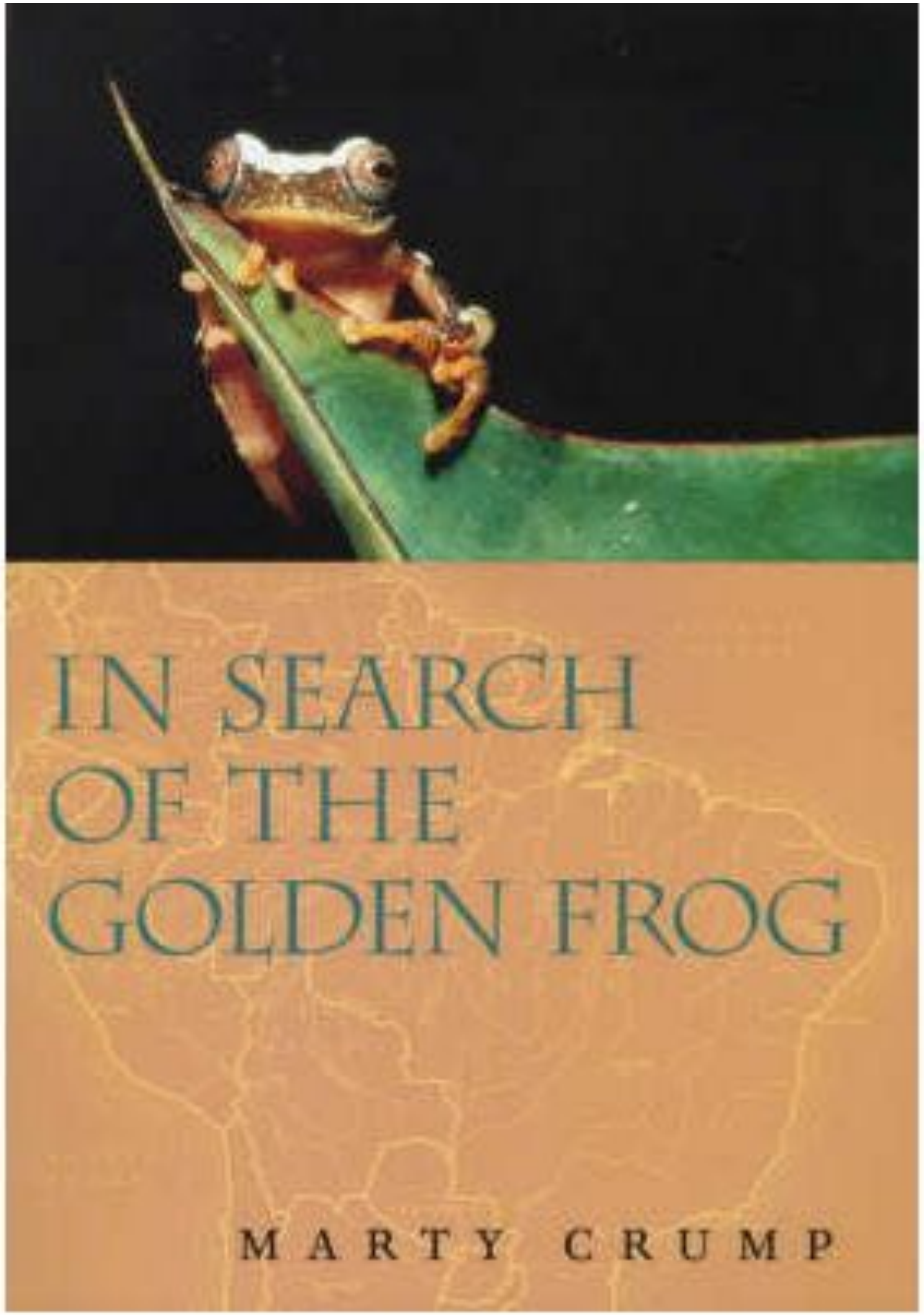
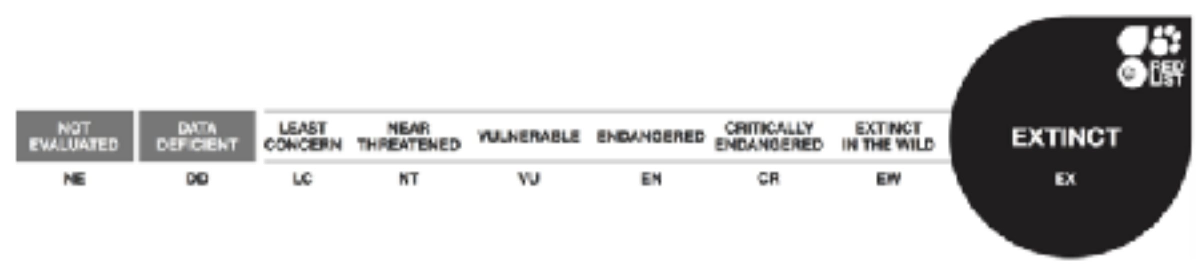
Incilius periglenes



The IUCN Red List of Threatened Species™
ISSN 2307-8235 (online)
IUCN 2008: T3172A9654595

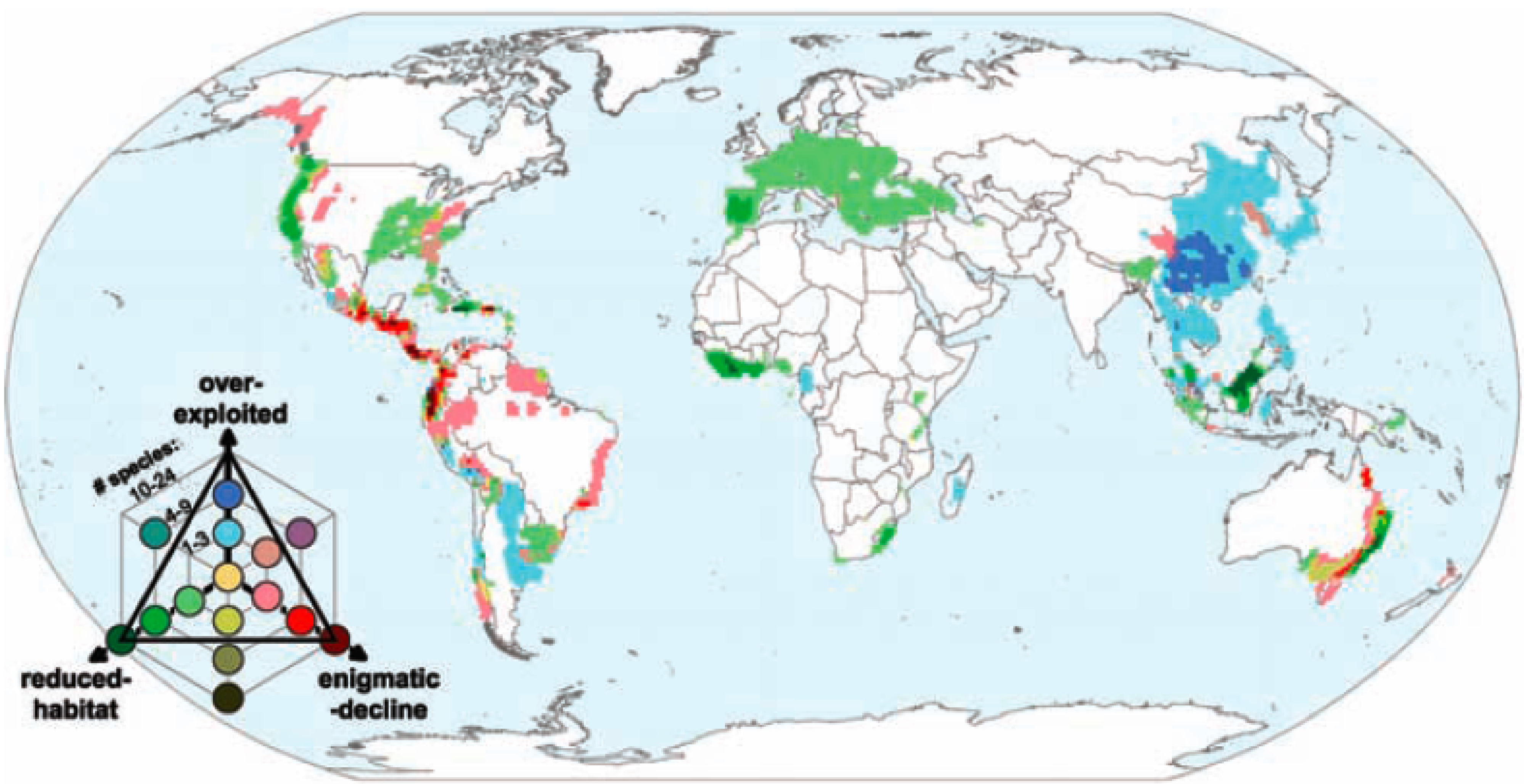
Incilius periglenes, **Golden Toad**

Assessment by: Savage, J., Pounds, J. & Bolaños, F.



Status and Trends of Amphibian Declines and Extinctions Worldwide

Simon N. Stuart,[1*] Janice S. Chanson,[1] Neil A. Cox,[1]
Bruce E. Young,[2] Ana S. L. Rodrigues,[3] Debra L. Fischman,[3]
Robert W. Waller[3]



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Habitat preferences	Total number of species (%)	Number of rapidly declining species (%)	Number of enigmatic-decline species (%)
Forest	4699 (81.8)	365 (82.6)	187 (90.3)***↑
Savanna	487 (8.5)	7 (1.6)***↓	0 (0.0)***↓
Shrubland	814 (14.2)	47 (10.6)*↓	14 (6.8)***↓
Grassland	953 (16.6)	81 (18.3)	39 (18.8)
Flowing water	2650 (46.1)	277 (62.7)***↑	164 (79.2)***↑
Marshes/swamps	760 (13.2)	43 (9.7)*↓	14 (6.8)**↓
Still water bodies	2030 (35.3)	107 (24.2)***↓	28 (13.5)***↓
Artificial terrestrial habitats	1304 (22.7)	40 (9.0)***↓	22 (10.6)***↓
Tropical lowland habitats	3392 (59.1)	212 (48.0)**↓	79 (38.2)***↓
Tropical montane habitats	2714 (47.3)	251 (56.8)***↑	155 (74.9)***↑
Biogeographic realms			
Afrotropical	951 (16.6)	28 (6.3)***↓	1 (0.5)***↓
Australasian/Oceanic	561 (9.8)	36 (8.1)	23 (11.1)
Australia and New Zealand	219 (3.8)	32 (7.2)***↑	23 (11.1)***↑
Indomalayan	938 (16.3)	59 (13.3)	1 (0.5)***↓
Nearctic	331 (5.8)	24 (5.4)	9 (4.3)
Neotropical	2,825 (49.2)	279 (63.1)***↑	174 (84.1)***↑
Palearctic	451 (7.9)	34 (7.7)	2 (1.0)***↓

$^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$ (27). ↑Significantly higher than average; ↓significantly lower than average.

El Método Científico

Observaciones de
la Naturaleza, búsqueda de
Patrones Repetidos.

Planteamiento de Preguntas
de Investigación

Planteamiento de
Hipótesis

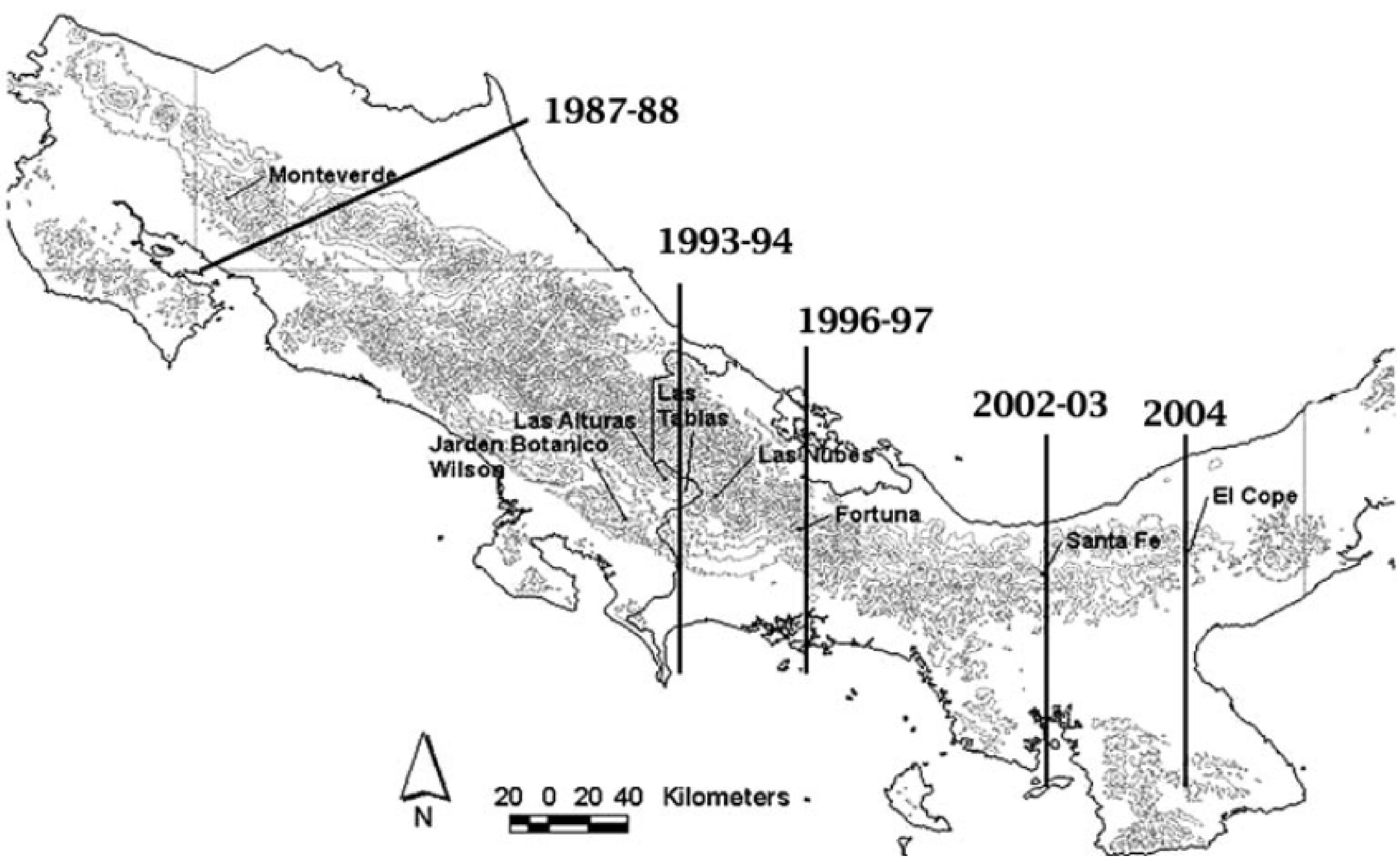
Puesta a prueba de Hipótesis
(Importancia de Falsabilidad -
Predicciones) mediante
Experimentos u Observaciones

