Analysis of the Impacts of Climate Change on the Herpetofauna of the Papuan Region (New Guinea to the Solomon Islands)

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Introduction

The study of climate change can be traced back some 200 years when scientists first began debating the timing and extent of glaciation associated with the last ice age in northern Europe. As the factors involved became better understood, scientists recognized that increasing concentrations of various gasses could produce a greenhouse effect and lead to a global rise in temperature. In the late 1950s measurements of atmospheric carbon dioxide demonstrated an annual increase of approximately 1.4 ppm/yr and led to predictions that the earth's average temperature was likely to rise by 3-5° C by 2050. This led to vigorous debate, but by around 2005 most scientists and many politicians came to realize that increasing levels of CO_2 were causing the earth's temperature to rise, that a major portion of this increased CO_2 came from human activities, particularly the burning of fossil fuels to produce energy, and that these changes would profoundly change the world's weather patterns and lead to a significant rise in sea level as polar icecaps melted and the oceans expanded as they warmed. Much recent work has focused on understanding the various environmental and atmospheric factors involved in climate change and incorporating these findings into sophisticated climate models to project future climate conditions. Although much of this work is in its infancy and most projections involve generalized effects over large areas, it is now widely agreed that sea temperature is likely to rise most rapidly in equatorial regions. This will potentially affect known drivers of periodic climate change in the southwest Pacific, such as ENSO, and could lead to increased droughts in some parts of Melanesia and increased rainfall in others. In addition, rising sea level may inundate low-lying islands, potentially causing the extinction of species endemic to those islands, and increasing temperature and changing rainfall patterns may lead to the expansion of ranges of some species and to contraction in the ranges of others. Those species endemic to high elevations, particularly single mountain summits, are especially vulnerable inasmuch as habitat essential for their survival could shrink or completely disappear.

It is virtually impossible, based on our current understanding of climate change, to predict its effects on specific populations and species of plants and animals in the equatorial tropics. This is particularly difficult in New Guinea where upwards of half the species remain unknown to science. However, some general predictions are possible. It is likely that those species that have broad ecological tolerances and large geographic ranges are less susceptible to the effects of climate change than are those species that have narrow ecological tolerances and small geographic ranges. Similarly, it is likely that those species that occupy broad altitudinal ranges will be less susceptible to the effects of climate change than those species confined to narrow altitudinal bands. Similarly, species endemic to small islands are more likely to be impacted than are species occurring on large islands or mainland New Guinea.

Background and analysis

In this analysis we focus on the herpetofauna (amphibians and reptiles) of the Papuan Region (New Guinea to the Solomon Islands, including the Bismarck and Admiralty archipelagos). This group is composed of an estimated 1400 species (based on rates of species discovery and the number of areas that remain under-explored or unexplored [Allison and Kraus, in prep], of which only 793 species are currently known to science. As a result of recent survey work, we have reasonably good information on the geographic ranges of all currently recognized species (Allison and Kraus, http://www.bishopmuseum.org/research/pbs/papuanherps/ accessed 28 April 2009). Nearly all known species have been mapped (the exceptions involve species of taxonomic uncertainty that require further study before their ranges can be accurately determined).

