Understanding the role of climate change and land use modifications in facilitating pathogen invasions and declines of ectotherms

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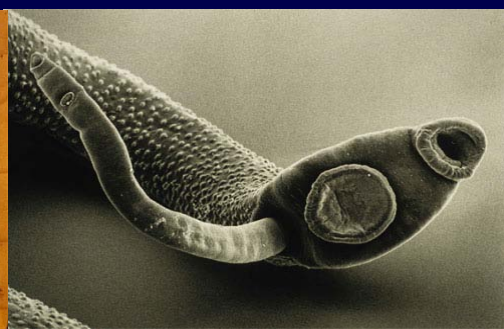
Emerging Parasites = Invasive Species

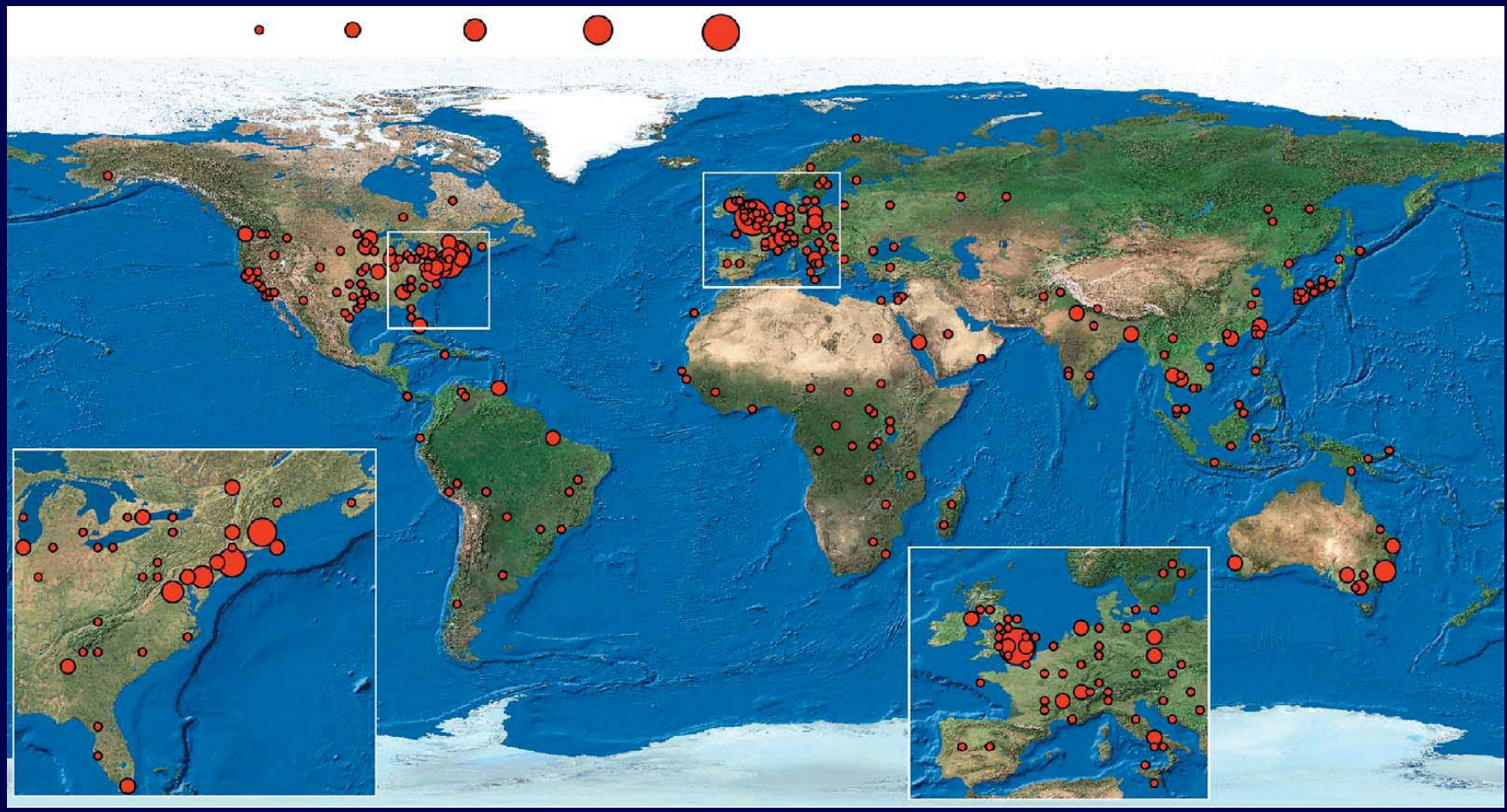
- Parasites are often ignored in invasion research because disease ecologists commonly use the terms “emerging disease” or “emerging parasite” in reference to invasive parasitic species
- Like other invasive species, invasive parasites are crippling our economy, decimating our biodiversity, and becoming more problematic
- Human & wildlife diseases are emerging at unprecedented rates
- Causes of these invasions/emergences are often unknown



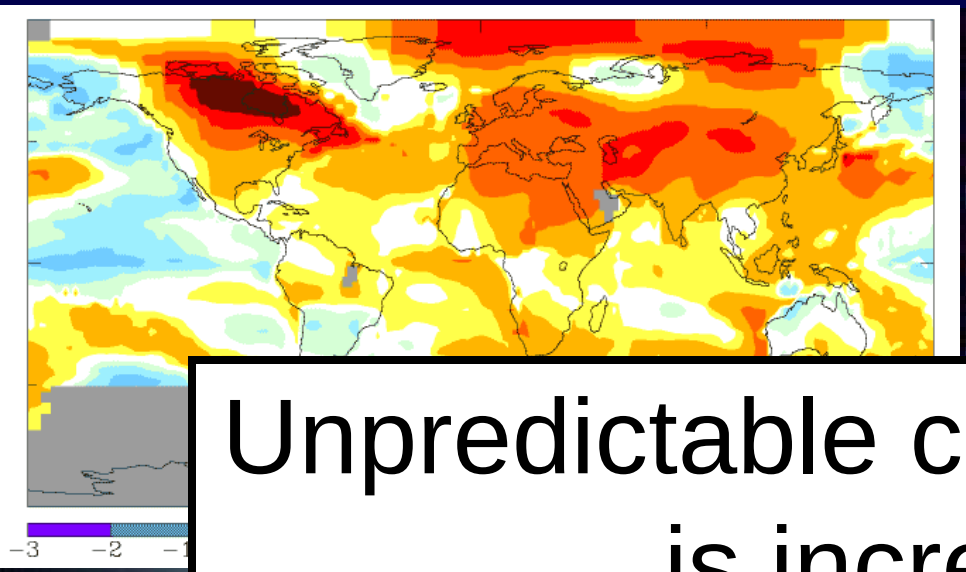
Emerging Infectious Diseases:

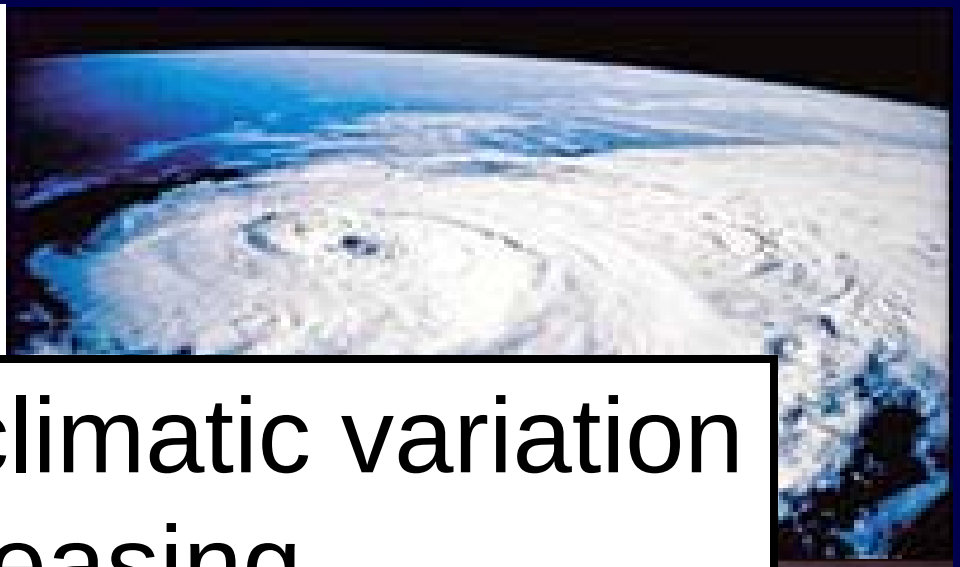
Not just a third-world problem!



