibian populations.

DISCUSSION

Global temperatures in the past have been reconstructed from analysis of proxies (see graphs in Wegman et al. Undated Report to the U.S Congress), and these reconstructions during the period AD 800 to AD 2000 have shown temperature variations, with amphibians surviving several episodes of past temperature fluctuations. The temperature reconstructions agree on a warm period at about AD 1000. It is also agreed that global average temperature has been rising since the 1850s, as evidenced by the melting of the polar ice caps, which in turn are causing sea levels to rise. We investigated whether Philippine amphibians can adapt to rising global temperatures projected to reach 1.0-5.8° C above current levels by the year 2100 (Bickford et al. 2010). Temperatures in the Philippines are expected to rise 1.7°C to 2.4°C by 2050. Bickford et al. (2010) predicts scenarios of desiccation of frog eggs laid on arboreal microhabitats, soil and leaf litter; increased tadpole mortality due to insufficient dissolved oxygen level in water; increased susceptibility to disease(s) of eggs and tadpoles; decreased population size due to increased metabolism of adults and attrition of diversity at low and high elevations; and increased competition and change in community composition. These effects, however, will likely vary depending on the ecology and distribution of the vulnerable species.

Group 1 species, the **Highly Vulnerable** group, comprising direct developers occupying limited and special microhabitats in high altitude areas, are expected to be most vulnerable to desiccation of microhabitats due to climate change. These species spend most of their lives in perpetually moist microhabitats and utilize, as egg–laying sites, leaf axils of screw pines, root masses of aerial ferns, moss growing on tree trunks, and top surfaces of broad leaves of forest shrubs. These microhabitats easily desiccate with decreases in atmospheric moisture.

The desiccation of mossy montane and submontane microhabitats is believed to be due to rising sea surface temperatures that alter climatic patterns of tropical mountains through the lifting of cloud formation heights (Pounds et al. 1999; Frost 2001). Increased rates of vaporization could occur in these forests, especially in forest fragments, resulting in the loss of moisture in ground and above–ground amphibian microhabitats such as mosses, screw pines and aerial ferns. The mass extinction of Sri Lankan amphibians occurring in montane habitats has been attributed to a combination of increased temperatures and decreased rainfall in 1992-2003 (Pithiyagoda et al. 2008; Kohler et al. 2005).

Group 2, the **Moderately Vulnerable** group, is also composed mostly of direct developers that occupy the forest floor and karst limestone (cave) microhabitats, and are more widely distributed on different islands at various altitudes than Group 1. Group 2 includes amphibians on small islands which are especially susceptible to environmental and atmospheric perturbations and may be at risk of extinction (Fordham & Brook 2010) because populations are small (Brown & Alcala 2000; Alcala & Alcala 2005) and genetically homogenous (Brown 2009). Both Group 1 and Group 2 species may not be able to reproduce normally due to the desiccation of their microhabitats resulting from climate change. In order to avoid the effects of temperature increase and microhabitat desiccation, amphibians would have to migrate to higher elevations, where temperatures are lower, as air temperatures decrease by 6.5°C for every 1,000 m increase in altitude (Carey et al. 2003). However, as noted by Pounds et al. (1999), such a pattern of decreasing temperatures with altitudes may no longer be applicable as cloud formation is pushed higher relative to the present level. Moreover, Philippine amphibians such as the genera *Oreophryne, Platymantis, Rhacophorus*, and *Philautus*, which occupy very small arboreal microhabitat spaces (e.g. leaf axils of screw pines, root masses of aerial ferns, mosses on tree trunks, etc.), may not be able to shift to higher elevations because of their limited dispersal ability (Myers 2003; Bickford et al. 2010).

Group 3, the **Vulnerable** group, consists of both ground-dwelling and arboreal species that lay their eggs in water, on rocks near water, or on vegetation overhanging mountain streams, all with conventional aquatic tadpoles requiring variable periods of time to metamorphose into miniature adults. Given the extreme dry and wet weather predictions of the PAGASA, mountain streams would dry up during periods of drought, but during times of strong storms (e.g., typhoons), these streams would carry high loads of sediment that could reduce the efficiency of gills of tadpoles (Cox et al. 2008) leading to increased mortality. One way for amphibian species to escape the drying of breeding ponds and pools due to droughts would be to develop adaptations that hasten their larval development. But such evolutionary responses typically require long periods of time. The existing ability of Philippine amphibians to adapt to changing environmental conditions by responses such as shortened larval periods is not known.

Group 4, the **Least Vulnerable** group, consists of the common and widespread lowland species, including alien invasive species (Diesmos et al. 2006). Alien invasive species especially are adaptable to adverse conditions, which behaviors aid their ability to colonize or invade other habitats. Common Philippine species of the genera *Kaloula* and *Fejervarya* burrow into the soil or hide in moist microhabitats to escape periods of drought. *Kaloula* is opportunistic in breeding habits, being able to utilize temporary pools formed by occasional rainfall and their tadpoles develop rapidly into miniature frogs within a few weeks. *Fejervarya cancrivora* can utilize as breeding ponds saline water in mangrove swamps. The marine toad, *Rhinella marina (=Bufo marinus*), is adapted to many habitats, including those with saline water. *Rana* (*Hylarana*) *erythraea,* probably an introduced species in the Philippines, is an adaptable species (Alcala & Brown 1998; Diesmos et al. 2006), and can withstand flooding and drought conditions.

Finally, the majority of ongoing taxonomic work on Philippine amphibians involves unresolved species complexes in the forest frogs, treefrogs, and shrub frogs of the genera *Platymantis* and *Philautus* (Brown et al. 2008; Siler et al. 2007; 2009a, 2010). Most of these undescribed species are upper montane taxa and direct developers (Alcala & Brown 1982) with highly specialized life histories requiring forest microhabitats. As such, we expect that many will eventually be classified as **Highly Vulnerable** or **Moderately Vulnerable**, in our ranking system. As new species are described, we predict that an increasingly higher percentage of the total Philippine amphibian fauna will be recognized as under threat due to climate change.

In summary, we have classified expected amphibian responses to predicted climate changes. The classification of Philippine amphibian species into four vulnerability categories is a preliminary assessment and provides hypotheses which can be tested through future field investigations. We also emphasize the need to conduct field studies to determine the status of Philippine amphibian populations, and to separate (if possible) the effects of climate change from those resulting from other factors such as habitat contraction and fragmentation and from direct human exploitation. A promising initial investigation would be to revisit several mountain areas where early workers (including one of us, ACA), conducted herpetological studies in the 1950s through the 1980s. Past survey resultscan serve as baselines for comparisons to future work, to determine what changes in population or distribution variables can be reasonably attributed to climate change.

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