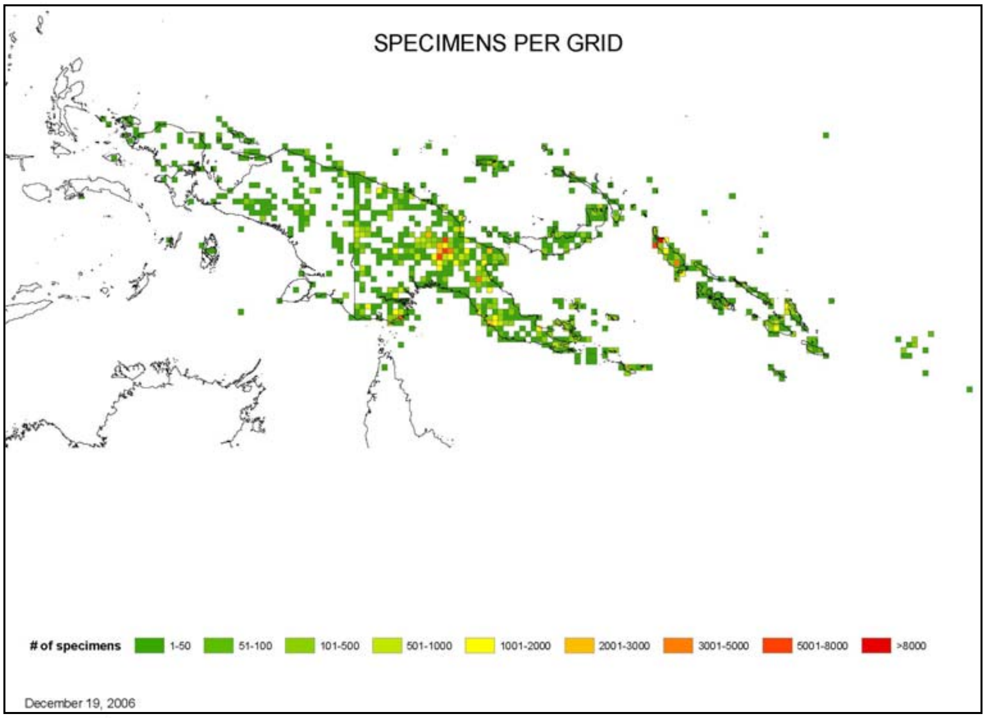

Figure 1. Survey intensity of amphibians and reptiles in the Papuan region: numbers of specimens in the world's museum by quarter-degree grid.

The distribution maps of Papuan amphibians and reptiles are based on all available data from museum collections and field surveys. However, large parts of New Guinea remain biologically unknown or poorly known (Figure 1), and many of the range maps must be considered preliminary. In addition, it is difficult to accurately map the range of a species in a mountainous landscape such as New Guinea where lowlands may be separated from mountain summits by a straight-line distance of only a few kilometers. In spite of these limitations, it is possible to use these maps to identify species occupying narrow altitudinal bands or small geographic areas and which are, therefore, most likely to be susceptible to the effects of climate change.

Table 1. Numbers of families, genera and species of New Guinea amphibians and reptiles

	Families	Genera	Species
Frogs	4	29	315
Turtles	5	11	18
Crocodiles	1	1	2
Lizards	6	34	212
Snakes	9	24	113
TOTAL	25	99	660

The current distribution of amphibians and reptile species numbers by taxonomic class is shown in Table 1. As mentioned earlier, it is important to recognize that our knowledge of the herpetofauna is growing rapidly (Figure 2). In most cases, recently named species appear to have relatively small geographic ranges because most recent surveys have focused on small islands or isolated mountain ranges and have documented species endemic to those areas. Although our understanding of patterns of distribution and diversity of the New Guinea herpetofauna are in their infancy, it is clear that the highly dissected, mountainous terrain of that island has produced relatively high beta diversity (otherwise known as species turnover) compared to other tropical areas dominated by lowlands (e.g., Borneo, Amazonia). The patterns of species richness of frogs, lizards and snakes are shown in Figures 3-5. It is clear that the central mountains, north-coast mountains, and satellite islands, which comprise more than 60% of the land area of New Guinea and its satellite islands, are the areas with the highest overall species richness. These areas also have the highest concentrations of restricted-range species.