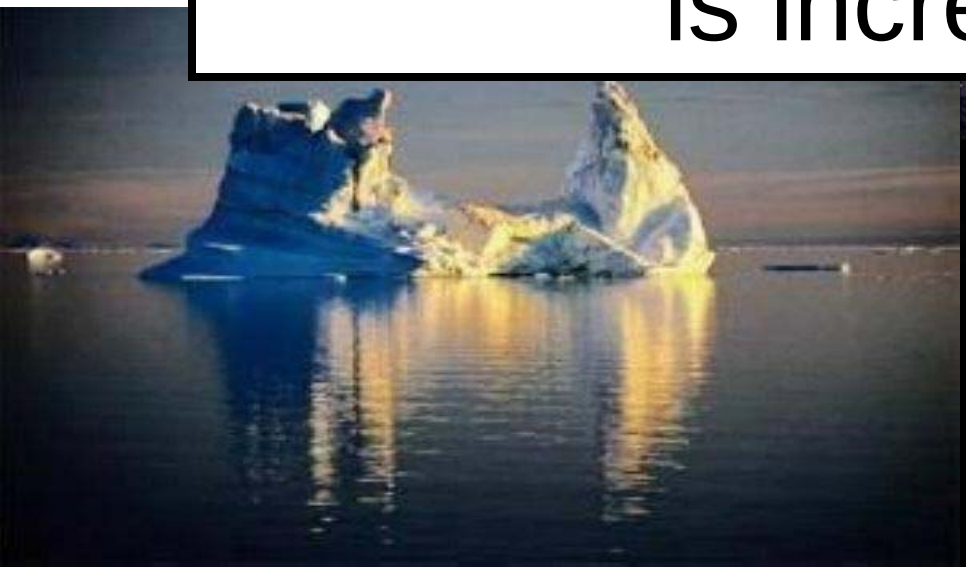
Jones et al 2008-- Nature

Climate Change





Unpredictable climatic variation is increasing



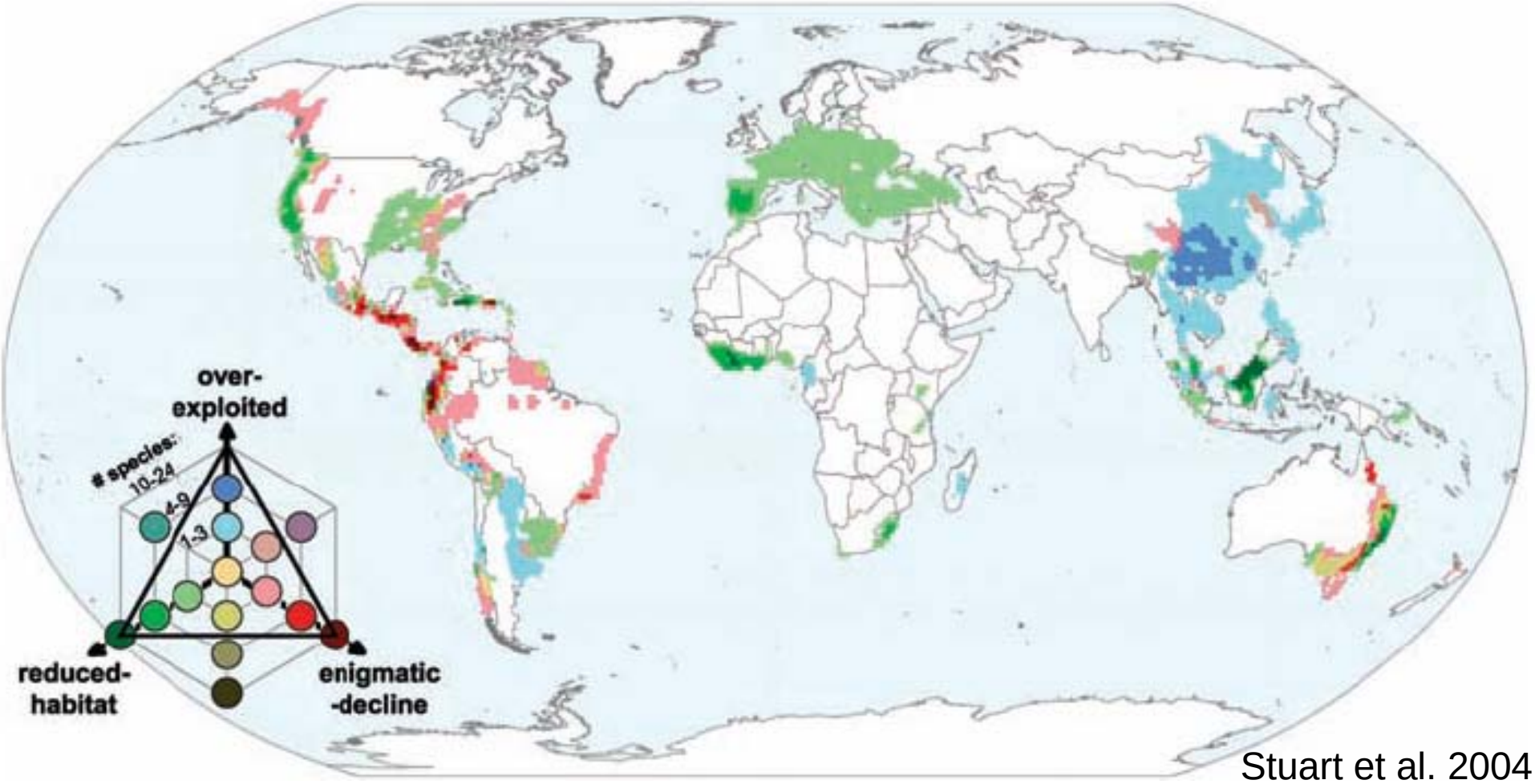
Climate Variability Hypothesis

- Hypothesis: unpredictable temperature shifts, which are increasing with global climate change, benefit pathogens more than hosts.
  - faster metabolisms of parasites should allow them to acclimate more quickly to unpredictable temperature shifts, especially for ectothermic hosts
  - parasites have fewer cells and processes to adjust and generally withstand greater temperature extremes than hosts (Portner 2002)
  - owing to their shorter generation times, parasites should evolve more quickly than hosts to changes in climate

Climate Variability Hypothesis

- The categorically faster metabolisms, smaller size, and greater reproductive capabilities of parasites than hosts provides a general hypothesis for how global climate change will affect disease risk– **unpredictable climate variability should increase invasive parasites and disease.**

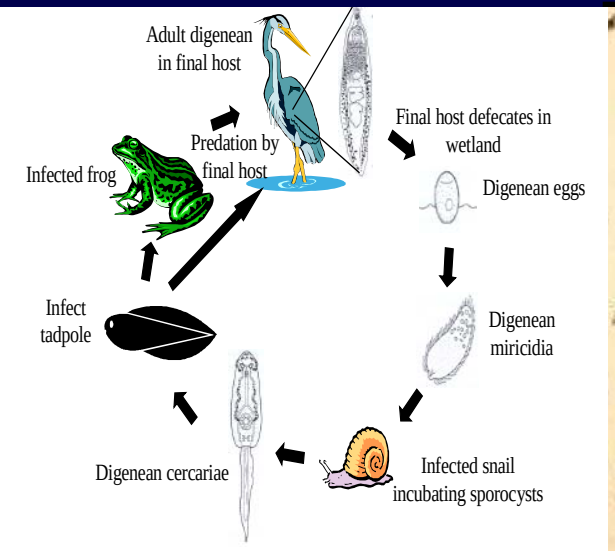
Amphibians: The Most Threatened of All Vertebrate Taxa

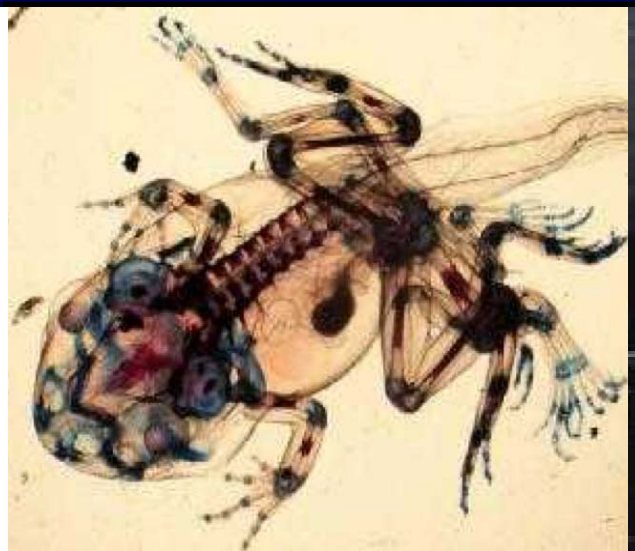


Stuart et al. 2004

Emerging Amphibian Diseases of Amphibians

- Diseases more common now than they have been historically
  - Chytridiomycosis
  - Larval trematode infections

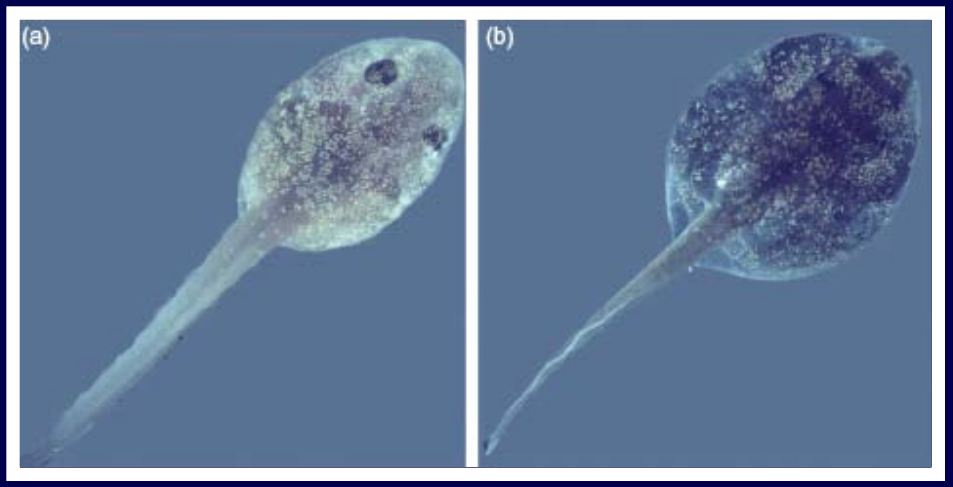




Chytridiomycosis

- Caused by the fungus *Batrachochytrium dendrobatidis* (hereafter referred to as *Bd*)
- Skin disease that likely causes cardiac arrest
- Implicated in hundreds of amphibian extinctions in the last four decades
- Possibly the most deadly invasive species on the planet behind humans

Larval Trematodes:
deformities, kidney damage, debility



from Holland et al. 2007

Cercariae make contact, migrate to limb bud

Alternate Hypotheses for Amphibian Declines

Outline for Talk

Non-climate-related Hypotheses

1. **Land use change hypothesis**: declines of ectotherms are simply caused by changes in the landscape and associated pollution (e.g. agrochemicals).
2. **Epidemic spread hypothesis**: species extinctions are strictly due to the spatial spread of a highly virulent parasite, independent of other factors.

