COMENTARIO

Global warming from a frog's perspective: A call for immediate action

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"If we can discover the meaning in the trilling of a frog, perhaps we may understand why it is for us not merely noise but a song of poetry and emotion".
— Adrian Forsyth —
A Natural History of Sex, 1986

We, the frogs, have continuously inhabited and evolved on this planet since the Devonian period some 350 million years ago. Our calls announce the beginning of spring, we keep insect populations under control, we serve as toxic pollutant indicators for human health, we are bellwethers for environmental change, we provide important medicine from the chemicals we produce, we help forest peoples hunt food with our poisons, we inspire art and poetry, and perhaps most importantly we inspire peoples to appreciate nature. Once a stronghold of 6200 species, we are now disappearing rapidly and scientists predict that nearly one third, or about 2000 species, will disappear within this century. Our population declines have been attributed to a number of factors such as habitat loss, disease outbreaks, and environmental pollutants (Stuart *et al.*, 2004; Blaustein *et al.*, 2010). In particular, the global spread of an emerging infectious disease, the pathogenic chytrid fungus *Batrachochytrium dendrobatidis (Bd),* has resulted in population collapses and outright extinctions among many amphibian taxa over the past 20 years (Fisher *et al.*, 2009; Blaustein *et al.*, 2010).

Now, we serve as indicators to humans of a more insidious slow-motion catastrophe playing out on a global scale. Human-created climatic shifts resulting in increasing temperature and changing precipitation patterns are having large impacts on amphibian assemblages, population numbers, reproduction, behavior, phenology, and physiology (Blaustein *et al.*, 2010). The climate changes are resulting in desiccation of ponds and aquatic breeding habitats, reducing leaf litter, reducing precipitation in cloud forests, all culminating in increased stress, disease outbreaks, and mortality (Pounds and Crump, 1994; Pounds *et al.*, 1999; Whitfield *et al.*, 2007; McMenamin *et al.*, 2008; Blaustein *et al.*, 2010). This article will highlight some of the severe climate-related threats that amphibians are dealing with around the world.

We are altering our lifestyle and behavior

In the northern part of the midwest and eastern United States, spring peepers (*Pseudacris crucifer*) are one of the first amphibians to emerge from hibernation in early spring. When they emerge they vocalize a loud mating call that sounds like a high-pitched reverberating peep, which is how their name of "spring peeper" was derived. Based on comparisons of first calling dates between 1900-1912 and 1990-1999 noted by human observers in Ithaca, New York, the spring peepers are emerging on average 15

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days earlier to breed (Gibbs and Breisch, 2001). Earlier breeding has been documented in several other species around Ithaca such as the wood frog (*Rana sylvatica*), the bullfrog (*Rana catesbeiana*), and the grey tree frog (*Hyla versicolor*), as well as amphibian species found in other countries such as Britain and Japan (Beebee, 1995; Gibbs and Breisch, 2001; Kusano and Inoue, 2008). This is in contrast to amphibians in the northwestern and northern midwest United States and Ontario Canada that, when monitored over a decade ago, did not exhibit earlier breeding patterns (Blaustein *et al.*, 2001). Also, while *P. crucifer* monitored in the state of Michigan between 1960 and 2000 do not appear to be breeding consistently earlier, a strong correlation has been observed between years with warmer spring temperatures and earlier breeding (Blaustein *et al.*, 2001). Repeat surveys in these areas are vital to determine if these breeding patterns are changing, if any trends are associated with changes in climate, and if such trends may be related to other factors such as increased competition or changing food resources, decreased survival rates, disease outbreaks, or other negative impacts.

A good example of potential negative impacts that earlier breeding might have on frogs was demonstrated in a laboratory study of temperate-zone amphibians conducted over 25 years ago. Researchers found that frogs that were prevented from hibernating had decreased growth rates, were smaller, matured faster, and had higher rates of mortality than control groups that underwent hibernation (Jorgensen, 1986). These results suggested that a warming climate may decrease hibernation time and negatively impact the growth and reproduction of amphibians. This hypothesis was recently tested in a toad species, *Bufo bufo,* found near South Dorset in the United Kingdom. When 23 years of daily weather data was analyzed, the results showed a significant upward trend in both the mean diurnal minimum (0.8°C) and maximum (1.5°C) temperatures for that period (Reading, 2007). Furthermore, the observed thermal increase correlated with decreased body condition and survival of the toads. In the report, it was suggested that the increased mortality may be due to depleted energy reserves that are utilized faster in warmer hibernating months resulting in animals that are no longer able to survive hibernation (Reading, 2007). Amphibians that do survive shorter hibernation periods are smaller in size and lay fewer eggs. Therefore mild winters can lead to declines in amphibian populations by decreasing both survival and fecundity (Reading, 1998; Reading, 2007).