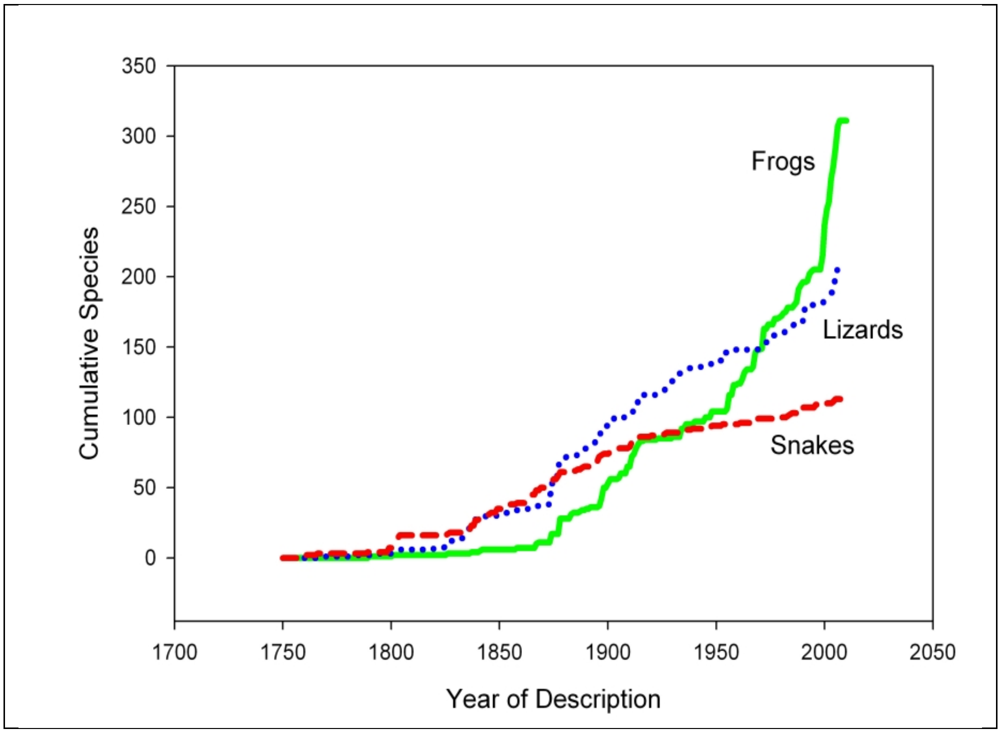

Figure 2. Cumulative species totals of New Guinea amphibians and reptiles by date of description.