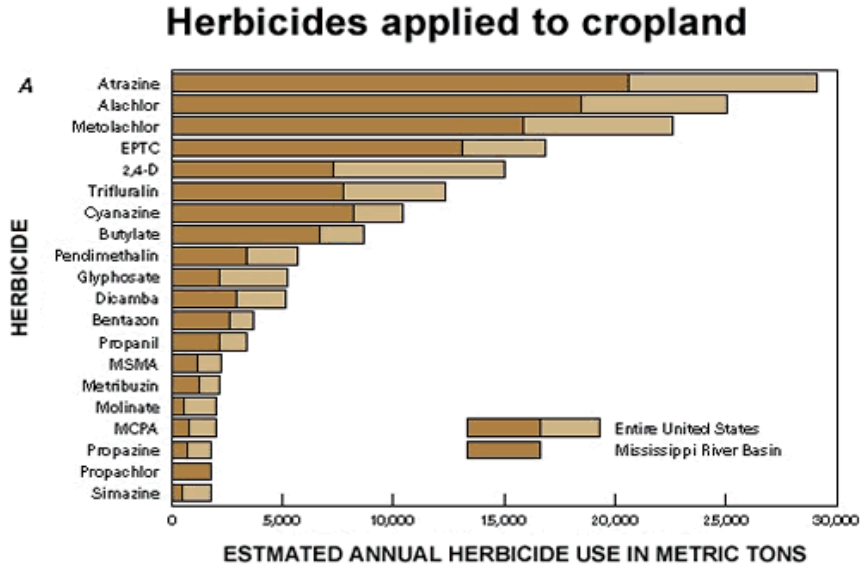
Climate-related Hypotheses

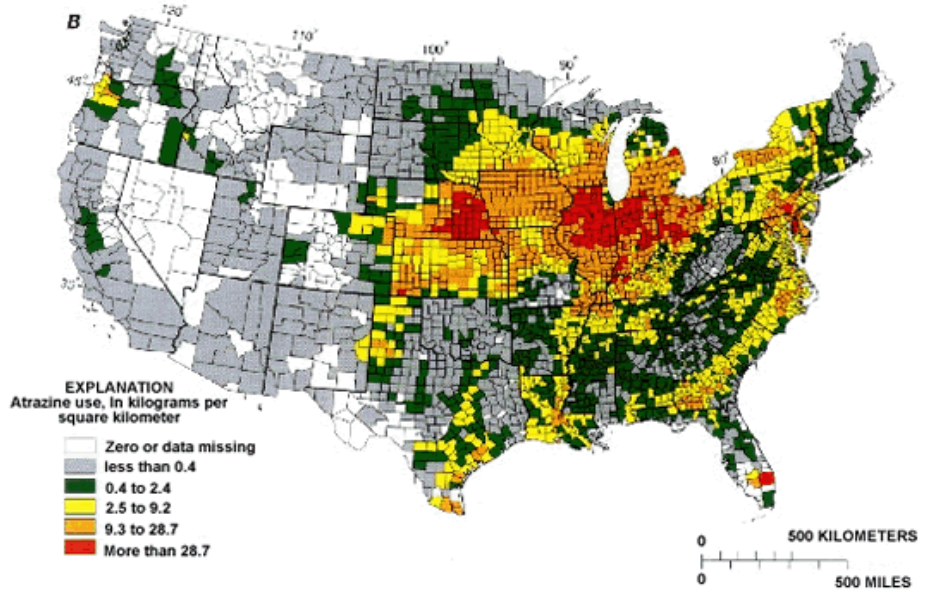
3. **Chytrid thermal optimum hypothesis**: increased cloud cover due to warmer oceanic temperatures leads to higher nighttime and lower daytime temperatures, causing these temperatures to converge on the optimum temperature for growth of *Bd*.
4. **Mean climate hypothesis**: changes to mean precip. or temp. adversely affect amphibians.
5. **Climate variability hypothesis**

Ultimate Goal

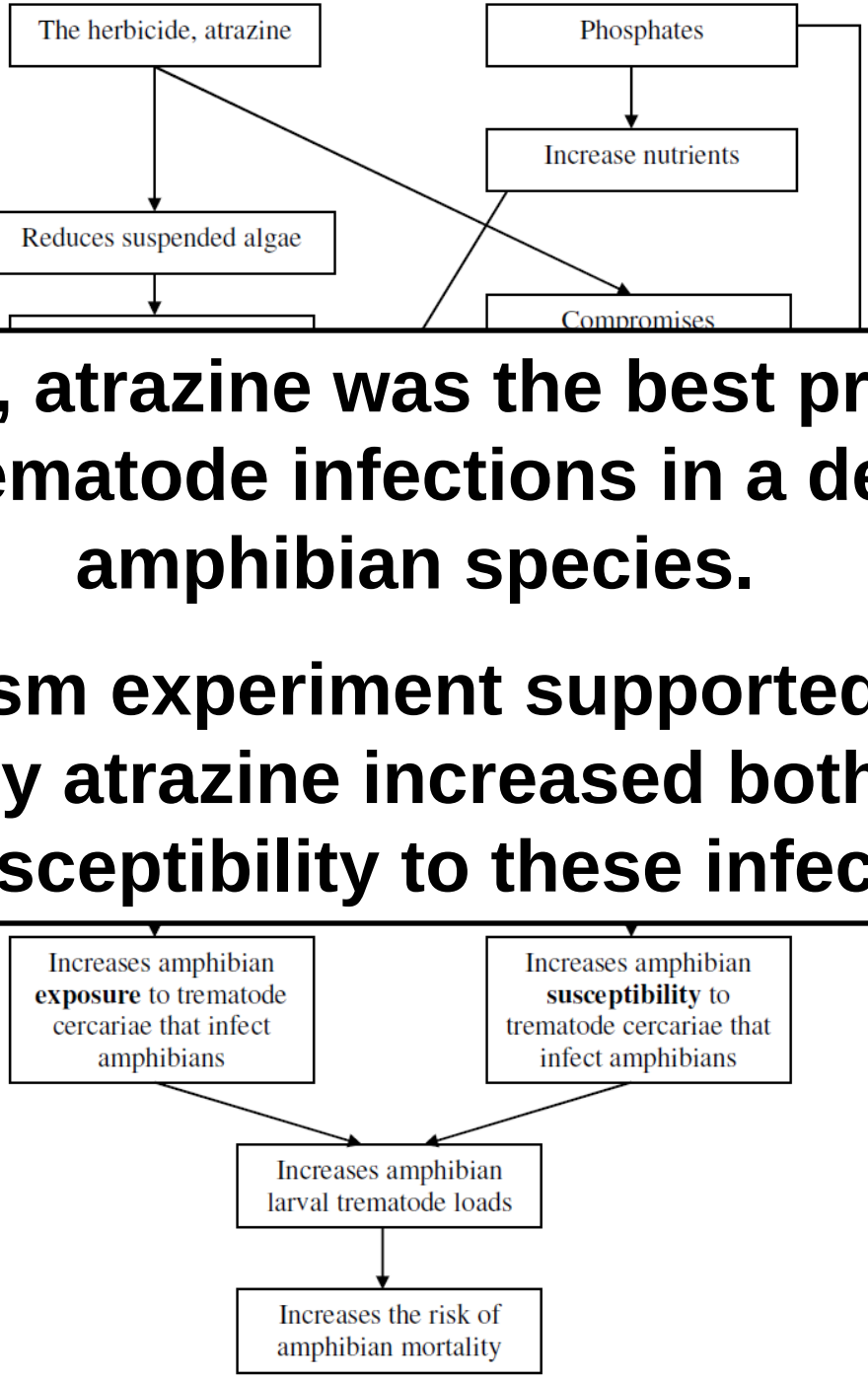
- Use our findings to predict when, where disease outbreaks will occur.
- Plan, prevent, or minimize the impacts of disease.

Atrazine





- Persistent & mobile
- Seasonal peak coincides with amphibian breeding & development (Rohr *et al.* 2003, 2004)
- Upper range in water bodies near agriculture: 200-2,300 µg/L (Kadoum & Mock 1978, deNoyelles 1982, Battaglin et al. 2000, USGS NAWQA)



In the field, atrazine was the best predictor of larval trematode infections in a declining amphibian species.

A mesocosm experiment supported a causal link whereby atrazine increased both exposure and susceptibility to these infections.