Planteamiento de nuevas
hipótesis y pruebas adicionales
a hipótesis previamente
apoyadas

Construcción de teorías con
base en conjunto de hipótesis
bien apoyadas

Emerging infectious disease and the loss of biodiversity in a Neotropical amphibian community

Karen R. Lips*†, Forrest Brem*, Roberto Brenes*, John D. Reeve*, Ross A. Alford‡, Jamie Voyles§, Cynthia Carey§, Lauren Livo§, Allan P. Pessier¶, and James P. Collins||



PNAS | February 28, 2006 | vol. 103 | no. 9 | 3165–3170

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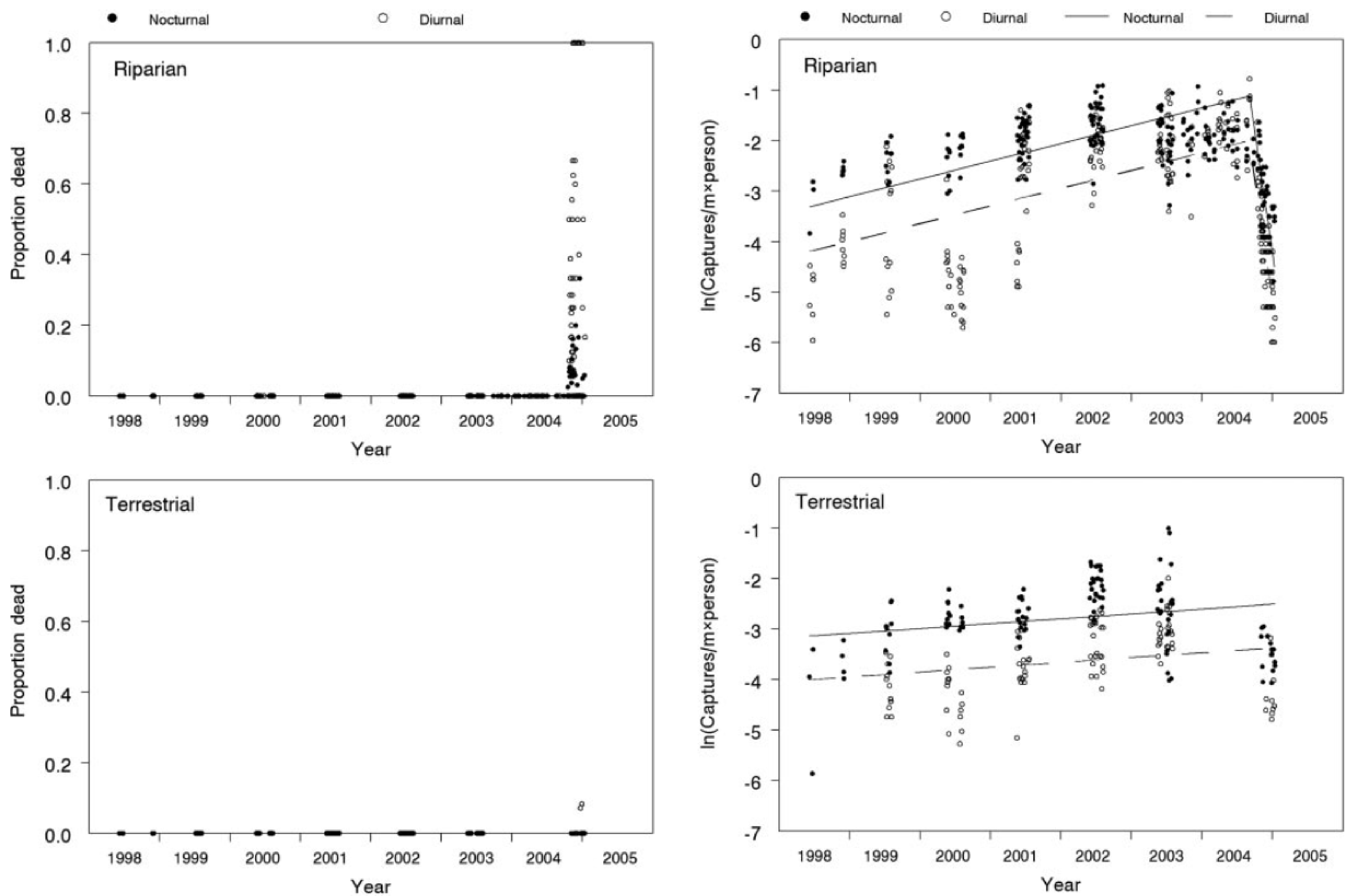

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Table 1. Sampling effort for *B. dendrobatidis* by time period

Date	Technique	No. of species	No. of individuals	No. infected	Prevalence (95% CI)
2000	Histology	3	10	0	0 (0–0.309)
2002	Histology	5	11	0	0 (0–0.285)
May–Jul 2003	Histology	43	125	0	0 (0–0.029)
May–Jul 2003	Toes–PCR	7	100	0	0 (0–0.036)
Jan 2004	Swabs–PCR	36	400	0	0 (0–0.009)
Mar 2004	Swabs–PCR	32	282	0	0 (0–0.013)
May 2004	Swabs–PCR	43	311	0	0 (0–0.012)
Jul 2004	Swabs–PCR	38	327	0	0 (0–0.011)
Pre die-off totals		43	1,566	0	0 (0–0.0030)
23 Sep–2 Oct 2004	Swabs–PCR	2	86	9	0.10 (0.049–0.189)
Oct 2004	Swabs–PCR	21	216	127	0.59 (0.519–0.654)
Nov 2004	Swabs–PCR	31	456	240	0.53 (0.479–0.573)
Dec 2004	Swabs–PCR	16	121	56	0.34 (0.372–0.556)
Post die-off totals	Swabs–PCR	48	879	432	0.49 (0.498–0.569)

Columns indicate technique used for assessing *B. dendrobatidis,* number of species and individuals examined, and number found infected. Prevalence includes 95% confidence intervals (CI).

PNAS | August 3, 2010 | vol. 107 | no. 31 | 13777–13782

Epidemic disease decimates amphibian abundance, species diversity, and evolutionary history in the highlands of central Panama

Andrew J. Crawford[a,b,c,1], Karen R. Lips[a,d], and Eldredge Bermingham[a]

Amphibian populations around the world are experiencing unprecedented declines attributed to a chytrid fungal pathogen, *Batrachochytrium dendrobatidis*. Despite the severity of the crisis, quantitative analyses of the effects of the epidemic on amphibian abundance and diversity have been unavailable as a result of the lack of equivalent data collected before and following disease outbreak. We present a community-level assessment combining long-term field surveys and DNA barcode data describing changes in abundance and evolutionary diversity within the amphibian community of El Copé, Panama, following a disease epidemic and mass-mortality event. The epidemic reduced taxonomic, lineage, and phylogenetic diversity similarly. We discovered that 30 species were lost, including five undescribed species, representing 41% of total amphibian lineage diversity in El Copé. These extirpations represented 33% of the evolutionary history of amphibians within the community, and variation in the degree of population loss and decline among species was random with respect to the community phylogeny. Our approach provides a fast, economical, and informative analysis of loss in a community whether measured by species or phylogenetic diversity.