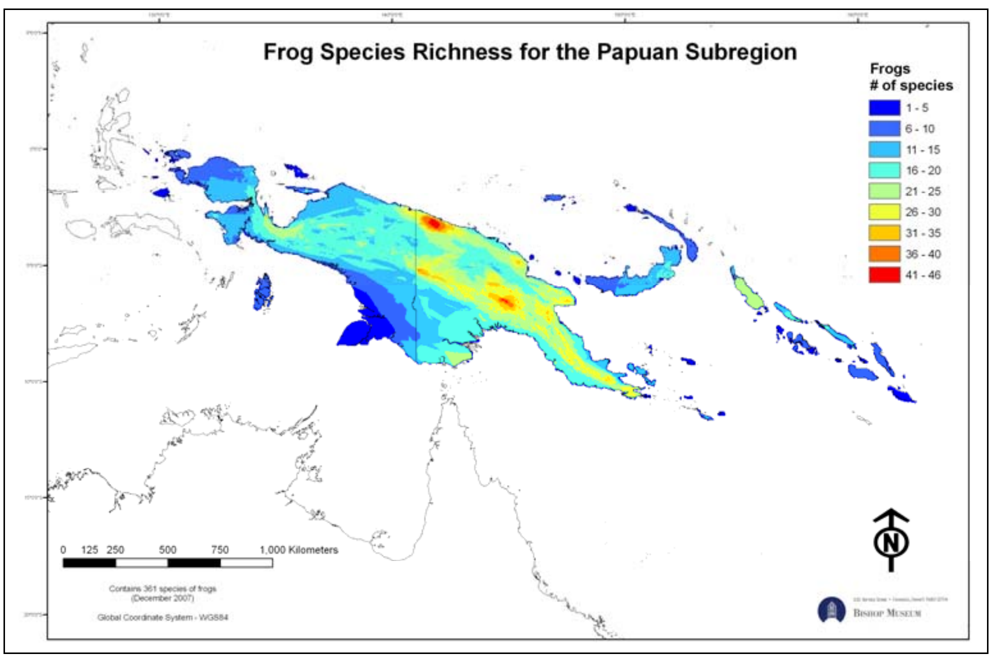

Figure 3. Species richness of Papuan frogs

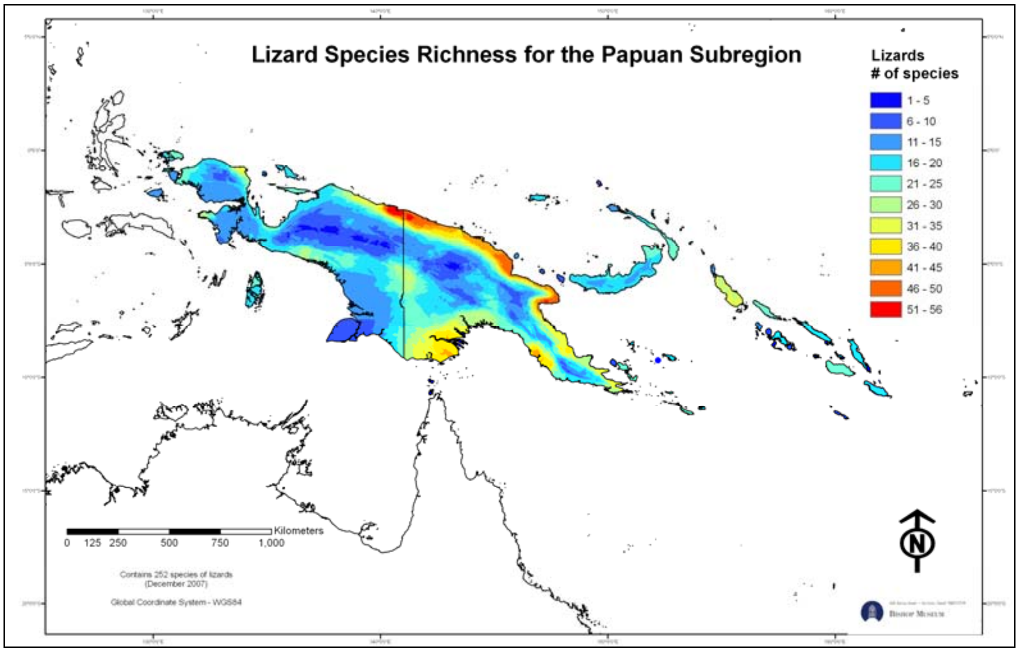

Figure 4. Species richness of Papuan lizards

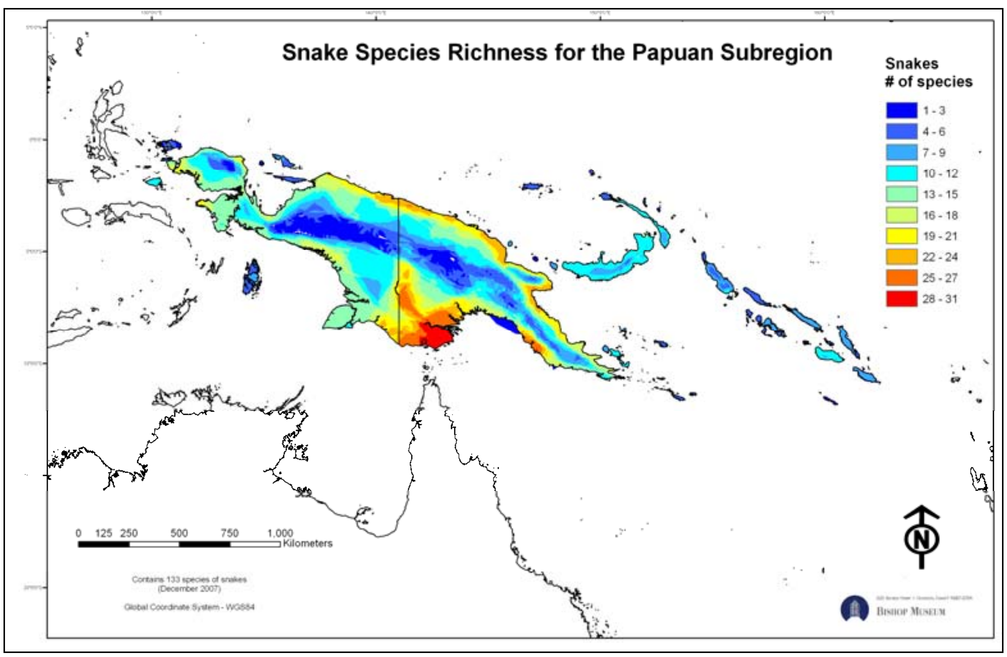

Figure 5. Species richness of Papuan snakes

Frogs

Based on current understanding of scientifically named species, there are 133 species of frogs with geographic ranges of 500 km^2 or less (Appendix 1). At least 105 of these have ranges of <200 km^2 and eight of those have a range of <50 km^2. Sixty-four species with a range of <500 km^2 are generally found at approximately 1000 m or higher and 21 of those are generally found at elevations of 2000 m or higher. It is this latter group that may be most vulnerable to the effects of climate change. At least half of these species inhabit mountain summits and could be driven to extinction by disappearance of their habitat attendant upon increasing temperature. It is possible that the Massenerhebung effect (compression of forest zonation in outlying ranges) could play an important mitigating role, although this depends on cloud cover/precipitations changes that cannot be predicted. In fact, it is also possible that climate change could lead to reductions of rainfall and the disappearance of wet forest current dependently on the Massenerhebung Effect (Mueller-Dombois and Fosberg, 1988). This would almost certainly lead to the extinction of species inhabiting cloud forest on the d'Entrecasteaus and Louisiade archipelagos, including species at relatively low elevations, such as a recently discovered frog on Rossel Island that is known only from a small patch of cloud forest that occurs from 630-800 m elevation on the upper slopes of Mt. Rio (Kraus and Allison, in press).

Twenty-five currently named species of frogs are confined to islands off the coast of New Guinea (Appendix 2) and, of those, 16 (64%) have ranges of 500 km^2 or less. Another 17 insular endemics await description by Kraus and Allison. Although offshore islands were once thought to have low-to-modest levels of endemism, recent studies by Günther, Richards, Kraus and Allison, and others have demonstrated that many of these islands