Rohr et al.
2008 *Nature*

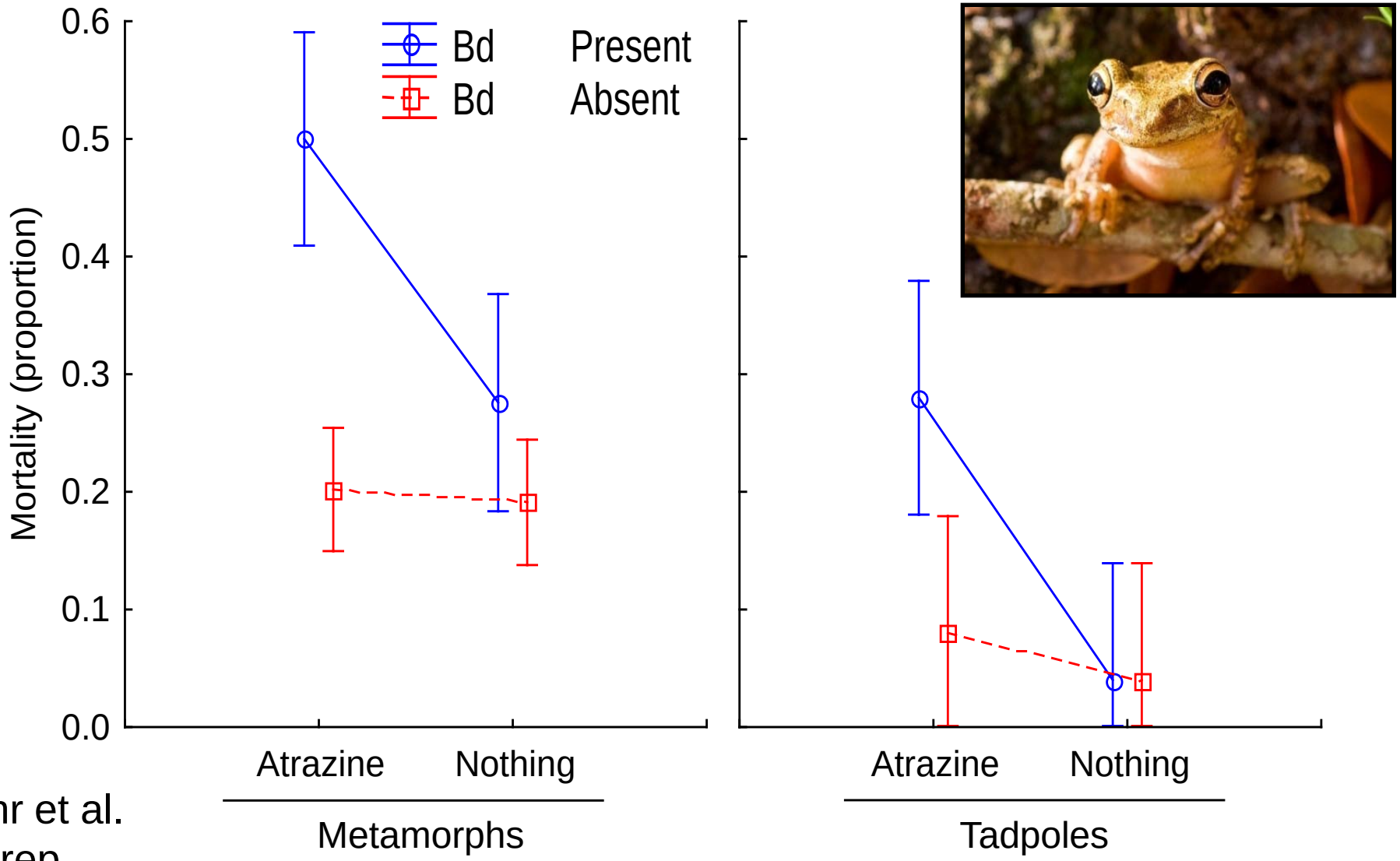
Results of Meta-analysis

Effect of atrazine	No. of studies/ endpoints where effect was observed	Total no. of studies/ endpoints	Percent of studies/ endpoints
Reduced growth	15	17	88.24
Elevated activity	12	13	92.31
Reduced antipredator behaviors	6	7	85.71
Reduced immune endpoints	33	43	76.74
Increased infection endpoints	13	16	81.25
Altered gonadal morphology	7	10	70.00
Altered sex hormones	6	7	85.71

Rohr and McCoy 2010 *Environmental Health Perspectives*

Does Atrazine Affect Chytridiomycosis?

Atrazine Increased Chytridiomycosis-Induced Mortality



Rohr et al. in prep.

Conclusions

- Landscape modifications and associated pollution (specifically atrazine) can facilitate pathogen emergence/invasive species.

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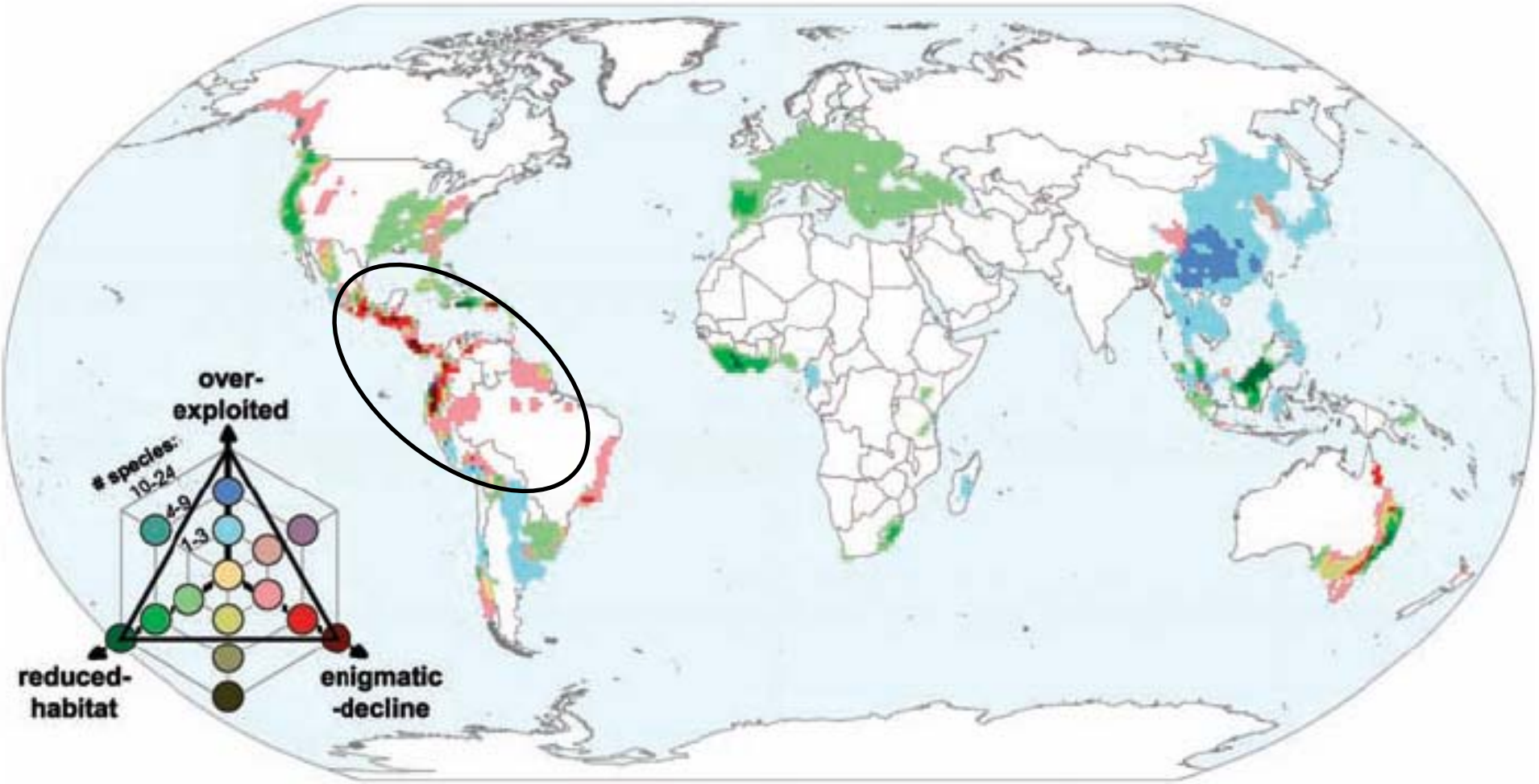
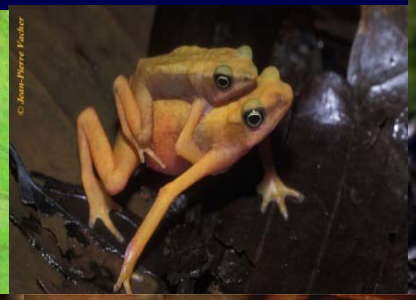
Enigmatic Amphibian Declines