Ponds are drying up, and our population numbers are plummeting

In the central part of the United States, the negative effects of climatic change on amphibian communities have been recently documented. Six decades of climate monitoring and repeated surveys of 49 ponds in Yellowstone National Park, one of the longest-protected areas on Earth, revealed a clear increase in drought and pond desiccation due to climatic warming. During the last 16 years, while precipitation has decreased, temperature in the warmer months has risen, leading to a four-fold increase in the number of permanently dry ponds. The loss of ponds has been catastrophic to amphibians such as the blotched tiger salamander (*Ambystoma tigrinum melanostictum*), boreal chorus frog (*Pseudacris triseriata maculata*), and Columbia spotted frog (*Rana luteiventris*), and has led to both decreases in the number of species that inhabit the remaining ponds and the population numbers inhabiting them (McMenamin *et al.*, 2008). Since the early 1990's, tiger salamander populations have decreased by over 40 %, chorus frogs by 70 %, and spotted frogs by 68 %, due to the loss of pond habitat (McMenamin *et al.*, 2008).

We are scaling mountains in search of new habitat

Madagascar is vulnerable to changes in the El Niño Southern Oscillation (ENSO), and global climate change is predicted to increase the frequency of the ENSO phenomenon leading to changes in the natural environment (Ingram and Dawson, 2005). In the Tsaratanana Massif of northern Madagascar, recent warming trends have been tied to a 19 to 51 m upslope movement in the elevational midpoint of 30 species of reptiles and amphibians over a 10-year period (Raxworthy *et al.*, 2008). These observations are consistent with climate model predictions of regional warming and affirm the expectation that amphibians, notably ones that live in narrow ecological niches and a have a low range of thermal tolerance, are particularly climate-sensitive taxa (Duellman and Trueb, 1994). Using an elevational range displacement analysis, these researchers also found that a temperature increase of 1.7 °C over the next century is likely to lead to complete habitat loss for the three endemic species, *Plethodontohyla sp*. Z, *Platypelis tsaratananensis*, and *Phelsuma lineata punctulata,* that live in the uppermost elevations of the massif (Raxworthy *et al.*, 2008). This may be an ongoing example of the "summit-trap phenomenon", whereby species living close to mountain summits are effectively pushed off their mountaintops as climate change locally eliminates their ecological niches causing their native habitat to disappear.

Central America is also being impacted by climatic warming. In the Monteverde Cloud Forest of Costa Rica, increased dry periods associated with changes in ENSO are causing cloud banks to rise, resulting in reduced mist precipitation received in the cloud forest. As a result, amphibians and reptiles are declining (Pounds *et al.*, 1999). The role of climate change-mediated declines in amphibians is further complicated by the presence of an emerging pathogenic chytrid fungus *Batrachochytrium dendrobatidis (Bd)*. Climate change has recently been suggested to contribute to the ongoing amphibian extinctions in Central and South America by increasing nighttime temperature to optimal ranges that promote growth and outbreaks of *Bd* (Pounds *et al.*, 2006). However, this chytrid-thermal-optimum hypothesis has been strongly challenged, and further analysis has not supported a direct role of climate change in promoting *Bd* outbreak; rather the key driver of disease is more likely through introduction and spreading of the fungus to naïve amphibian populations (Lips *et al.*, 2008). Interestingly, another study focusing on *Eleutherodactylus* species in Puerto Rico found a correlation between drought and chytrid outbreaks (Burrowes *et al.*, 2004). How climate change will alter disease dynamics of *Bd* is an area under current investigation.

The South American Andes offer examples where climatic warming and deglaciation are driving amphibian communities uphill by expanding their habitat. Around Lake Sibinacocha in southern Peru, three species of anurans *Telmatobius marmoratus*, *Rhinella spinulosa (*formerly *Bufo spinulosus)*, and *Pleurodema marmorata* have expanded their ranges and moved to unprecedented elevations for amphibians globally (5200-5400 m) to inhabit new terrain and ponds created by deglaciation (Seimon *et al.*, 2007). In the case of *P. marmorata*, climatic warming has resulted in an approximate 200 m vertical increase in its range since the cool period known as the Little Ice Age ended around 1880. As these highest-dwelling species are adapting to the warming climate by migrating to and spawning in ever-higher terrain, they are also being impacted by *Bd*, which unfortunately is tracking with the frogs into the newly created habitat. Since 2003, a year after *Bd* was first detected in this region, all three species have been decreasing in number and *T. marmoratus* has not been documented in the Sibinacocha watershed since 2005 (Seimon *et al.*, 2007; T. Seimon, A. Seimon, and P. Sowell, unpublished data). *Telmatobius* are an endemic genus to the Andes, but because of the concurrent impacts of disease, food trade, and habitat change, they are rapidly disappearing in many countries (Merino-Viteri and Coloma, 2005; Seimon *et al.*, 2005; Barrionuevo and Mangione, 2006; Angulo, 2008; Barrionuevo and Ponssa, 2008; von May *et al.*, 2008).