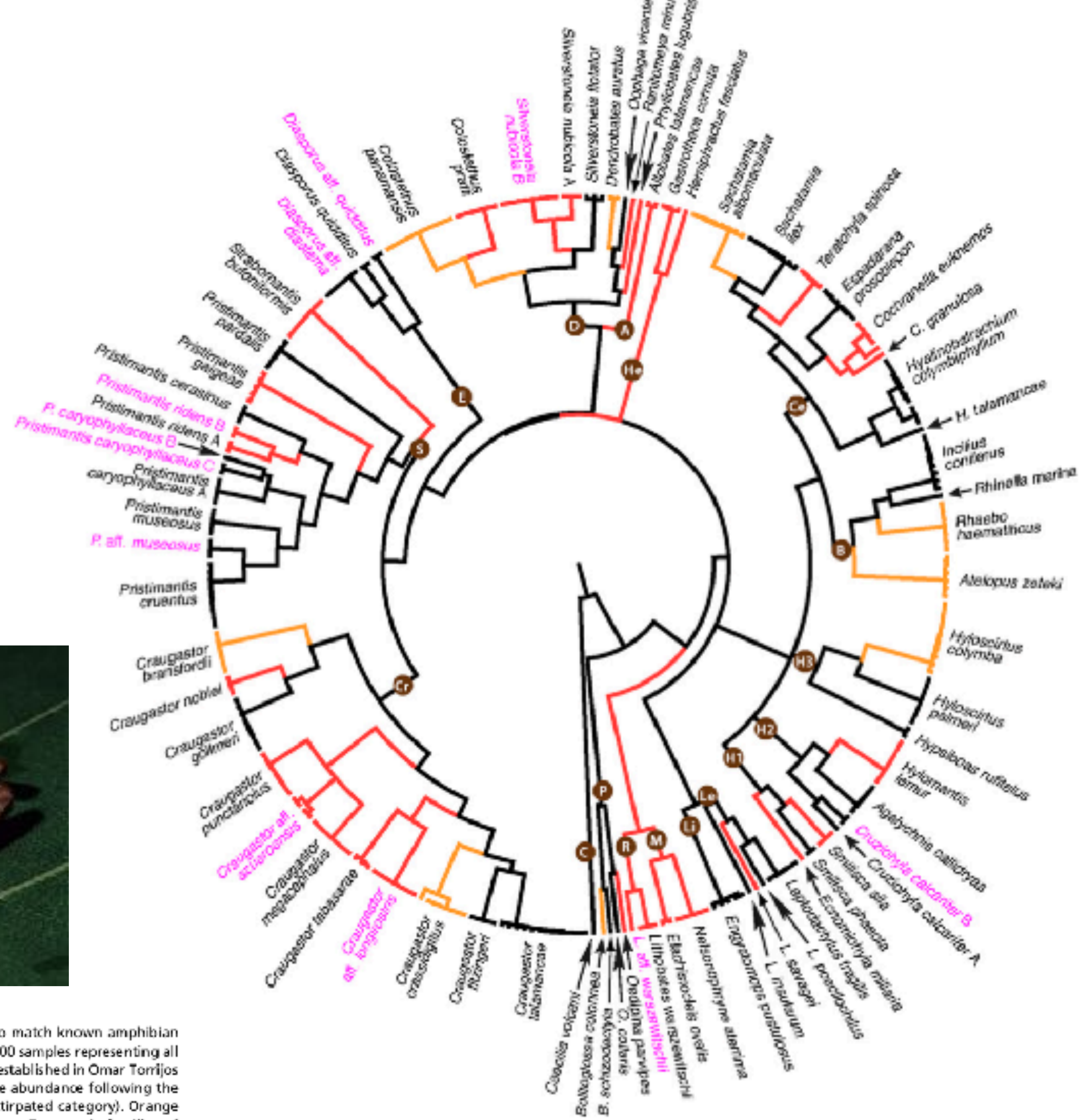


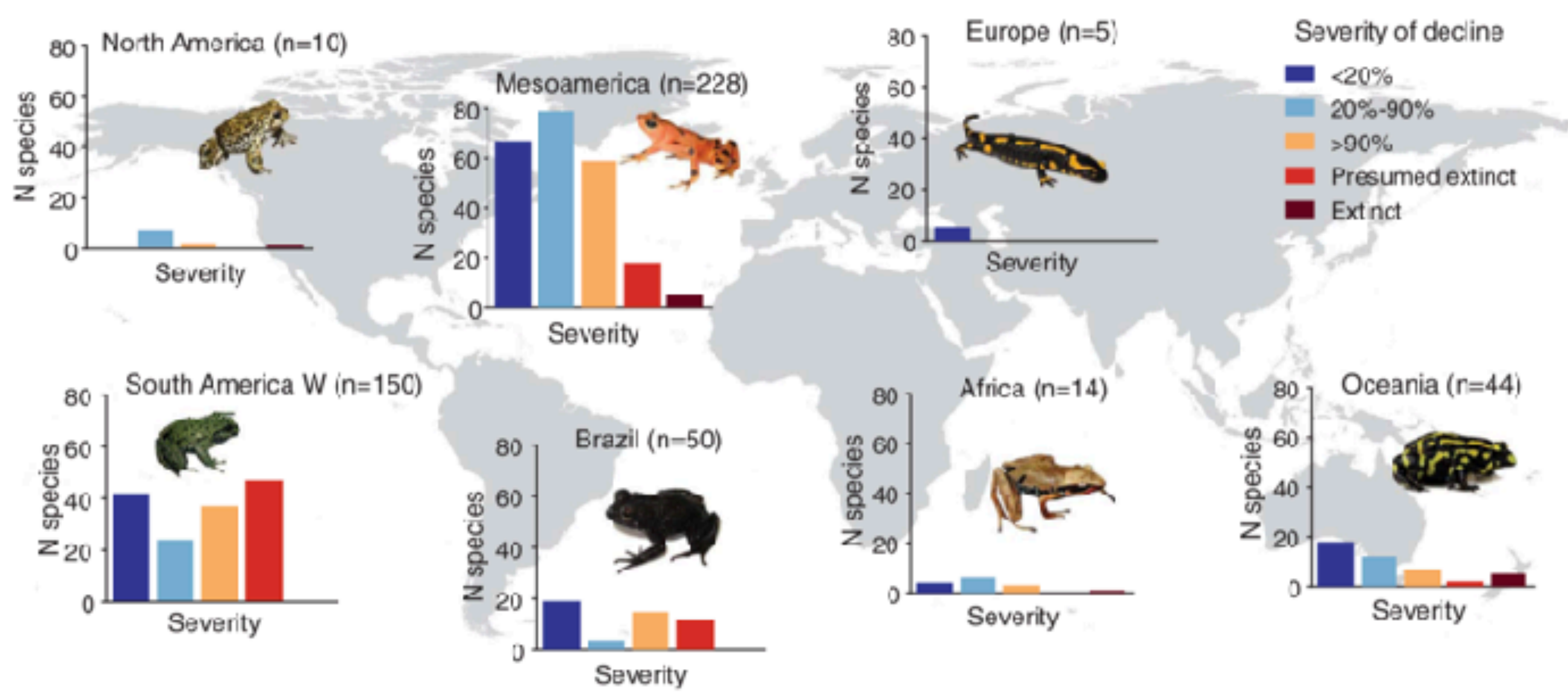
Fig. 2. Community phylogeny of the amphibians of El Copé, Panama, study site. Maximum likelihood phylogeny constrained to match known amphibian relationships (*Materials and Methods*) and inferred from concatenated DNA sequences of the COI and 16S gene fragments from 300 samples representing all 63 named amphibian species plus 11 candidate species (labeled in purple) known from the study transects of approximately 4 km^2 established in Omar Torrijos National Park. Branch lengths made ultrametric using the MPL algorithm. Branches are color-coded by percent decline in relative abundance following the catastrophic decline caused by the arrival of *B. dendrobatidis* (5). Red branches indicate 100% decline in relative abundance (extirpated category). Orange branches indicate a decline of 85% to 99% (critical category). Black indicates less decline or an increase in relative abundance. Taxonomic families of amphibians are indicated by brown circles: A, Aromobatidae; B, Bufonidae; C, Caecilidae (a caecilian); Ce, Centrolenidae; Cr, Craugastoridae; D, Dendrobatidae; E, Eleutherodactylidae; H1–H3, Hylidae (H2, Phyllomedusinae); He, Hemiphractidae; Le, Leptodactylidae; Li, Leiuperidae; M, Microhylidae; *P*, Plethodontidae (salamanders); R, Ranidae; and S, Strabomantidae.

WILDLIFE DISEASE

Amphibian fungal panzootic causes catastrophic and ongoing loss of biodiversity

Ben C. Scheele, Frank Pasmans, Lee F. Skerratt, Lee Berger, An Martel, Wouter Beukema, Aldemar A. Acevedo, Patricia A. Burrowes, Tamilie Carvalho, Alessandro Catenazzi, Ignacio De la Riva, Matthew C. Fisher, Sandra V. Flechas, Claire N. Foster, Patricia Frías-Álvarez, Trenton W. J. Garner, Brian Gratwicke, Juan M. Guayasamin, Mareike Hirschfeld, Jonathan E. Kolby, Tiffany A. Kosch, Enrique La Marca, David B. Lindenmayer, Karen R. Lips, Ana V. Longo, Raúl Maneyro, Cait A. McDonald, Joseph Mendelson III, Pablo Palacios-Rodriguez, Gabriela Parra-Olea, Corinne L. Richards-Zawacki, Mark-Oliver Rödel, Sean M. Rovito, Claudio Soto-Azat, Luís Felipe Toledo, Jamie Voyles, Ché Weldon, Steven M. Whitfield, Mark Wilkinson, Kelly R. Zamudio, Stefano Canessa

Anthropogenic trade and development have broken down dispersal barriers, facilitating the spread of diseases that threaten Earth's biodiversity. We present a global, quantitative assessment of the amphibian chytridiomycosis panzootic, one of the most impactful examples of disease spread, and demonstrate its role in the decline of at least 501 amphibian species over the past half-century, including 90 presumed extinctions. The effects of chytridiomycosis have been greatest in large-bodied, range-restricted anurans in wet climates in the Americas and Australia. Declines peaked in the 1980s, and only 12% of declined species show signs of recovery, whereas 39% are experiencing ongoing decline. There is risk of further chytridiomycosis outbreaks in new areas. The chytridiomycosis panzootic represents the greatest recorded loss of biodiversity attributable to a disease.



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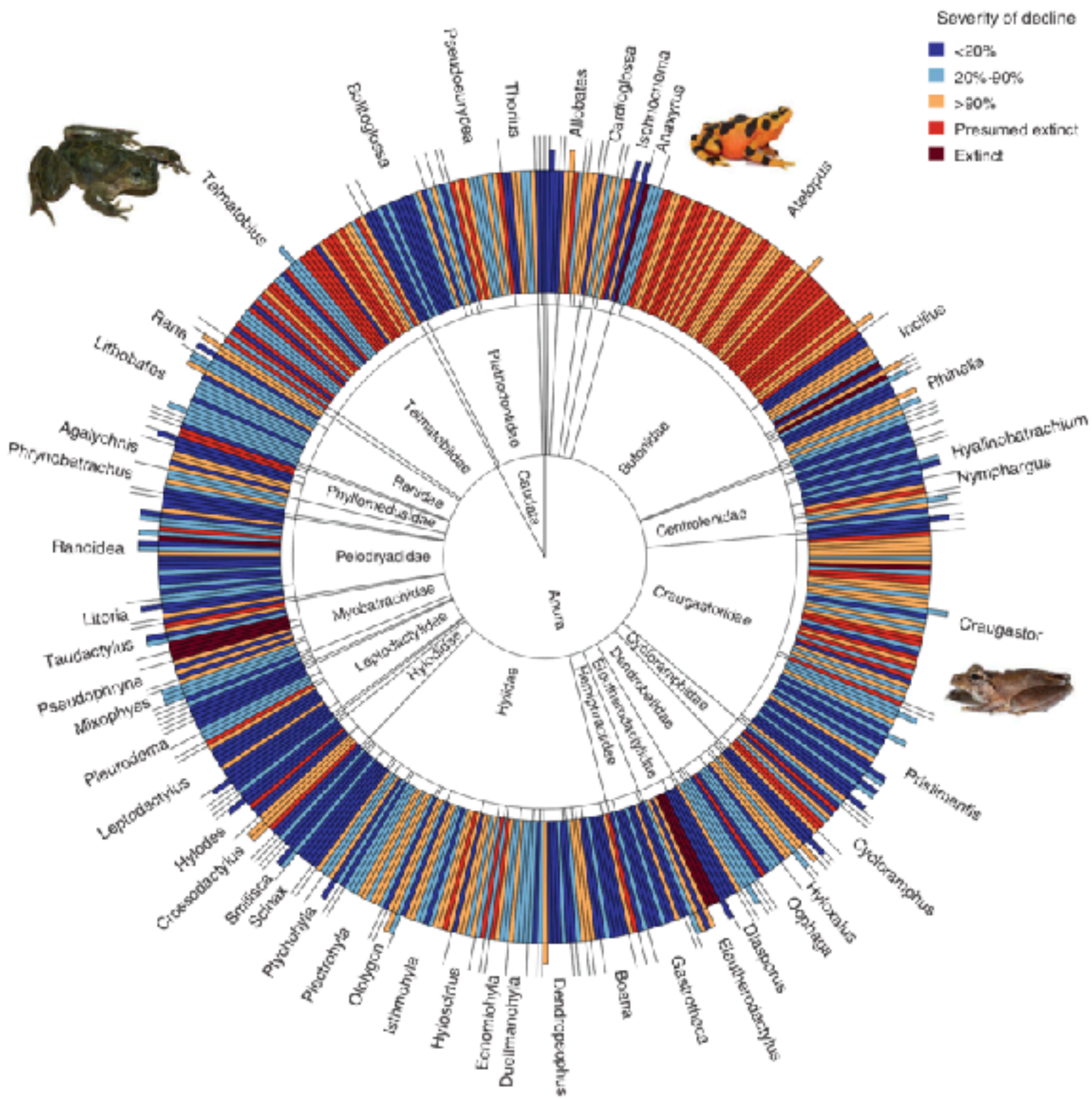
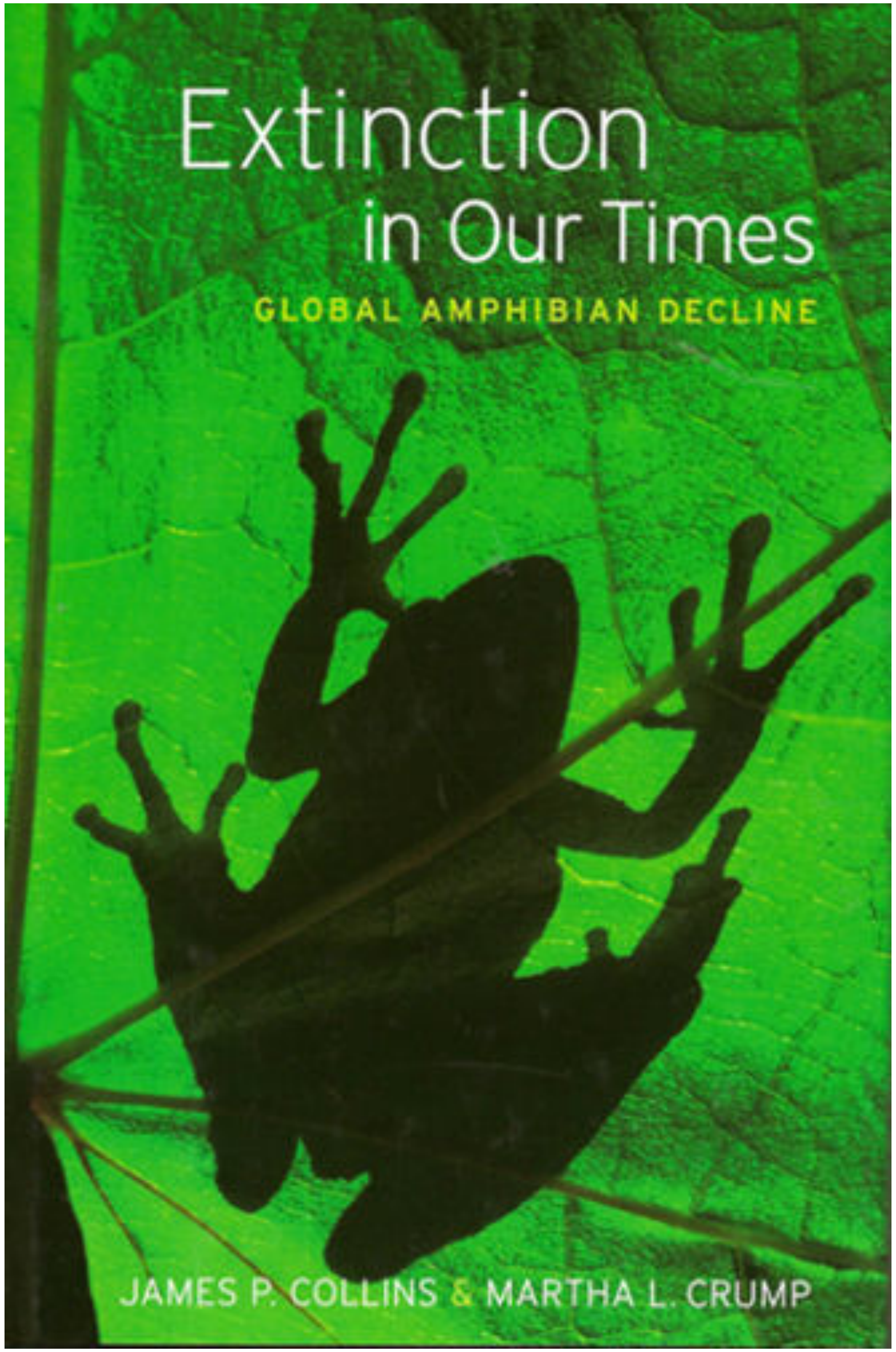


Fig. 2. Taxonomic distribution of chytridiomycosis-associated amphibian declines. Each bar represents one species, and color denotes the severity of its decline. Concentric circles indicate, from inner to outer, order (Caudata or Anura), family, and genus. Full names are given only for families and genera that include >5 and >2 species, respectively; details for all taxa are in table S4. Within each taxonomic level, sublevels are ordered alphabetically. Protruding bars indicate species for which there is evidence of recovery. [Photo credits (left to right): *Telmatobius bolivianus*, I.D.I.R.; *Atelopus zeteki*, B.G.; and *Craugastor crassidigitus*, B.G.]

https://youtu.be/O5aQlV4ajOw



BOOKS & ARTS

Amphibian mystery misread

A book blaming a fungus for the disappearance of amphibians from wild places wrongly downplays the role of environmental change, warn **Alan Pounds** and **Karen Masters.**

Extinction in Our Times: Global Amphibian Decline
by James P. Collins and Martha L. Crump
Oxford University Press: 2009. 304 pp. $29.95


FROGEVER.COM/L. A. COLOMA

Amphibians such as this Tapichalaca tree frog are seen as bellwethers of environmental deterioration.