Genus *Atelopus*

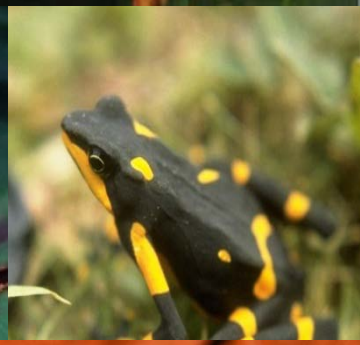




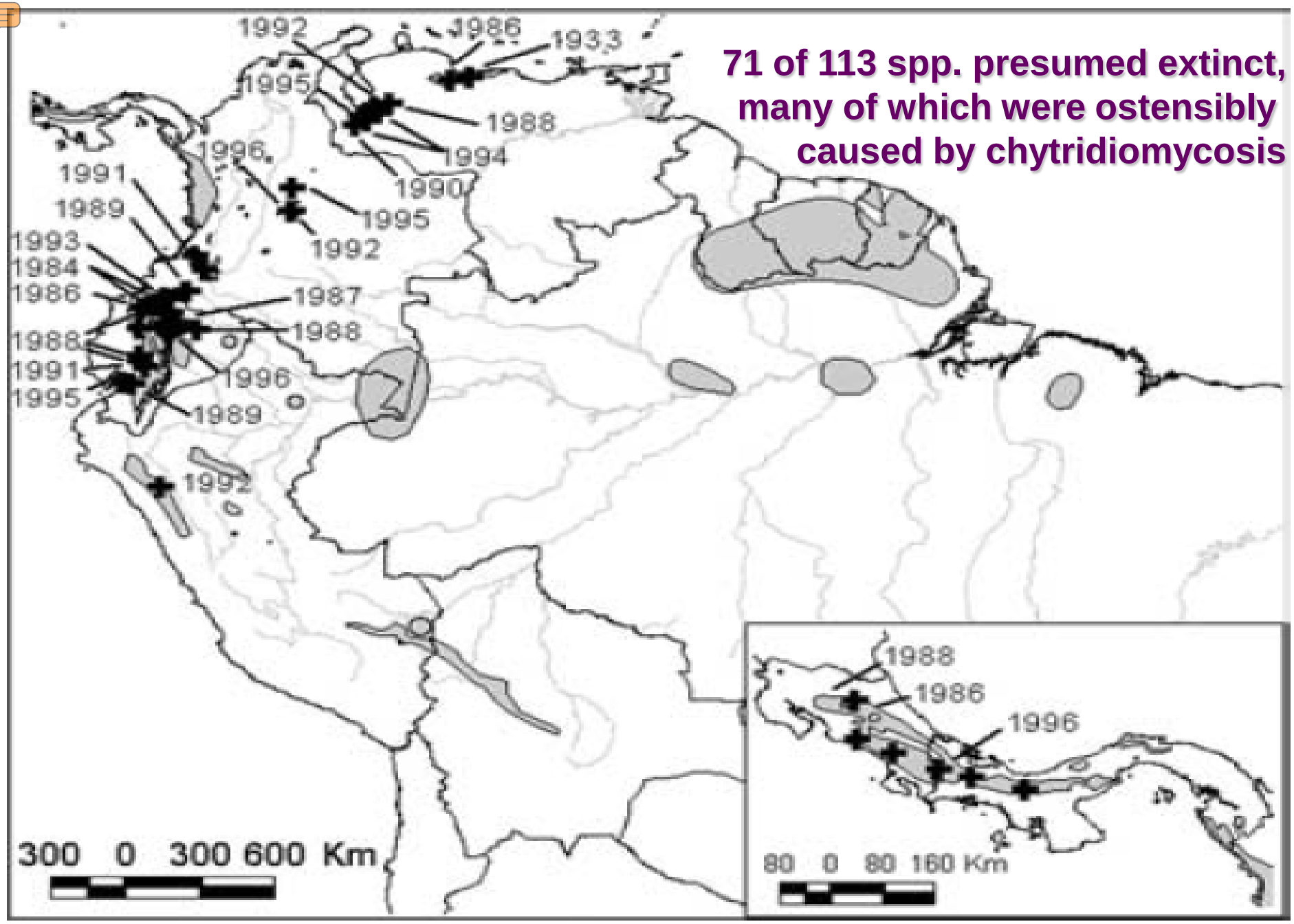








from La Marca et al. 2005. Biotropica

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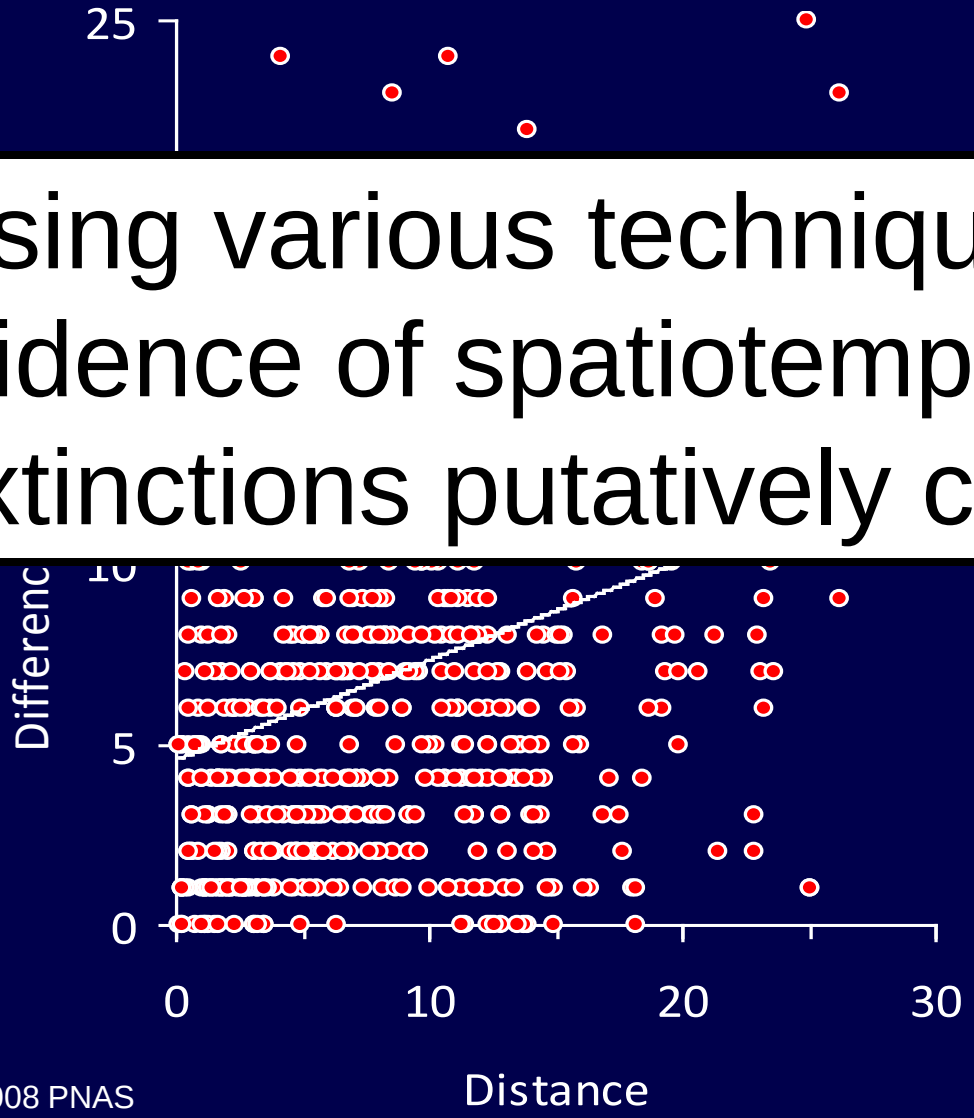
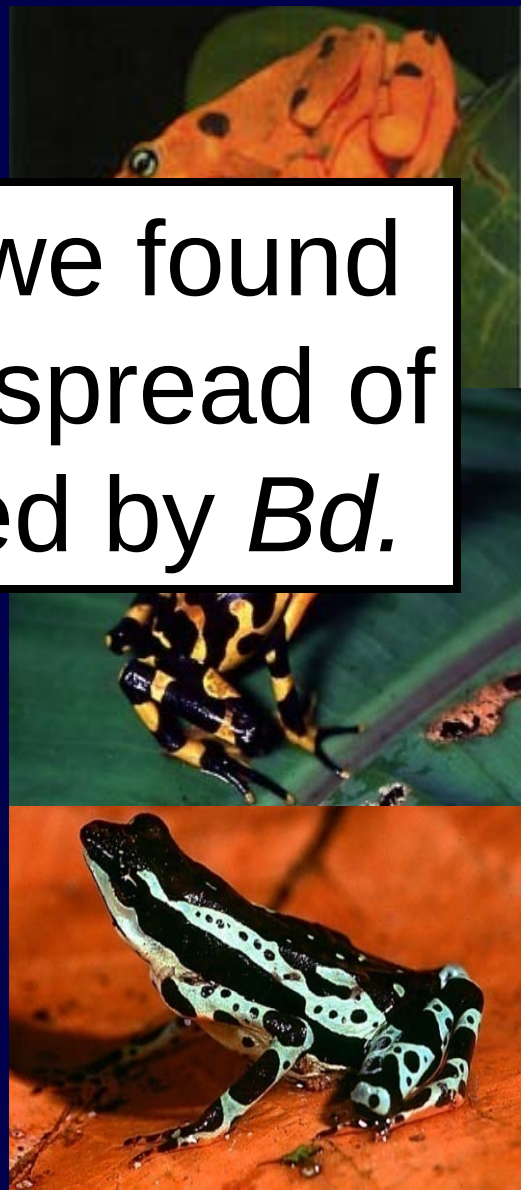
Is there Spatiotemporal Spread of Atelopus Extinctions?



Using various techniques, we found evidence of spatiotemporal spread of extinctions putatively caused by *Bd*.