The glaciers in which we depend will soon be gone

Melt water from glaciers have long been known to increase both wetlands and support high mountain lakes. However, what happens when the glaciers disappear altogether? Recent evidence now reveals that ongoing deglaciation is now threatening major water sources for 30 million people living in Peru, Ecuador, and Bolivia, and many of the lower altitude glaciers in the Andes are expected to disappear in the next 1-2 decades (Vergara *et al.*, 2007). As glaciers disappear, abrupt changes occur in surface hydrology upon which not only humans but also high-dwelling amphibian populations depend (Fig. 1). The drop in water table may change the hydrology of the pond, alter the types of vegetation that grows, kill off existing vegetation causing increased eutrophication, and subsequently change plant, microbial, and amphibian assemblages. Shrinking pond size or desiccation increases population density within existing species leading to clustering of amphibian communities. The higher density of frogs increases the potential for disease exposure and transmission making them more susceptible to disease outbreak, for example by *Bd;* larvae become more exposed to UV irradiation and fungal infection, and weakened immunity caused by stress. Shrinking pond size can also convert a permanent pond to one that is ephemeral thereby reducing the amount of time for a tadpole to develop, or result in the loss of spawning grounds all together (Pounds *et al.*, 2006; Gervasi and Foufopoulos, 2008; Blaustein *et al.*, 2010).

Our future prospects…

Bioclimatic modeling approaches have been utilized to predict future outcomes of climate change-mediated impacts on amphibians. Lawler *et al.* (2009) assessed the geographic vulnerability of amphibians to climate change in the western hemisphere by mapping projected changes in amphibian assemblages. Using a variety of climate-change simulations, they mapped the areas that were consistently projected to have warmer temperatures and reduced precipitation over the next century. In their study they found a wide range of responses to climate change. As an example, several species including the northern leopard frog (*Rana pipiens*) are projected to exhibit poleward and elevational shifts in their distributions as a function of temperature changes. Overall, model projections showed that species were expected to experience larger range contractions than expansions. Approximately 85 % of all species were projected to experience a net loss in habitat range under the more conservative low B1 emissions scenario whereby greenhouse gases are projected to be under control by mid-century. The B1 scenario, as compared to the higher A2 scenario, results in an estimated global temperature increase of 2 °C versus 3-4 °C, respectively, by the end of the 21st century (IPCC, 2007). Species turnover rates are projected to be the highest in Mexico, Central America, and the Andes of South America. In addition, some of these and other areas such as northeastern Brazil, Peruvian and Atacaman deserts, and Valdivian mountains in the Southern Andes are consistently projected to experience reduced precipitation and increasing dryness within this century (Lawler *et al.*, 2009).

Southeast Asia is another area where amphibians are projected to be at risk. To predict where the largest changes in amphibian habitat will likely occur, a recent study mapped biodiversity hotspots and compared these regions with areas projected to be impacted by climate change between 2000 and 2050. Both Indo-Burma and Sundaland are biodiversity hotspots with over 200 amphibian species recorded for each region. Unfortunately, these two regions were also predicted to have the highest precipitation and temperature anomalies in this part of the world over the next several decades (Bickford *et al.*, 2010). These changes are therefore predicted to cause major alterations in ecosystem functions and will likely lead to catastrophic declines of amphibians (Bickford *et al.*, 2010).

Climate change driven by greenhouse gas emissions is now well recognized to be truly global in scope, and no area is likely to remain unaffected. For taxa such as amphibians that tend to occupy specific ecological niches largely determined by climate, their prospects are extremely daunting. Under the A2 IPCC emissions scenario, Williams *et al.* (2007) predict that approximately 10-48 % of the world's terrestrial surface will experience a disappearance of current climatic conditions or regimes within this century, while 12-19 % will experience the development of unknown "novel" climatic regimes. Using a more conservative B1 scenario, the projected effect was reduced to 4-20 % of terrestrial surface for both disappearance and novel climates. Regions where present-