and island groups in fact support a high number of endemic species. Some of these have been named and many more are in the process of being named. As a result of recent survey work the number of frogs endemic to the Louisiades, for example, has doubled from four to eight and, on the basis of collections still being worked on, is likely to again increase to at least 15-20 species.

Lizards, Snakes, Crocodiles, and Turtles

Lizard species tend to occupy larger geographic ranges than do frogs (Figures 6 and 7), probably because they can more readily cross oceanic barriers and are less restricted to relatively wet areas. For example, the average range size of Papuan frogs is 39,079 km^2 while that for lizards is 71,258 km^2. The incidence of restricted range endemism is also lower. Approximately 35% of frogs have ranges of 500 km^2 or less, but only 12 out of 233 lizard species (~5%) have analogous ranges (Appendix 3). This includes two species of skinks (genus *Ctenotus*) that have extensive ranges in Australia and are represented in New Guinea by small populations confined to the Trans-Fly region of southern New Guinea. In addition, the distributions of two species of agamid lizards (genus

Hypsilurus), two species of skinks (genus *Lipinia*) and a gecko (*Cyrtodactulys aaroni*) are relatively poorly known and may have larger geographic ranges than is known at present. This leaves five species of lizards, a gecko (*Nactus acutus*), three species of skinks and a monitor lizard (*Varanus telenesetes*) which are all restricted to islands. One of the skinks (*Sphenomorphus transversus*) is endemic to Bougainville where it is very rare, and another, *Tribolonotus annectens*, is endemic to montane areas of the Gazelle Peninsula in eastern New Britain. The three remaining species, a gecko (*Nactus acutus*), a skink (*Sphenomorphus louisiadensis*) and the *Varanus* are all endemic to the Louisiade Archipelago. The *Nactus* is known only from a single specimen from montane areas (~700 m) on Rossel Island. At least another 15 species of lizards with ranges <500km2 are awaiting description; most of these are restricted to offshore islands in Milne Bay Province.