Across the globe, frogs, toads and salamanders are disappearing, even in protected habitats. In *Extinction in Our Times*, James Collins and Martha Crump try to reassure us that these vanishing creatures are not warning of large-scale environmental deterioration like canaries in a coal mine, but are simply "telling us that they themselves are in trouble".

The cause of amphibian declines in wild places, the authors assert, is often a single agent: the chytrid fungus *Batrachochytrium dendrobatidis*, which can produce a fatal skin disease in these animals. According to this view, the mass die-offs result from movement of the fungus between continents and across landscapes. However, this 'lone killer' hypothesis wrongly downplays the role of environmental change.

Collins and Crump see evidence for a lone-killer chytrid in reports that a wave of amphibian extinction spread with the fungus from northwest to southeast across Central America, beginning in the early 1980s. But this wave is still being evaluated. Federico Bolaños at the University of Costa Rica in San Pedro and his co-workers propose that it stems from biased sampling and from a failure to take into account all of the region's amphibian die-offs. Moreover, this pattern does not rule out the importance of environmental change in these declines. Studies of such losses must test hypotheses that consider multiple factors.

The authors recognize the interplay of factors, but treat this as a complication that obscures a simple reality. If the chytrid plays a part in a die-off, they reason, then other forces are not needed. This is like attributing a car crash to excessive speed and deciding that other contributing issues, such as alcohol consumption, need not be considered. Such a deterministic view of causation, blind to probabilistic influences, has no place in ecology. Nor is the simplest explanation necessarily the best. Collins and Crump invoke Occam's 'law of parsimony', but were Occam here today, he might quiz them about their assumptions.

For one, is the chytrid fungus really deadly? The resulting disease is sometimes lethal but often it is not, for reasons that go beyond genetics and history — environment matters in disease outcomes. Laboratory studies can be misleading: often they put amphibians under stress or erase the microclimatic heterogeneity that helps the animals to fend off disease. Such experiments can also exclude microbes that might otherwise keep the chytrid in check. Add to the picture how little we know about this fungus in the wild, especially outside its amphibian hosts, and the assumption that it is inherently lethal to many species becomes indefensible.

> "Amphibians are telling us one thing: Earth's life-support system is in trouble."

The chytrid's impact may instead depend on environmental changes. Collins and Crump's selection of published work and quoted opinions downplays such links. Nevertheless, studies show that increasingly extreme climate and weather, together with land-use change, pollution, ultraviolet (UV) radiation and species invasions, are degrading amphibian health in many regions. These factors can interact and their effects may cross the boundaries of protected areas. Associations between climatic changes and reduced amphibian survival have been found in western and eastern North America, Central and South America, Australia, Spain, Italy and England.

Evidence showing that amphibians have undergone climatic stress before chytrid outbreaks have taken place challenges the idea of a lone-killer fungus, yet Collins and Crump fail to acknowledge this. Instead, they argue that such evidence casts doubt on the largely untested 'chytrid-thermal-optimum' hypothesis, which proposes that microhabitat temperatures in many places are shifting towards the chytrid's optimum, thereby favouring this pathogen's growth and hindering amphibian defences. However, the climatic-stress hypothesis is compatible with this model. And contrary to the authors' claims, neither hypothesis assumes that the fungus is native to regions that are experiencing die-offs. Climate may influence a disease regardless of the pathogen's place of origin, and the presence of exotic microbes makes global warming an even greater threat.

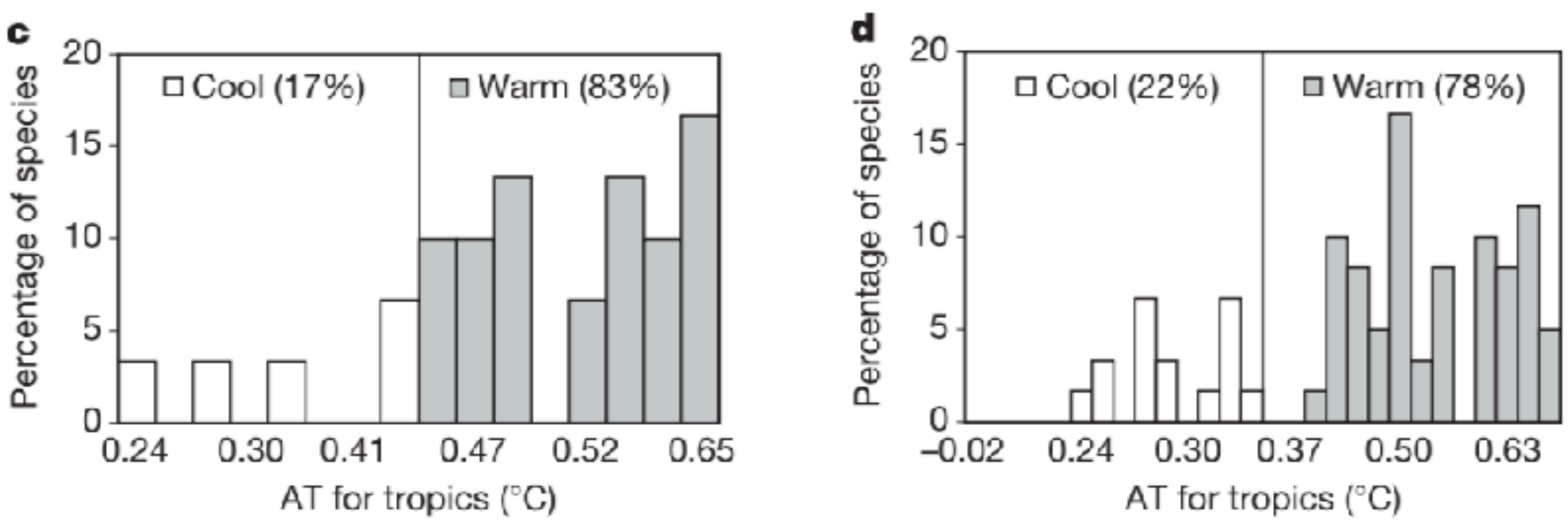
The authors' narrow thinking biases their 'road map' for future research on amphibian declines. Consider UV radiation, which harms amphibians and interacts with pathogens, chemical pollution and climate in ways that scientists are only beginning to study. For example, global warming alters patterns of cloud cover, reducing UV exposure in some places and increasing it in others. By oversimplifying the

Vol 439|12 January 2006|doi:10.1038/nature04246 nature

Widespread amphibian extinctions from epidemic disease driven by global warming

J. Alan Pounds[1], Martín R. Bustamante[2], Luis A. Coloma[2], Jamie A. Consuegra[3], Michael P. L. Fogden[1], Pru N. Foster[4†], Enrique La Marca[5], Karen L. Masters[6], Andrés Merino-Viteri[2], Robert Puschendorf[7], Santiago R. Ron[2,8], G. Arturo Sánchez-Azofeifa[9], Christopher J. Still[10] & Bruce E. Young[11]

As the Earth warms, many species are likely to disappear, often because of changing disease dynamics. Here we show that a recent mass extinction associated with pathogen outbreaks is tied to global warming. Seventeen years ago, in the mountains of Costa Rica, the Monteverde harlequin frog (*Atelopus* sp.) vanished along with the golden toad (*Bufo periglenes*). An estimated 67% of the 110 or so species of *Atelopus*, which are endemic to the American tropics, have met the same fate, and a pathogenic chytrid fungus (*Batrachochytrium dendrobatidis*) is implicated. Analysing the timing of losses in relation to changes in sea surface and air temperatures, we conclude with 'very high confidence' (>99%, following the Intergovernmental Panel on Climate Change, IPCC) that large-scale warming is a key factor in the disappearances. We propose that temperatures at many highland localities are shifting towards the growth optimum of *Batrachochytrium*, thus encouraging outbreaks. With climate change promoting infectious disease and eroding biodiversity, the urgency of reducing greenhouse-gas concentrations is now undeniable.



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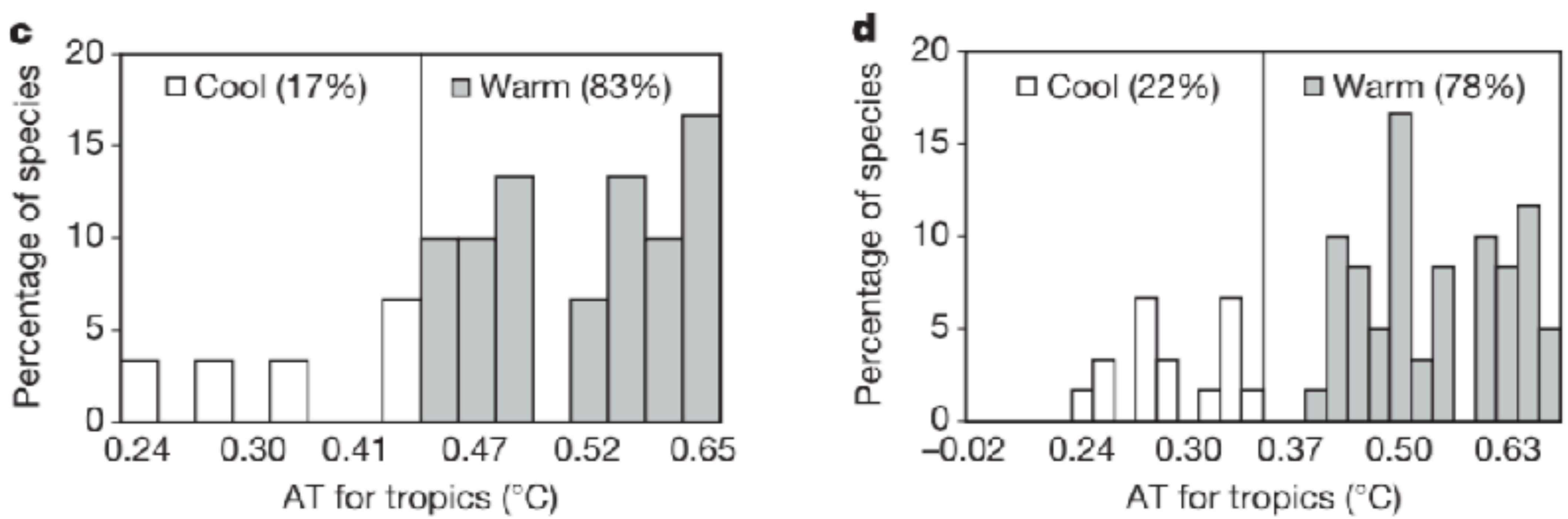
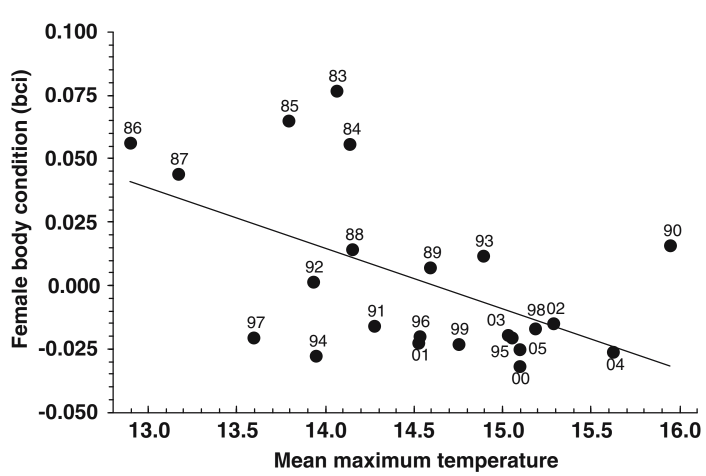


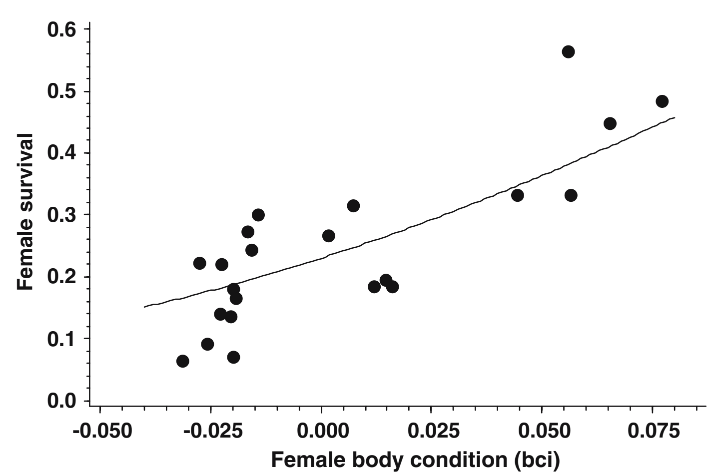
Oecologia (2007) 151:125–131
DOI 10.1007/s00442-006-0558-1