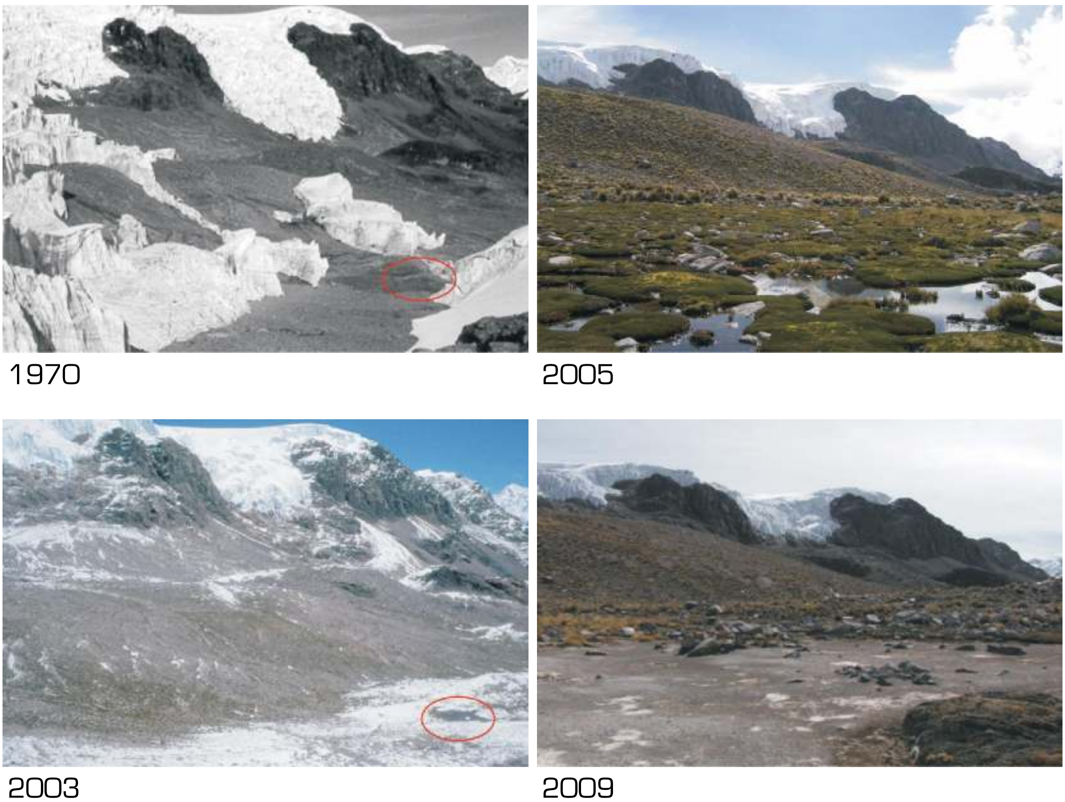

Figure 1. Creation and destruction of amphibian habitat by climate change at the extreme upper limit of amphibian range on Earth.
A once permanent amphibian pond at 5348 m near Lake Sibinacocha Peru, that developed around 1970 from glacier meltwater, is now desiccated and no longer supports the surrounding vegetation and amphibians that once inhabited it. Top left image was taken in 1970 by John Ricker, and the bottom left is a repeat image taken in August of 2003 (Seimon *et al.*, 2007). Both images were taken in the dry season (August) and show water in the pond. Top right is an image taken at the same pond in March of 2005 where *Pleurodema marmorata* and pathogenic chytrids were found. Bottom right is a similar image taken in August 2009. No amphibians have been observed at this site since 2005. Note the dead vegetation, dry pond bed, and receding glacier in the background. Observations of a reduction in water table may indicate a broader phenomenon and set of landscape changes whereby glacier melt initially contributes to new pond development, but continued ice recession eventually causes a reduction in melt water that no longer sustains ponds or the amphibian communities inhabiting them.

day climatic regimes are predicted to disappear include the Colombian and Peruvian Andes, Central America, the African Rift Mountains, Zambian and Angolan highlands, parts of South Africa, southeast Australia, parts of the Himalayas, and the Indonesian and Philippine Archipelago. Novel climatic regimes are predicted to develop in the Amazonian and Indonesian rainforest, western Sahara, lowlands of east Africa, Arabian Peninsula, southeast United States, eastern India, southeast Asia, and northwest Australia (Williams *et al.*, 2007). In other words, every continent will be impacted by our changing climate.

What do all these changes mean for amphibians? Global warming will change microclimates, create novel climates, and affect hydrological patterns that will affect species ranges, disease dynamics, physiology, behavior, and reproduction, all culminating in catastrophic losses that will contribute to the largest mass extinction of amphibians along with numerous species from other taxonomic groups in 65 million years.