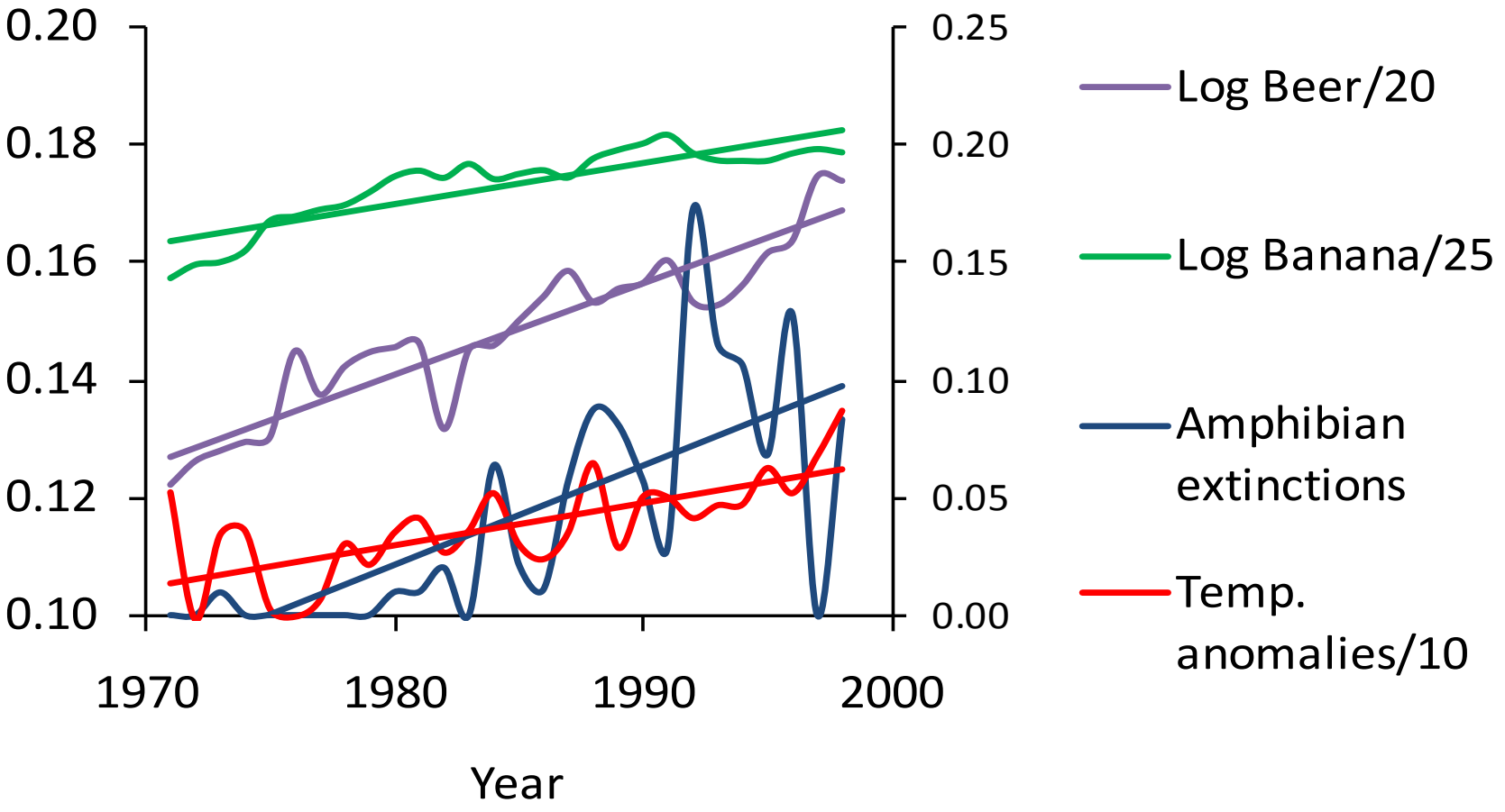


Rohr et al. 2008 PNAS

Climate Change, Amphibian Declines, and *Bd*

Also evidence that *Bd*-related declines are linked to climate change (Pounds et al. 2006, Bosch et al. 2006)