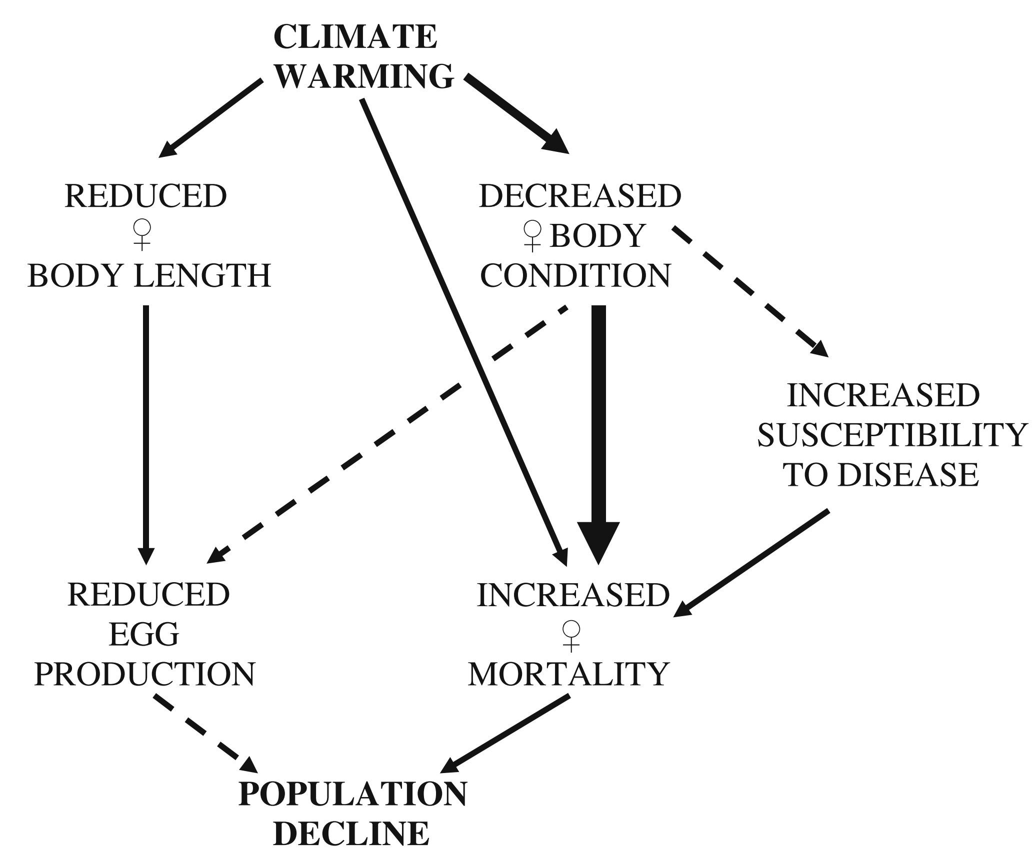
GLOBAL CHANGE AND CONSERVATION ECOLOGY

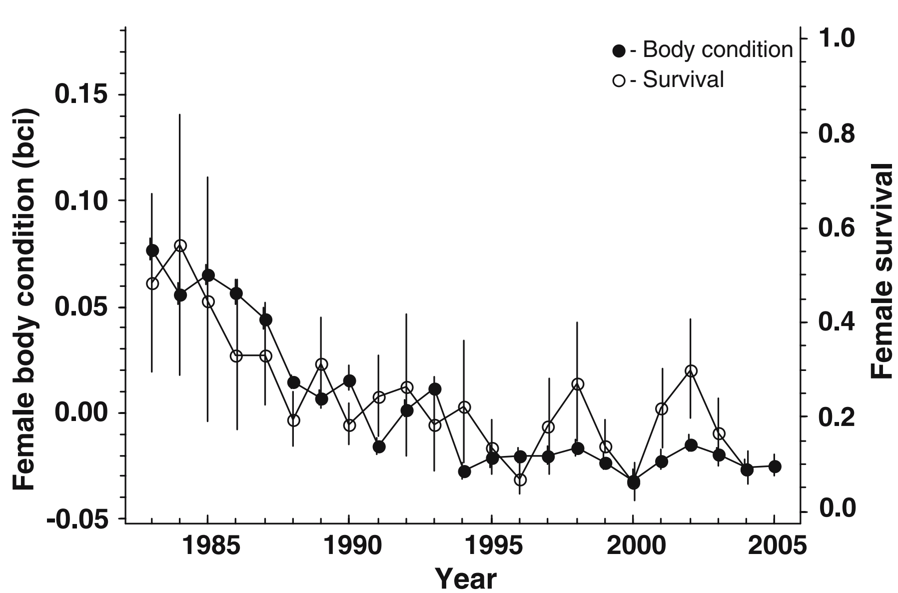
Linking global warming to amphibian declines through its effects on female body condition and survivorship

C. J. Reading









8352–8356 | PNAS | May 15, 2007 | vol. 104 | no. 20

Amphibian and reptile declines over 35 years at La Selva, Costa Rica

Steven M. Whitfield*†, Kristen E. Bell*†, Thomas Philippi*, Mahmood Sasa§, Federico Bolaños¶, Gerardo Chaves¶, Jay M. Savage‖, and Maureen A. Donnelly*

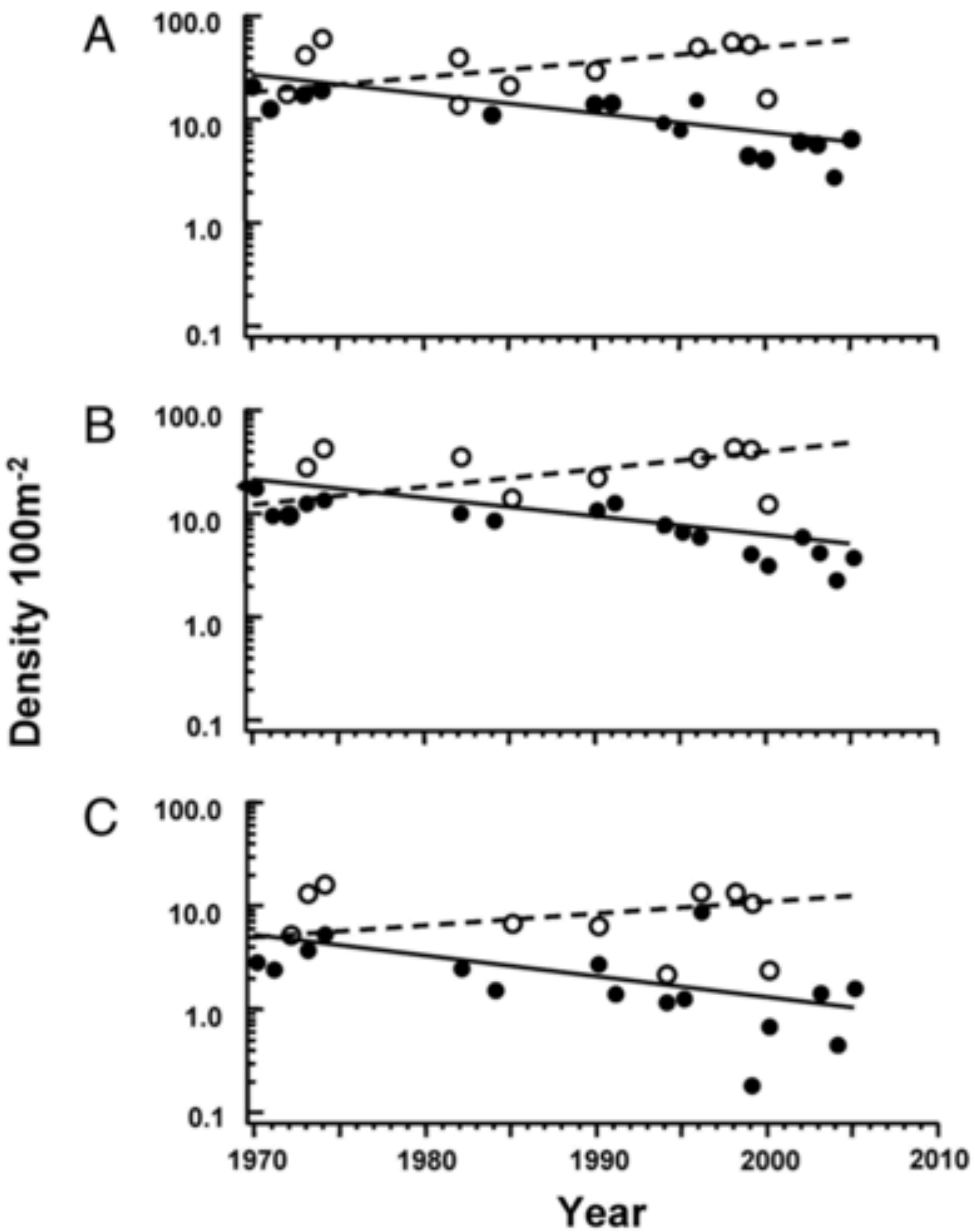


Fig. 1. Amphibian and reptile density over 35 years at La Selva Biological Station, Costa Rica. Each point indicates mean density for all quadrats in a given year. The closed symbols and solid line indicate data from primary forest. The open symbols and dashed line indicate data from abandoned cacao plantations. (*A*) Trends for all terrestrial amphibians and reptiles. (*B*) Trends for frogs only. (*C*) Trends for lizards only.

Amphibians stand at the forefront of a global biodiversity crisis. More than one-third of amphibian species are globally threatened, and over 120 species have likely suffered global extinction since 1980. Most alarmingly, many rapid declines and extinctions are occurring in pristine sites lacking obvious adverse effects of human activities. The causes of these "enigmatic" declines remain highly contested. Still, lack of long-term data on amphibian populations severely limits our understanding of the distribution of amphibian declines, and therefore the ultimate causes of these declines. Here, we identify a systematic community-wide decline in populations of terrestrial amphibians at La Selva Biological Station, a protected old-growth lowland rainforest in lower Central America. We use data collected over 35 years to show that population density of all species of terrestrial amphibians has declined by ≈75% since 1970, and we show identical trends for all species of common reptiles. The trends we identify are neither consistent with recent emergence of chytridiomycosis nor the climate-linked epidemic hypothesis, two leading putative causes of enigmatic amphibian declines. Instead, our data suggest that declines are due to climate-driven reductions in the quantity of standing leaf litter, a critical microhabitat for amphibians and reptiles in this assemblage. Our results raise further concerns about the global persistence of amphibian populations by identifying widespread declines in species and habitats that are not currently recognized as susceptible to such risks.

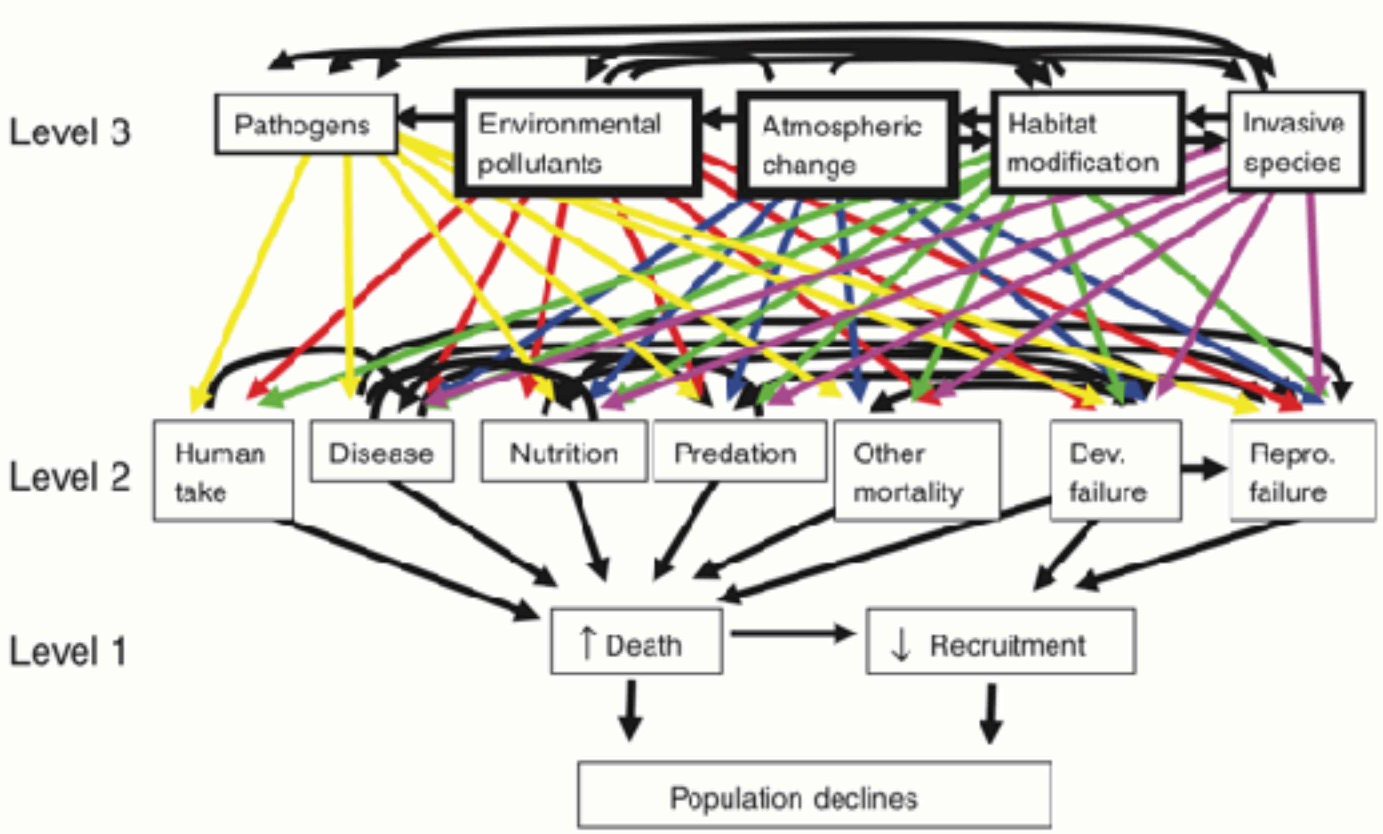


Fig. 1. Tiered approach showing interactions of the many factors that contribute to amphibian declines. Effects at any given level have no impact on higher levels, but interact with other factors on the same level and impact factors at lower levels. The five ultimate factors at Level 3 affect multiple factors at Level 2, which in turn interact with each other and ultimately contribute to amphibian declines due to death and decreased recruitment (Level 1). Line weights at Level 3 reflect rankings as described in the text ('Horizontal interactions at Level 3').