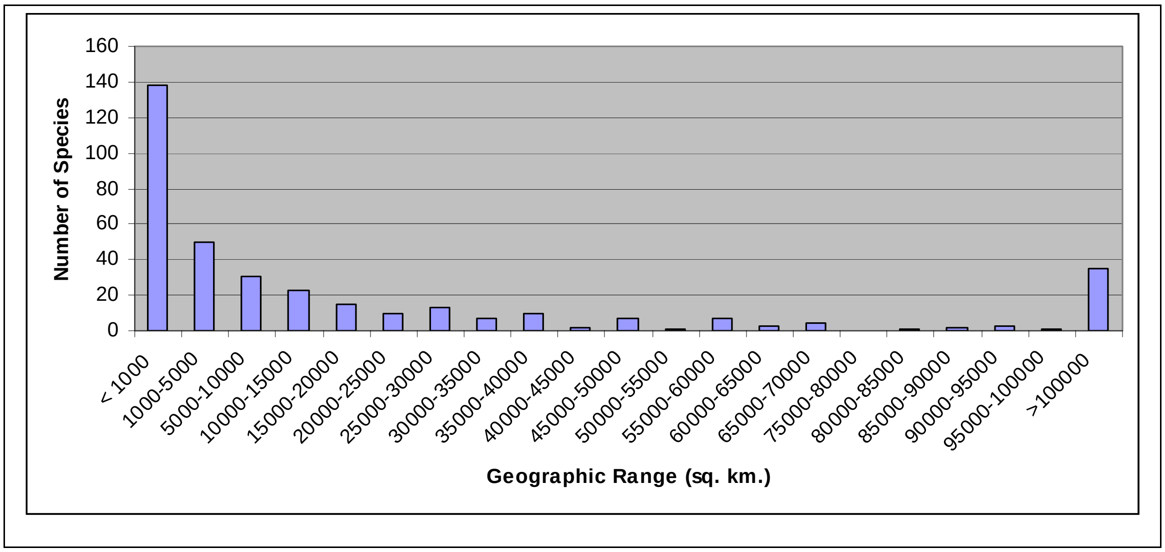

Figure 6. Numbers of species of frogs by geographic range size.

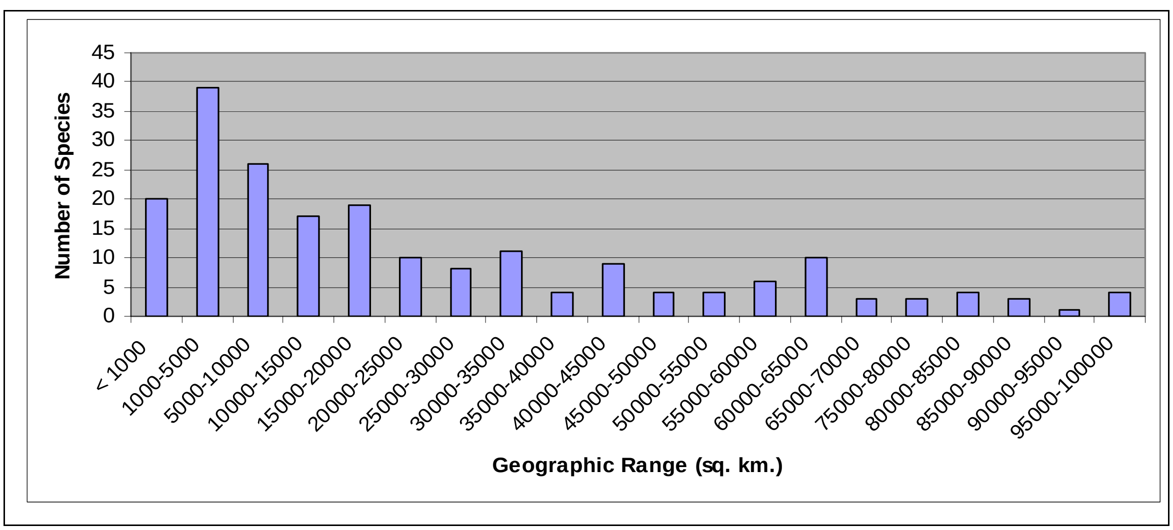

Figure 7. Numbers of species of lizards by geographic range size.

There are only eight species of currently recognized species of lizards found at elevations of 2000 m or higher (Appendix 4). Four of these (*Lobulia alpina*, *L. glacialis*, *L.stellaris* and L. *subalpina*) and at least one as yet unnamed species are confined to high elevation grasslands and would be vulnerable to extinction if this habitat disappears due to increasing temperatures and other climate-related changes (Greer, Allison and Cogger, 2005).

There are 95 species of terrestrial snakes known from the Papuan region. Five of these (~5%) are known from areas of 500 km^2 or less. One of these, a python (*Antaresia maculosa*), is a widely distributed Australian species that was recently found to also occur in southern New Guinea (O'Shea, 2004). The other three species, three elapids (*Toxicocalamus holopelturus*, *T. longissimus* and *T. misimae*) and a blindsnake (*Typhlops hades*) are endemic to the Louisiade Archipelago.

Snakes are largely confined to low elevations. There are only two species found above 2000 m, and both are widespread.