Tenuous Links Between Climate and Amphibian Declines

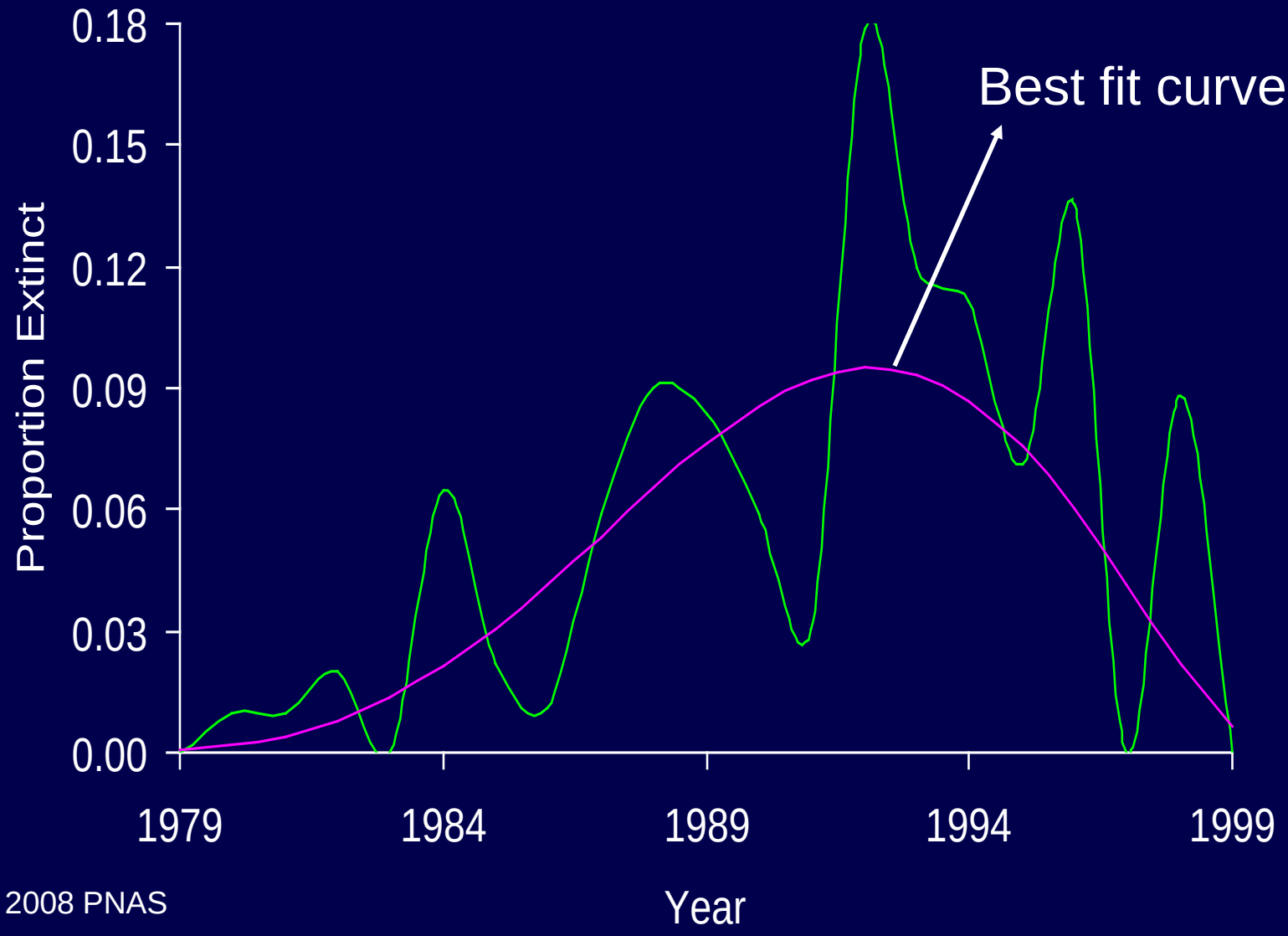


Rohr et al. 2008 PNAS

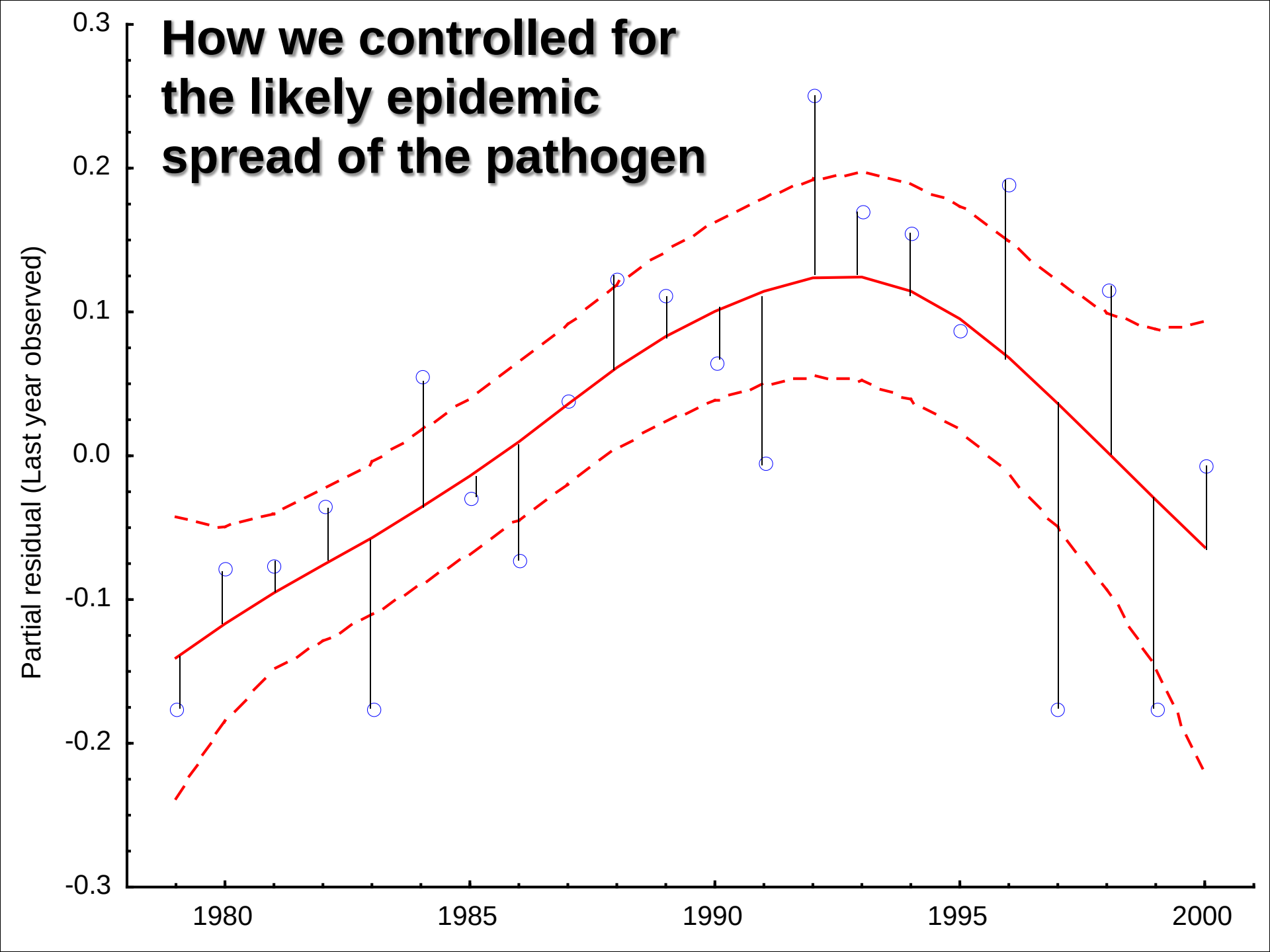
Need to Conduct Detrended Analyses?

- If there is a true relationship between climate and *Bd*-related extinctions, fluctuations around temporal trends in temperature and extinctions should also be positively correlated
- There would many fewer non-causal explanations for this correlation than the multidecadal relationship between declines and temperature