The Journal of Experimental Biology 213, 921-933

doi:10.1242/jeb.040865

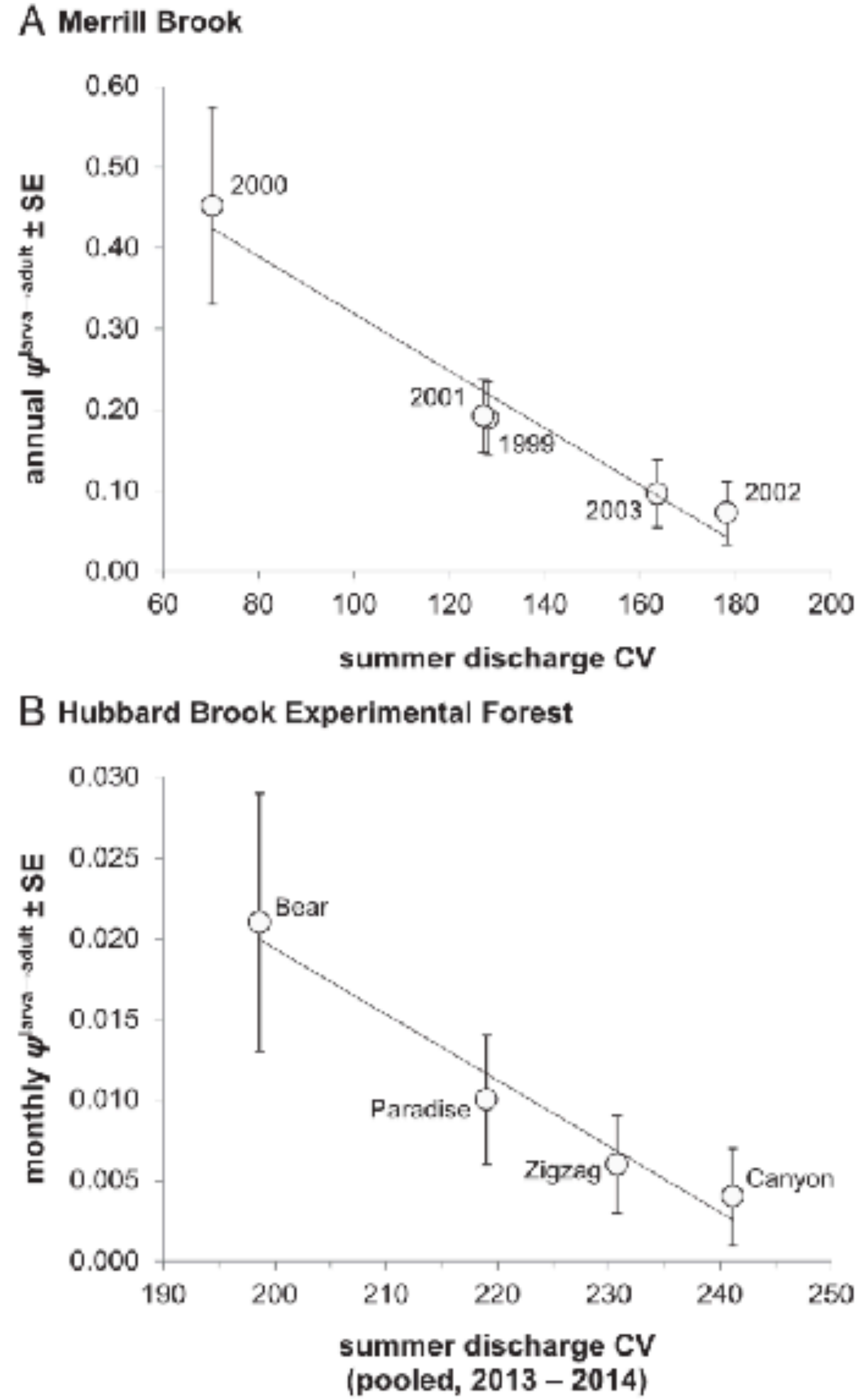
The cause of global amphibian declines: a developmental endocrinologist's perspective

T. B. Hayes*, P. Falso, S. Gallipeau and M. Stice

Greater than 70% of the world's amphibian species are in decline. We propose that there is probably not a single cause for global amphibian declines and present a three-tiered hierarchical approach that addresses interactions among and between ultimate and proximate factors that contribute to amphibian declines. There are two immediate (proximate) causes of amphibian declines: death and decreased recruitment (reproductive failure). Although much attention has focused on death, few studies have addressed factors that contribute to declines as a result of failed recruitment. Further, a great deal of attention has focused on the role of pathogens in inducing diseases that cause death, but we suggest that pathogen success is profoundly affected by four other ultimate factors: atmospheric change, environmental pollutants, habitat modification and invasive species. Environmental pollutants arise as likely important factors in amphibian declines because they have realized potential to affect recruitment. Further, many studies have documented immunosuppressive effects of pesticides, suggesting a role for environmental contaminants in increased pathogen virulence and disease rates. Increased attention to recruitment and ultimate factors that interact with pathogens is important in addressing this global crisis.

PNAS | September 24, 2019 | vol. 116 | no. 39 | 19563–19570

Changes in the amount, intensity, and timing of precipitation are increasing hydrologic variability in many regions, but we have little understanding of how these changes are affecting freshwater species. Stream-breeding amphibians—a diverse group in North America—may be particularly sensitive to hydrologic variability during aquatic larval and metamorphic stages. Here, we tested the prediction that hydrologic variability in streams decreases survival through metamorphosis in the salamander *Gyrinophilus porphyriticus*, reducing recruitment to the adult stage. Using a 20-y dataset from Merrill Brook, a stream in northern New Hampshire, we show that abundance of *G. porphyriticus* adults has declined by ~50% since 1999, but there has been no trend in larval abundance. We then tested whether hydrologic variability during summers influences survival through metamorphosis, using capture–mark–recapture data from Merrill Brook (1999 to 2004) and from 4 streams in the Hubbard Brook Experimental Forest (2012 to 2014), also in New Hampshire. At both sites, survival through metamorphosis declined with increasing variability of stream discharge. These results suggest that hydrologic variability reduces the demographic resilience and adaptive capacity of *G. porphyriticus* populations by decreasing recruitment of breeding adults. They also provide insight on how increasing hydrologic variability is affecting freshwater species, and on the broader effects of environmental variability on species with vulnerable metamorphic stages.



Hydrologic variability contributes to reduced survival through metamorphosis in a stream salamander

Winsor H. Lowe[a,1], Leah K. Swartz[a], Brett R. Addis[a], and Gene E. Likens[b,c,1]

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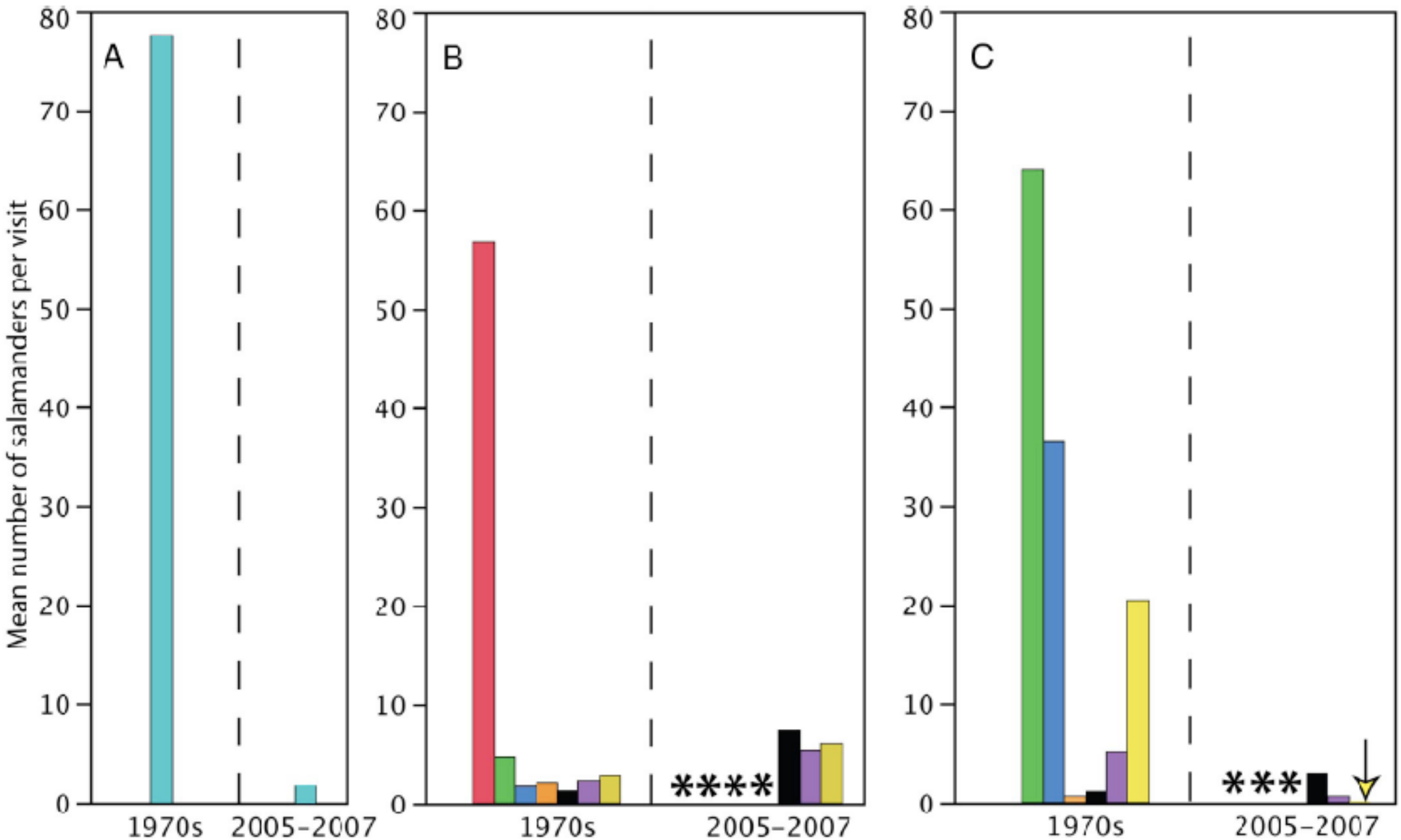
Dramatic declines in neotropical salamander populations are an important part of the global amphibian crisis

Sean M. Rovito[a], Gabriela Parra-Olea[a,b], Carlos R. Vásquez-Almazán[c], Theodore J. Papenfuss[a], and David B. Wake[a,1]



WILDLIFE DISEASE

Recent introduction of a chytrid fungus endangers Western Palearctic salamanders

A. Martel,[1*] M. Blooi,[1,2†] C. Adriaensen,[1†] P. Van Rooij,[1†] W. Beukema,[3] M. C. Fisher,[4] R. A. Farrer,[5] B. R. Schmidt,[6,7] U. Tobler,[6,7] K. Goka,[8] K. R. Lips,[9] C. Muletz,[9] K. R. Zamudio,[10] J. Bosch,[11] S. Lötters,[12] E. Wombwell,[13,14] T. W. J. Garner,[14] A. A. Cunningham,[14] A. Spitzen-van der Sluijs,[15] S. Salvidio,[16] R. Ducatelle,[1] K. Nishikawa,[17] T. T. Nguyen,[18] J. E. Kolby,[19] I. Van Bocxlaer,[20] F. Bossuyt,[20] F. Pasmans[1]

Emerging infectious diseases are reducing biodiversity on a global scale. Recently, the emergence of the chytrid fungus *Batrachochytrium salamandrivorans* resulted in rapid declines in populations of European fire salamanders. Here, we screened more than 5000 amphibians from across four continents and combined experimental assessment of pathogenicity with phylogenetic methods to estimate the threat that this infection poses to amphibian diversity. Results show that *B. salamandrivorans* is restricted to, but highly pathogenic for, salamanders and newts (Urodela). The pathogen likely originated and remained in coexistence with a clade of salamander hosts for millions of years in Asia. As a result of globalization and lack of biosecurity, it has recently been introduced into naïve European amphibian populations, where it is currently causing biodiversity loss.