There are only two species of crocodiles and 21 species of freshwater turtles. All inhabit lowland waterways, mostly on the south coast of New Guinea, and do not appear to be in any immediate peril as a result of loss of habitat due to climate change. However, elevated temperatures are known to limit hatching success in sea turtles (Western and Sinclair, 2001) and to bias the sex ratio toward females. This could adversely impact freshwater and marine turtle populations in New Guinea.

Conclusion

This analysis has demonstrated that approximately 35 species of frogs, several species of lizards and several species of snakes are represented by small populations on islands or mountain summits and may be particularly vulnerable to extinction as a result of climate-change related habitat loss. With further biological survey work in New Guinea there are likely to be modest increases in the number of vulnerable lizards and snakes and at least a doubling and perhaps as much as a tripling in the number of vulnerable frog species.

A recent global assessment of frog populations (Stuart et al. 2004) has demonstrated that upwards of a third of frog species are threatened with extinction. The factors involved vary, but primarily include habitat loss and mortality caused by a pathogenic fungus, *Batrachochytrium dendrobatidis*. This fungus, generally known as the chytrid fungus, has been documented to occur in most parts of the world, including isolated areas such as Australia but is currently unknown from New Guinea. While its potential impact in New Guinea is only speculative at this point, it could prove devastating. Inasmuch as its virulence is known to increase with temperature, the (presumed) presence or arrival of the fungus in Melanesia, combined with regional warming, could cause even more devastating loss of amphibian populations.

It is quite possible that some species that are currently confined to small, upland areas may expand their range if climate-related change produces an increase in critical habitat. However, most of the restricted-range species occur in upland areas or on small islands where additional habitat is unlikely to become available. In the case of montane species, increasing temperature could drive populations to higher elevations. Because total land area decreases with elevation, this would force such species into smaller areas and most likely lead to population declines and extinctions. Moreover, high elevation grassland and elfin forest are highly susceptible to loss due to fire, which has been increasing in frequency and severity during the past several decades (Shearman et al., 2009) and is expected to continue to increase with increasing temperatures.

The high beta diversity of the New Guinea herpetofauna and uncertainty over the impacts of climate change on the local biota make it impossible to assess site-specific effects from climate change or to identify specific areas of low risk to climate change that should be incorporated into a protected-area management network. However, it seems fairly clear that large areas with high ecological diversity, particularly areas with a wide range of elevations, probably have the greatest capacity to buffer the impacts of climate change. However, this strategy will not protect island endemics, and so they may require other types of conservation interventions. However, given the scarcity of conservation funding resources and the need to prioritize, we recommend that current conservation efforts focus on the preservation of the former, many of which in Papua New Guinea have been incorporated into the Wildlife Management Area network, and in western New Guinea have been declared as national parks.

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Appendix 1

Papuan frog species with a total geographic range of 500 km^2 or less. Those species with an elevational range that is generally higher than 1000 m are marked with * and those that are found mostly above 2000 m are marked with **.

Albericus exclamitans*
Albericus fafniri**
Albericus gudrunae
Albericus laurini
Albericus rhenaurum*
Albericus sanguinopictus*
Albericus siegfriedi*
Albericus swanhildae
Aphantophryne minuta**
Aphantophryne sabini**
Austrochaperina archboldi*
Austrochaperina brevipes**
Austrochaperina kosarek**
Austrochaperina polysticta
Barygenys cheesmanae**
Barygenys flavigularis*
Barygenys maculata*
Barygenys parvula
Batrachylodes gigas
Callulops fuscus
Callulops glandulosus**
Callulops marmoratus*
Callulops pullifer
Callulops sagittatus*
Choerophryne allisoni*
Choerophryne amomani
Choerophryne burtoni
Choerophryne microps
Cophixalus aimbensis
Cophixalus ateles
Cophixalus bewaniensis
Cophixalus daymani**
Cophixalus humicola
Cophixalus kaindiensis*
Cophixalus misimae
Cophixalus nubicola**
Cophixalus pulchellus
Cophixalus tagulensis
Cophixalus timidus*
Cophixalus tridactylus