Our future prospects…
depend on the actions of humans

In order to survive climate change, amphibians urgently need your help. Immediate action is necessary to safeguard amphibians from the effects of climate change, disease, and other threats through expansion of ongoing and new captive breeding programs, additional private and public funding for research and monitoring, increased disease surveillance, and implementation of long term management plans for species on the brink of extinction. In 2005, scientists gathered together at the *IUCN/SSC Amphibian Conservation Summit* to create the Amphibi-

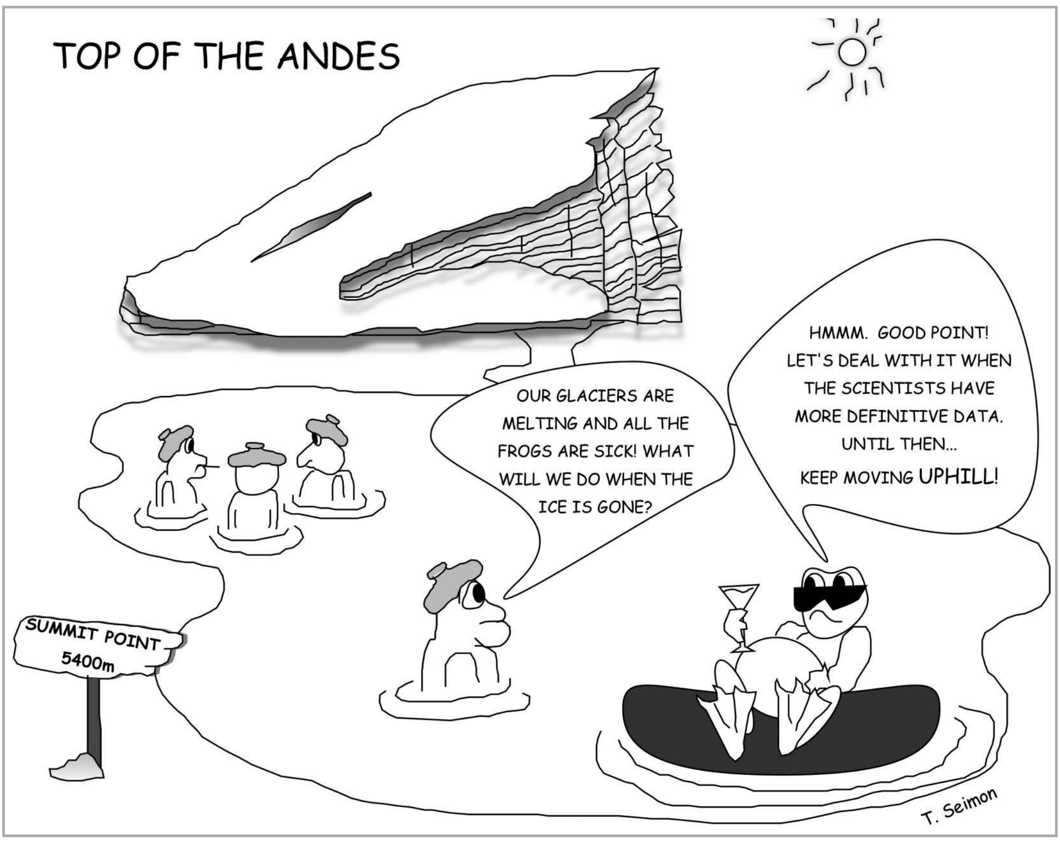

Figure 2.

an Conservation Action Plan, a critical document that outlines important steps to be taken in order to save amphibians from extinction (IUCN, 2005). Since 2008, the Year of the Frog, much public awareness and additional funding has filtered into amphibian conservation. However, these ongoing efforts represent only a small portion of what really needs to be done in order to truly save frogs from extinction. Therefore, in order to achieve the greatest impact and preserve biodiversity, the plight of amphibians must be thoroughly integrated into the public consciousness and prioritized through collaborations between governments, scientists, conservation organizations, educators, schools systems, donors, and the media. More people need to become aggressively involved by volunteering, building careers in amphibian conservation and scientific research, and actively donating to amphibian conservation groups. Networks and programs such as the Amphibian Specialist Group (http://www.amphibians.org/ASG/Home.html), the Amphibian Ark (http://www.amphibianark.org), Amphibiaweb (http://amphibiaweb.org), Tree Walkers International (http://www.treewalkers.org), and Adopt-a-pond (http://www.torontozoo.com/adoptapond) offer valuable information and easy ways for people to take action, make a difference, and save us from extinction.

Signed,
The Frogs

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