Additive threats from pathogens, climate and land-use change for global amphibian diversity

Christian Hof[1,2], Miguel B. Araújo[1,2,3], Walter Jetz[4] & Carsten Rahbek[1]

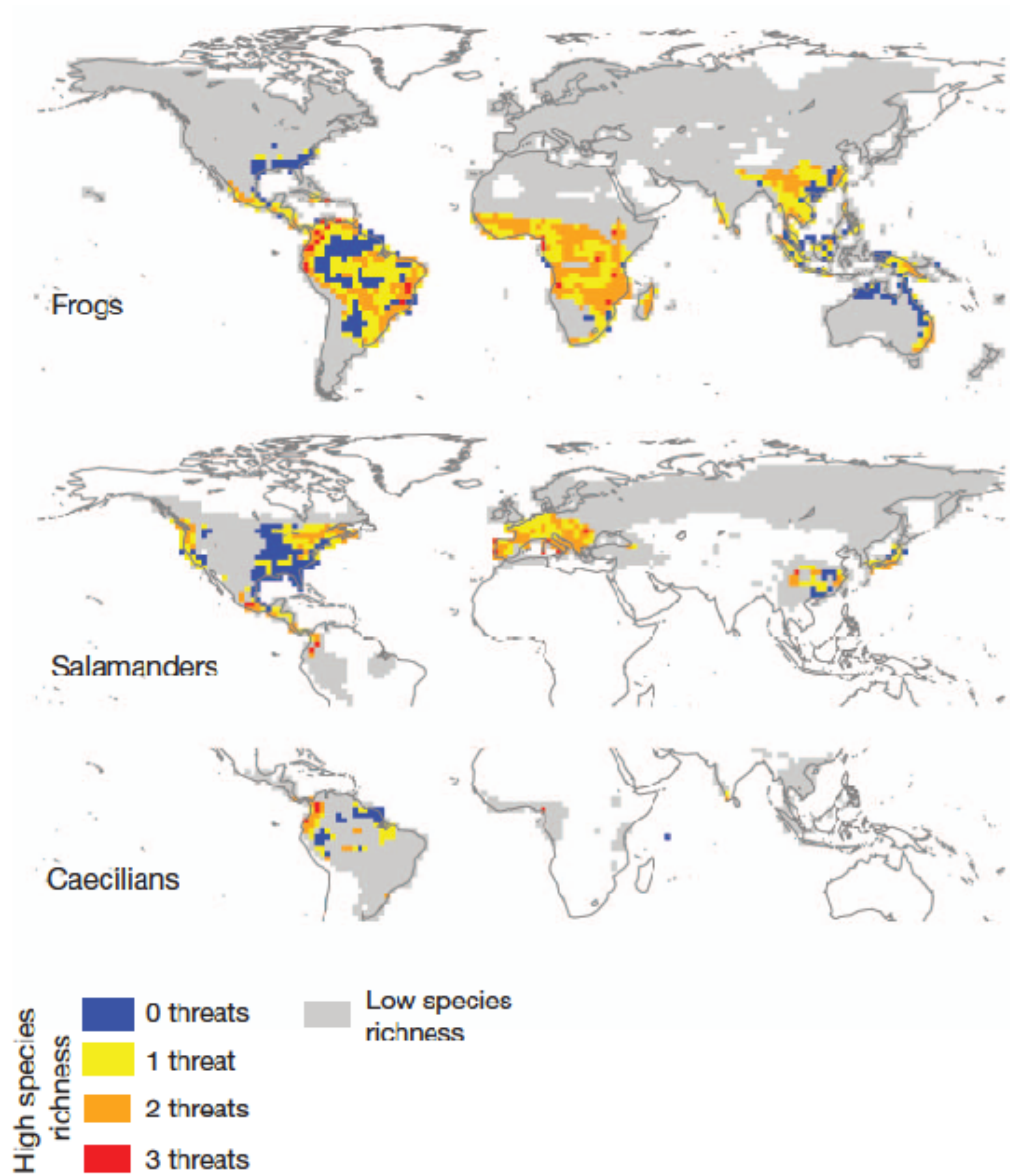


Figure 4 | Spatial overlap between areas with the highest amphibian species richness and the main factors threatening global amphibian diversity, projected for 2080. Areas with the highest species richness are defined as the 25% of all grid cells with the highest number of species. Areas where high levels of species richness coincide with high intensity of 1–3 of the main factors threatening amphibian diversity are coloured in yellow, orange and red, respectively (blue: no coincidence of high richness and high threat intensity). For definition of 25% areas of high threat intensity and further details see Figs 1 and 3.

El Método Científico

Observaciones de
la Naturaleza, búsqueda de
Patrones Repetidos.

Planteamiento de Preguntas
de Investigación

Planteamiento de
Hipótesis

Puesta a prueba de Hipótesis
(Importancia de Falsabilidad -
Predicciones) mediante
Experimentos u Observaciones

Planteamiento de nuevas
hipótesis y pruebas adicionales
a hipótesis previamente
apoyadas

Construcción de teorías con
base en conjunto de hipótesis
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The impact of amphibian disease on tropical snake communities p. 814

REVIEWS REVIEWS REVIEWS

The effects of amphibian population declines on the structure and function of Neotropical stream ecosystems

Matt R Whiles[1*], Karen R Lips[1], Cathy M Pringle[2], Susan S Kilham[3], Rebecca J Bixby[2], Roberto Brenes[1], Scott Connelly[2], Jose Checo Colon-Gaud[1], Meshagae Hunte-Brown[3], Alexander D Huryn[4], Chad Montgomery[1], and Scot Peterson[1]

Amphibians can be important consumers in both aquatic and terrestrial habitats and may represent an important energetic link between the two, particularly in the tropics, where amphibian species richness and abundance are high. In the past 20 years, amphibian populations have declined dramatically around the world; numbers have decreased catastrophically in protected upland sites throughout the neotropics, usually resulting in the disappearance of over 75% of amphibians at a given site, particularly those species that breed in streams. Most studies of amphibian declines have focused on identifying causes and documenting changes in adult abundance, rather than on their ecological consequences. Here, we review evidence for the potential ecological effects of catastrophic amphibian declines, focusing on neotropical highland streams, where impacts will likely be greatest. Evidence to date suggests that amphibian declines will have large-scale and lasting ecosystem-level effects, including changes in algal community structure and primary production, altered organic matter dynamics, changes in other consumers such as aquatic insects and riparian predators, and reduced energy transfers between streams and riparian habitats. Furthermore, because of habitat and functional differences between larvae and adults in most amphibians, the loss of a single species is akin to losing two species.

Front Ecol Environ 2006; 4(1): 27–34

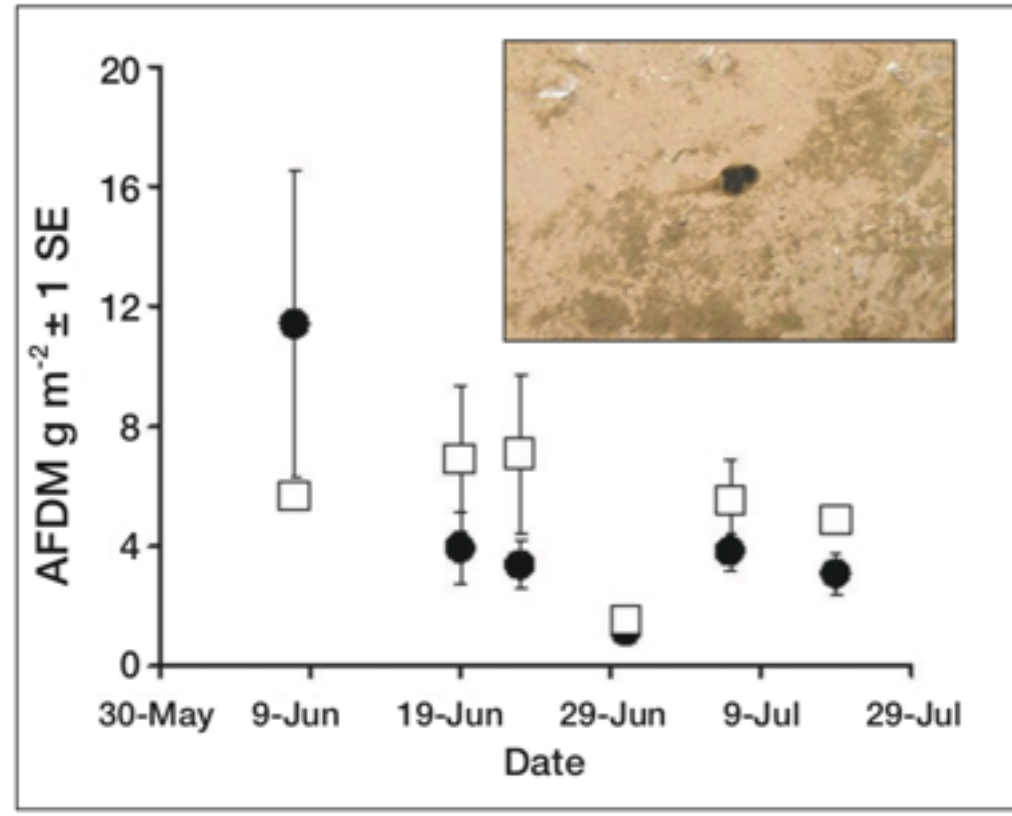

Figure 4. An experimental tile in a Panamanian highland stream with a Rana warszewitschii *tadpole grazing the surface, and a plot of total organic material (ash-free dry mass = AFDM) through time on tadpole grazed (black circles) and ungrazed (squares) tiles during a 52-day experiment that commenced on 24 May 2001. Differences between grazed and exclusion tiles are significant (repeated measures ANOVA:* $F_{1,8} = 10.3$, $P = 0.013$)*. Low values on July 1 were the result of a scouring flood. Data are from Ranvestal* et al. *(2004).*

Freshwater Biology

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Long-term changes in structure and function of a tropical headwater stream following a disease-driven amphibian decline

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SUMMARY

1. Taxonomic and functional diversity in freshwater habitats is rapidly declining, but we know little about how such declines will ultimately affect ecosystems. Neotropical streams are currently experiencing massive losses of amphibians, with many losses linked to the chytrid fungus, *Batrachochytrium dendrobatidis* (*Bd*).
2. We examined the ecological consequences of the disease-driven loss of amphibians from a Panamanian stream. We quantified basal resources, macroinvertebrates, N uptake and fluxes through food-web components and ecosystem metabolism in 2012 and 2014 and compared them to pre-decline (2006) and 2 year post-decline (2008) values from a prior study.
3. Epilithon biomass accrued after the decline, more than doubling between 2006 and 2012, but then decreased fivefold from 2012 to 2014. In contrast, suspended particulate organic matter (SPOM) concentrations declined continuously after the amphibian decline through 2014.
4. Biomass of filter-feeding, grazing and shredding macroinvertebrates decreased from 2006 to 2014, while collector–gatherers increased during the same time period. Macroinvertebrate taxa richness decreased from 2006 (52 taxa) to 2012 (30 taxa), with a subsequent increase to 51 taxa in 2014.
5. Community respiration, which initially decreased after the amphibian decline, remained lower than pre-decline in 2012 but was greater than pre-decline values in 2014. Gross primary production remained low and similar among years, while NH_4^+ uptake length in both 2012 and 2014 was longer than pre-decline. Nitrogen flux to epilithon increased after the decline and continued to do so through 2014, but N fluxes to fine particulate organic matter and SPOM decreased and remained low.
6. Our findings underscore the importance of studying the ecological consequences of declining biodiversity in natural systems over relatively long time periods. There was no evidence of functional

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BIODIVERSITY

Confronting Amphibian Declines and Extinctions

Stopping further global losses of amphibian populations and species requires an unprecedented conservation response.

Joseph R. Mendelson III,* Karen R. Lips, Ronald W. Gagliardo, George B. Rabb, James P. Collins, James E. Diffendorfer, Peter Daszak, Roberto Ibáñez D., Kevin C. Zippel, Dwight P. Lawson, Kevin M. Wright, Simon N. Stuart, Claude Gascon, Hélio R. da Silva, Patricia A. Burrowes, Rafael L. Joglar, Enrique La Marca, Stefan Lötters, Louis H. du Preez, Ché Weldon, Alex Hyatt, José Vicente Rodriguez-Mahecha, Susan Hunt, Helen Robertson, Brad Lock, Christopher J. Raxworthy, Darrel R. Frost, Robert C. Lacy, Ross A. Alford, Jonathan A. Campbell, Gabriela Parra-Olea, Federico Bolaños, José Joaquin Calvo Domingo, Tim Halliday, James B. Murphy, Marvalee H. Wake, Luis A. Coloma, Sergius L. Kuzmin, Mark Stanley Price, Kim M. Howell, Michael Lau, Rohan Pethiyagoda, Michelle Boone, Michael J. Lannoo, Andrew R. Blaustein, Andy Dobson, Richard A. Griffiths, Martha L. Crump, David B. Wake, Edmund D. Brodie Jr.

Amphibian declines and extinctions are global and rapid: 32.5% of 5743 described species are threatened, with at least 9, and perhaps 122, becoming extinct since 1980 (*1*). Species have disappeared across the entire taxonomic group and in nearly all regions of the planet. These figures are probably underestimates as entire clades of species are threatened. For example, of the 113 species of harlequin toads (genus *Atelopus*), 30 are possibly extinct, and only 10 have stable populations (*2*). Nearly a quarter of known amphibian species were deemed "data-deficient" with respect to conservation status in the recent global assessment (*1*). Losing biodiversity at this taxonomic scale impacts ecosystem goods and services [e.g. (*3*, *4*)]. As amphibian species disappear, we also lose their untapped potential for advances in biomedicine and biotechnology in general (*5*).

Losses result from familiar threats (land-use change, commercial overexploitation, and exotic species) and from the emerging infectious disease chytridiomycosis, caused by the fungus *Batrachochytrium dendrobatidis* (*Bd*). Predictions are that within 4 to 6 months of *Bd* arrival at a site where it has not previously been present, ~50% of amphibian species and ~80% of individuals may disappear (*6*). Global climate change may be encouraging local conditions ideal for *Bd*'s persistence and/or spread (*7*), commercial trade of wildlife may also contribute (*8*), and pollution may increase susceptibility of species to pathogens (*9*, *10*). Traditional programs and current laws and policies alone are insufficient to address global threats that cross boundaries of reserves and nations.

Global leaders in research, conservation, and policy agreed on an Amphibian Conservation Action Plan (ACAP) and Declaration in 2005 (see Supporting Online Material). A new, international body was recommended to coordinate and facilitate conservation programs for amphibians and to garner and administer funds. Thus, we call for formation of The Amphibian Survival Alliance (ASA)—led by an international secretariat of the Amphibian Specialist Group of the Species Survival Commission of IUCN (World Conservation Union). An initial 5-year budget requires at least U.S.$400 million.