Cophixalus verecundus*
Copiula expectata
Copiula major
Copiula obsti
Copiula pipiens
Hylophorbus nigrinus
Hylophorbus picoides
Hylophorbus rainerguentheri
Hylophorbus richardsi
Hylophorbus sextus
Hylophorbus tetraphonus
Hylophorbus wondiwoi
Liophryne similis**
Litoria albolabris
Litoria becki**
Litoria biakensis
Litoria chrisdahli
Litoria christianbergmanni
Litoria dorsivena*
Litoria hilli
Litoria humboldtorum
Litoria huntorum
Litoria macki
Litoria mareku
Litoria megalops
Litoria mucro
Litoria multicolor
Litoria mystax
Litoria obtusirostris
Litoria oenicolen*
Litoria ollauro*
Litoria pratti*
Litoria rara
Litoria robinsonae
Litoria scabra*
Litoria singadanae
Litoria spartacus
Litoria umarensis
Litoria vagabunda
Litoria verae
Litoria wapogaensis*
Litoria wisselensis*
Mantophryne infulata*
Mantophryne louisiadensis
Mixophyes hihihorlo
Nyctimystes daymani*

Nyctimystes kuduki
Nyctimystes montanus*
Nyctimystes obsoletus
Nyctimystes tyleri
Nyctimystes zweifeli*
Oreophryne albopunctata
Oreophryne alticola**
Oreophryne asplenicola
Oreophryne atrigularis
Oreophryne brevicrus**
Oreophryne brevirostris**
Oreophryne clamata
Oreophryne geminus*
Oreophryne habbemensis*
Oreophryne idenburgensis*
Oreophryne kampeni
Oreophryne kapisa
Oreophryne minuta*
Oreophryne pseudasplenicola
Oreophryne sibilans
Oreophryne terrestris*
Oreophryne unicolor
Oreophryne waira
Oxydactyla coggeri*
Platymantis bimaculatus
Platymantis bufonulus
Platymantis cryptotis
Platymantis macrops
Platymantis mamusiorum*
Platymantis nakanaiorum*
Platymantis parilis
Platymantis sulcatus
Platymantis wuenscheorum
Rana aurata
Xenobatrachus arfakianus*
Xenobatrachus huon
Xenobatrachus lanthanites
Xenobatrachus multisica**
Xenobatrachus ophiodon*
Xenobatrachus scheepstrai*
Xenobatrachus schiefenhoevel*
Xenobatrachus subcroceus
Xenorhina adisca**
Xenorhina eiponis**
Xenorhina macrodisca*
Xenorhina varia

Appendix 2

Species of frogs that are confined to satellite islands around the coast of New Guinea. Those marked with a * have a known geographic range of 500 km^2 or less.

Austrochaperina yelaensis
Cophixalus aimbensis*
Cophixalus balbus
Cophixalus humicola*
Cophixalus misimae*
Cophixalus tagulensis*
Copiula expectata*
Hylophorbus nigrinus*
Litoria biakensis*
Litoria bibonius
Litoria flavescens
Litoria hilli
Litoria louisiadensis
Litoria obtusirostris*
Mantophryne louisiadensis*
Nyctimystes avocalis
Nyctimystes perimetri
Oreophryne asplenicola*
Oreophryne kapisa*
Oreophryne pseudasplenicola*
Oreophryne waira*
Platymantis batantae
Platymantis wuenscheorum*
Xenobatrachus lanthanites*
Xenorhina varia*

[Plus another 17 undescribed species based on our surveys, the descriptions of 6 of which are in press.]

Appendix 3

Species of Papuan lizards with ranges of 500 km^2 or less.

Ctenotus robustus
Ctenotus spaldingi
Cyrtodactylus aaroni   Hypsilurus nigrigularis
Hypsilurus ornatus
Lipinia albodorsalis
Lipinia venemai
Nactus acutus
Sphenomorphus louisiadensis
Sphenomorphus transversus
Tribolonotus annectens
Varanus telenesetes

[Plus at least 6 described and 15 undescribed species of lizards based on our surveys, most of which are on offshore islands. So probably useful to include a separate appendix of insular endemics too.]

Appendix 4

Species of lizards occurring at 2000 m or higher in the Papuan region.

Lobulia alpina
Lobulia elegans
Lobulia glacialis
Lobulia stellaris
Lobulia subalpina
Papuascincus stanleyanus
Prasinohaema flavipes
Prasinohaema prehensicauda