Conservation activities should remain in affected countries where possible, with coordination and support through ASA, to engage and employ local scientists. A special initiative would be regional centers for disease research and captive breeding. Centers would exist within government agencies, zoos, or universities and would be staffed by local scientists, wildlife managers, and conservationists. ASA would create and support readily available databases from the global network of centers, as well as research and training in countries with few amphibian experts. Such dedicated research capacity in affected regions is required for this global crisis, as well as to keep amphibian research and conservation at the forefront of policy-making.

Chytridiomycosis deserves especial attention because of its massive impacts on amphibian diversity (*11*, *12*). Natural-agent control of *Bd* or selecting for resistance in amphibians may be possible (*13*, *14*). In the meantime, we must implement coordinated in situ actions (e.g., surveys, monitoring, and habitat protection) and ex situ husbandry programs (e.g., survival-assurance and research colonies) at unprecedented scales. Amphibian salvage operations are possible at an ecosystem level (*15*). Ex situ programs may be the only option to avoid extinction for many species [e.g., Kihansi Spray Toad and Panamanian Golden Frog (*16*, *17*)], while research progresses on disease control, treatment, and evolution of resistance (*18*).

The ASA model builds on programs such as the Turtle Survival Alliance (*19*), Global Environment Facility (GEF) Coral Program (*20*), and an Australian threat abatement plan (*21*). Success will depend on a paradigm shift in the scale of the coordinated response, with stakeholders from the academic, conservation, zoo, ethics, policy, global change, private sector, and international biodiversity convention communities uniting for one goal. Support from individuals, governments, foundations, and the wider conservation community is essential.

The Panamanian Golden Frog, *Atelopus zeteki*, is nearly extinct in the wild as a combined result of habitat change, illegal collecting, and fungal disease; the species is currently secure in several ex situ programs.

CREDIT: RON HOLT

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Supporting Online Material
www.sciencemag.org/cgi/content/full/313/5783/48/DC1

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Declining Amphibian Populations: What Is the Next Step?

MEGAN DEBRANSKI KELHART

Declines in global amphibian populations have been in news headlines around the world since they were acknowledged in 1989 at the First World Congress of Herpetology. Eager to explain the causes, biologists have established ambitious research, monitoring, and inventory programs. But what is being done at the policy level to stem current declines and prevent future losses?

According to biologist Edmund Brodie, a professor at Utah State University, very little is being done. In the *Salt Lake City Tribune* this past summer, Brodie argued that "scientists and environment managers around the world are well aware of the crisis facing amphibians, and it is time to quit talking and get on with the activity of trying to save those species we can still save."

In the United States, no federal government policy specifically targets amphibian population declines. However, Congress has periodically provided funding for increased monitoring and research. For instance, in fiscal year 2002, Congress appropriated modest funding to agencies in the Department of the Interior for programs to address vulnerability issues, such as the Amphibian Research and Monitoring Initiative undertaken by the US Geological Survey (USGS). The funding helped expand the geographic scope of amphibian monitoring efforts and increased the number of sample sites.

Representative Jack Kingston (R–GA), then vice chairman of the House interior appropriations subcommittee, wrote in an April 2002 feature story that amphibian population declines are "a serious environmental problem that could have far-reaching effects on our own health. Amphibians are disappearing and mutating for reasons unknown and, ultimately, there could be a risk for human health.... When you have major species disappearing or becoming deformed for unknown reasons, we all need to be concerned about it."

Kingston's concern often appears stronger than that of other policymakers, however. Since fiscal year 2002, the USGS has seen few increases in its funding for amphibian research, leaving conservation of amphibian populations to an often slow Endangered Species Act, which still awaits congressional reauthorization.

Despite the apparent lack of a concerted federal response, several federal agencies and nongovernmental organizations are working to assess amphibian population trends throughout the United States. The USGS has established several amphibian research initiatives, including the North American Amphibian Monitoring Program (NAAMP), the Amphibian Research and Monitoring Initiative, the Taskforce on Amphibian Declines and Deformities, and Frogwatch USA. Linda Weir, NAAMP coordinator at Patuxent Wildlife Research Center in Maryland, says "NAAMP's purpose is to provide population data and population trend analyses for calling amphibians for use by conservation managers, scientists, and the general public."

Frogwatch USA, a long-term amphibian study, was developed by the USGS Patuxent Wildlife Research Center and is currently managed by the National Wildlife Federation (NWF) in partnership with the USGS. According to Frogwatch USA associate volunteer coordinator Courtney Herrell, "Frogwatch USA and NWF strive to spread awareness of the issue of amphibian decline. We feel that providing citizens with knowledge of this issue is the first step to combating it."

But what is the second step? Research scientists have been reporting for decades that amphibian populations are declining, some to extinction. Yet mission-driven federal agencies continue to see their budgets cut, forcing program managers to make tough decisions about the allocation of limited resources.

In a July 2006 press release, leading biologists called for "a new Amphibian Survival Alliance, a $400-million initiative to help reduce and prevent amphibian declines and extinctions—an ecological crisis of growing proportion that continues to worsen." "Confronting Amphibian Declines and Extinctions," a policy forum article published a day later in the journal *Science,* echoed this call to action and encouraged a more structured approach to amphibian population conservation.

There is good reason to protect these species. Amphibians are often outstanding biological indicators of environmental quality. Sensitive to changes in water quality, temperature, pollution, and other phenomena, amphibians frequently alert scientists to changing environmental conditions long before those changes affect humans. The question before policymakers is not whether environmental conditions are changing—the declines in amphibian populations are but one indicator that they are. The question now is whether there is a will to protect these species and the habitat they require for survival.

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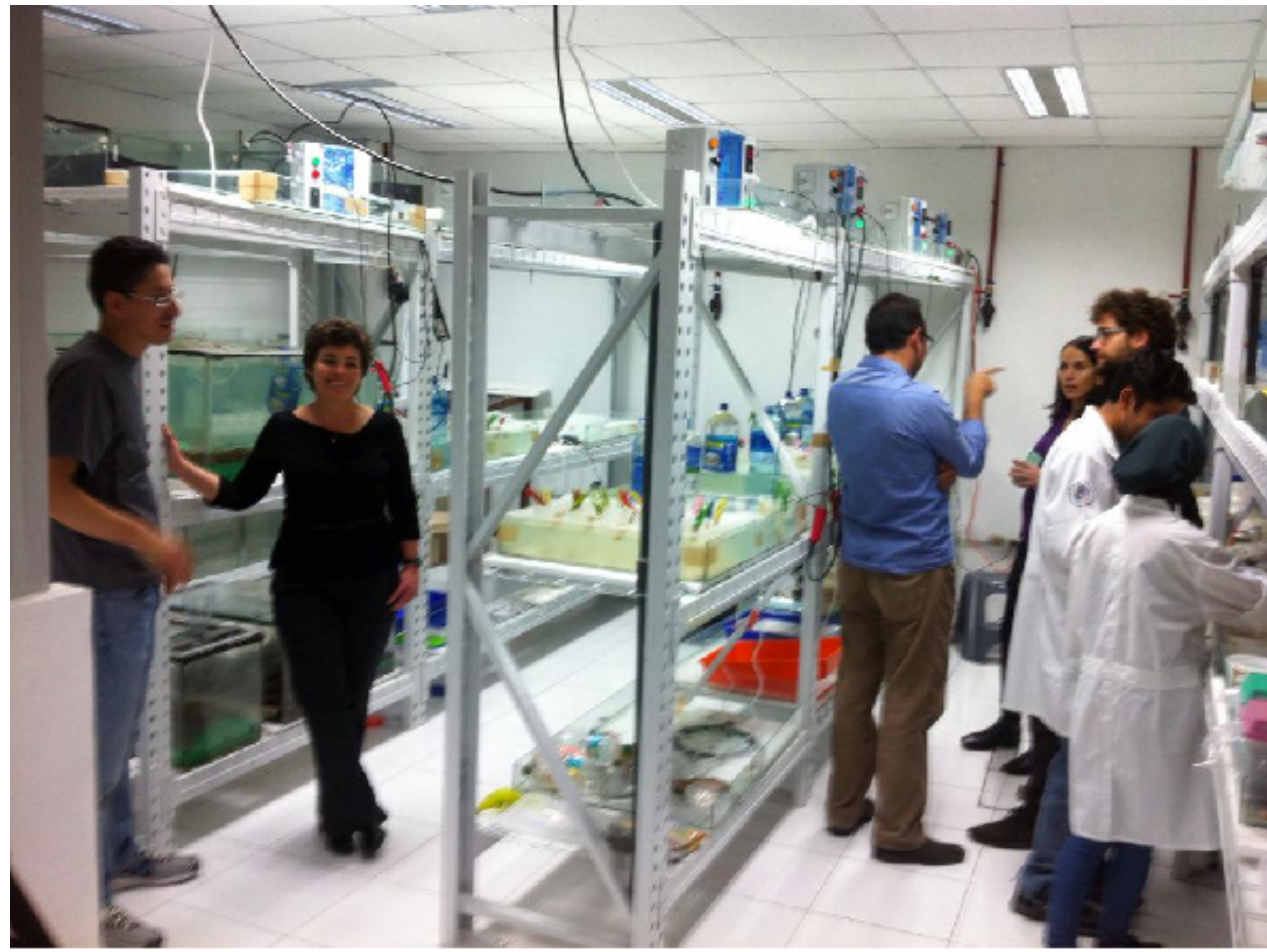

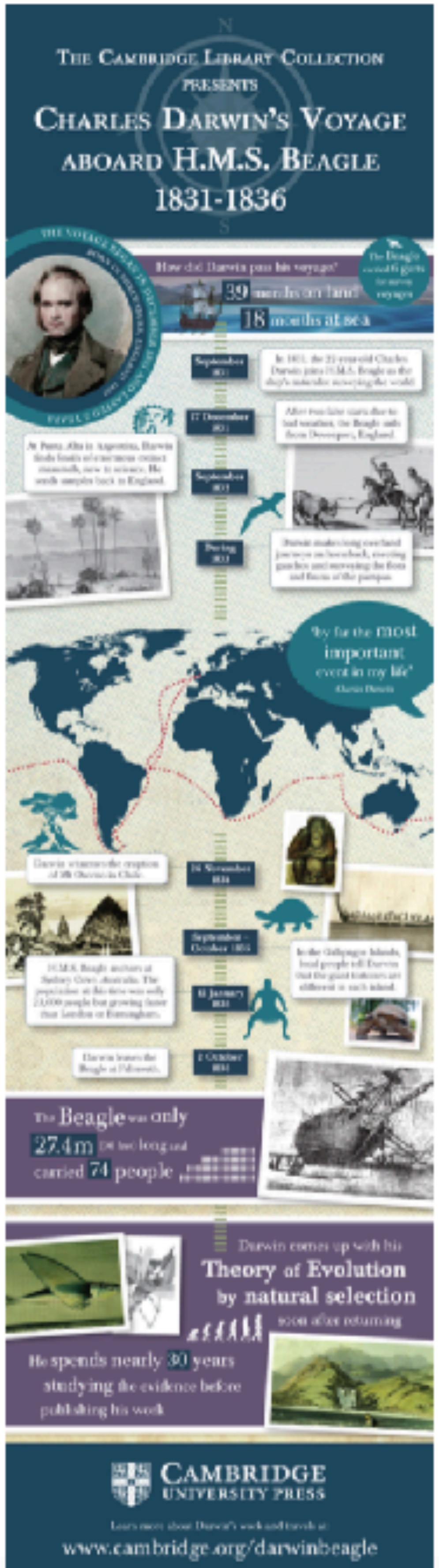
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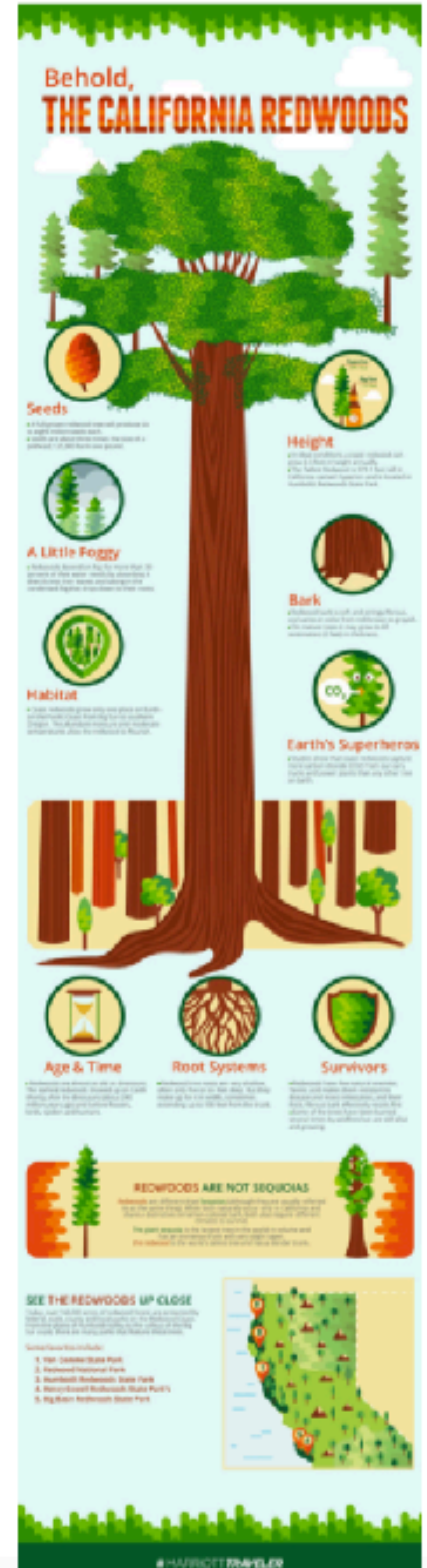
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