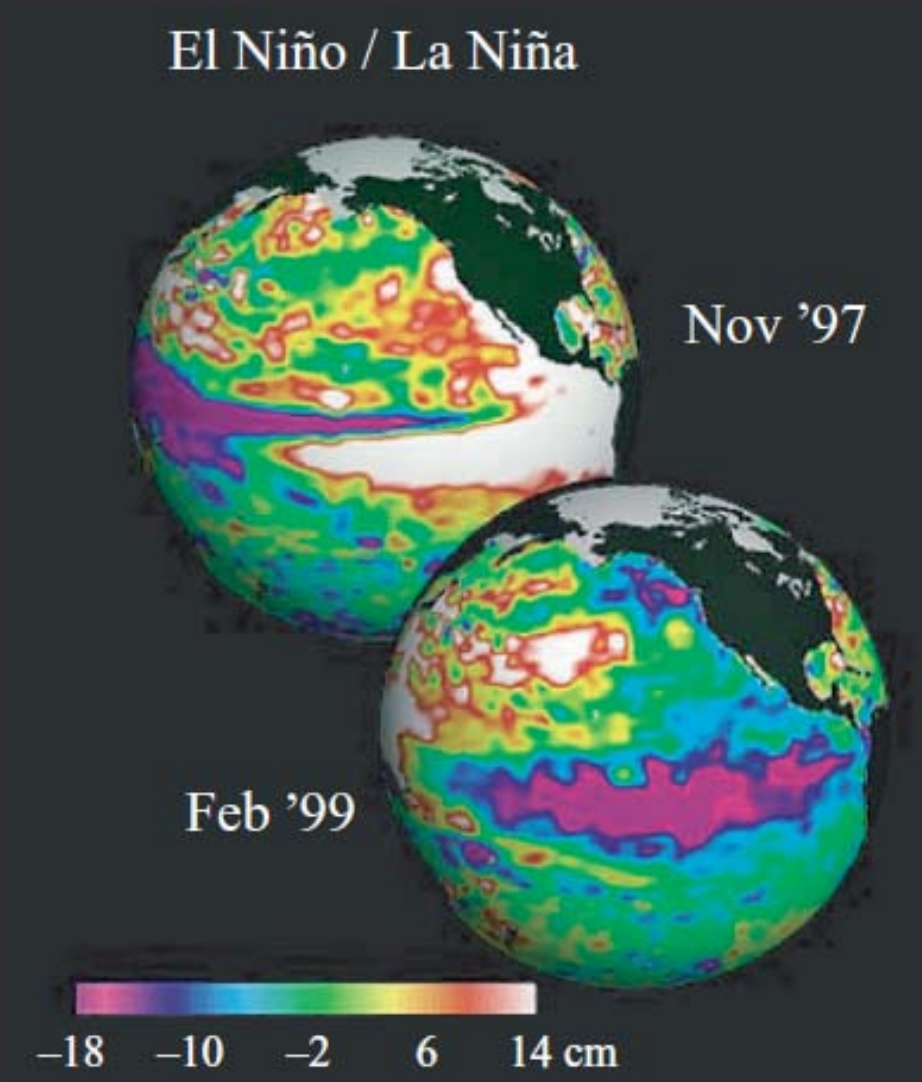
Atelopus Extinctions Through Time

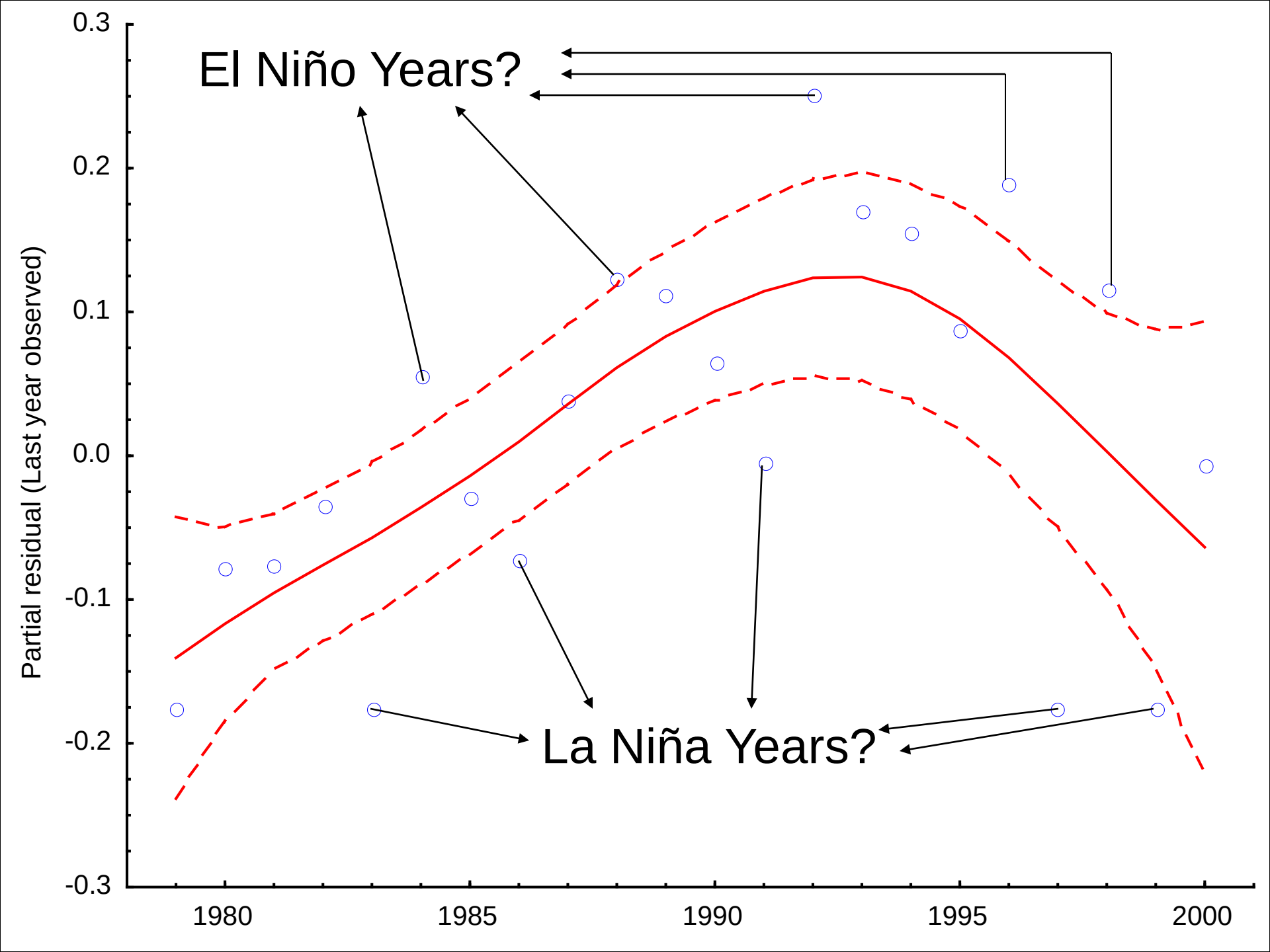


Rohr et al. 2008 PNAS

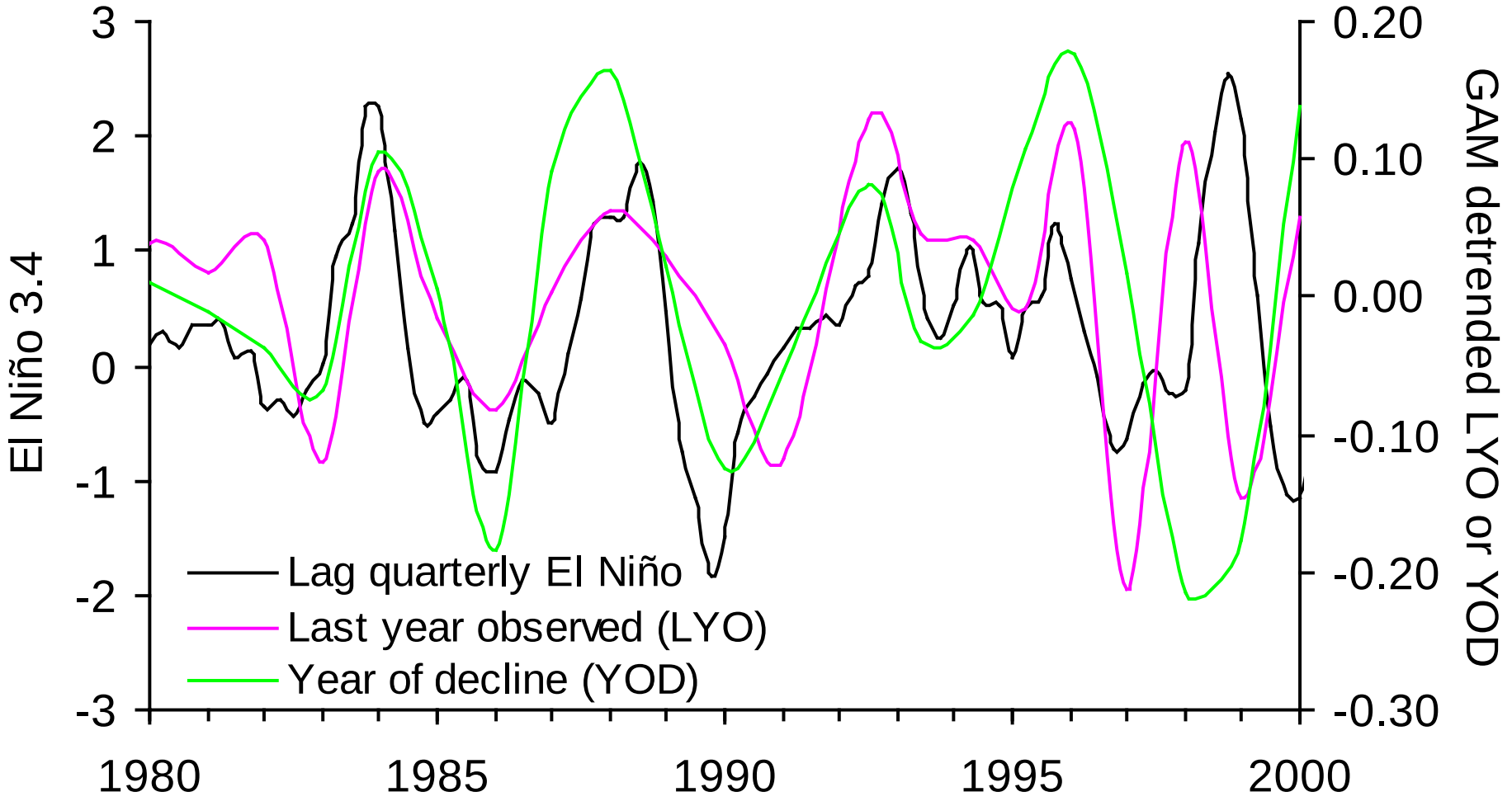

How we controlled for the likely epidemic spread of the pathogen
Partial residual (Last year observed)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
1980
1985
1990
1995
2000

Ultimate Hypothesis: ENSO Drives Amphibian Declines




El Niño Years?
La Niña Years?
Partial residual (Last year observed)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
1980
1985
1990
1995
2000

Ultimate Hypothesis: ENSO



Rohr and Raffel 2010 *PNAS*

Must Control for Intrinsic Dynamics to Detect Extrinsic Factors!

- No significant ENSO signature if we don't control for probable epidemic spread
- **Hence, the availability of susceptible hosts appears the primary factor influencing epidemic spread followed secondarily by climate**

But What is the Proximate Explanation?

What is it about El Nino years that is associated with amphibian extinctions?

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Regional Predictors

tested w/ and w/o a one year lag

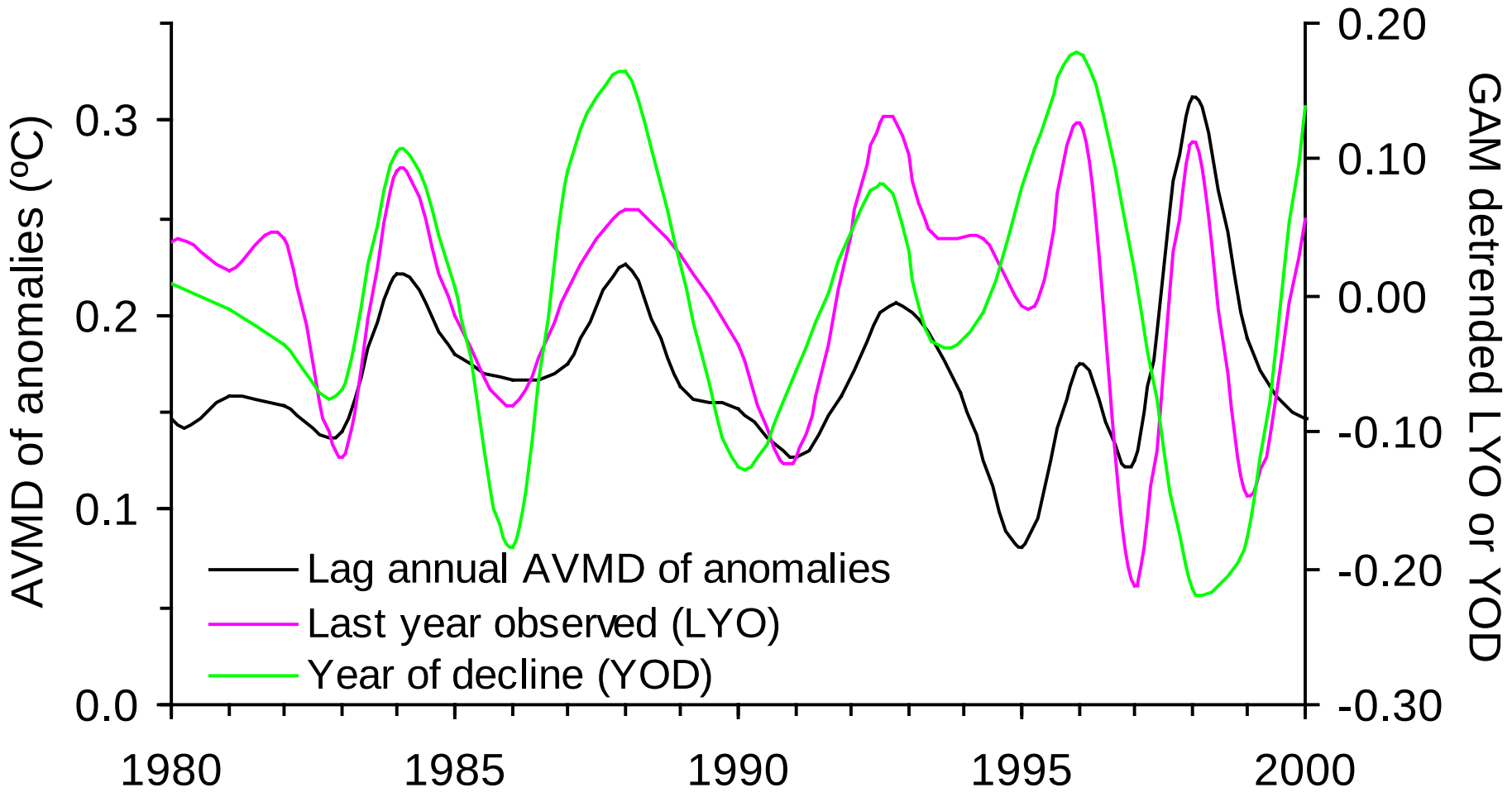
1. Mean absolute value of monthly differences (AVMD) in temp.
2. Cloud cover x temp. (Pounds et al. 2006)
3. Cloud cover (Pounds et al. 2006)
4. Temperature-dependent *Bd* growth (Pounds et al. 2006)
5. Precip. x temp. (Whitfield et al. 2007)
6. Diurnal temp. range
7. Frost freq.
8. Precip.
9. Temp.
10. Temp. max.
11. Temp. min.
12. Vapor press.
13. Wet day freq.

Results of Best Subset Model Selection

			t					t-1			
Model Ranking	Adjusted R^2	No. of effects	Precip.	Wet day freq.	AVMD temp.	Cloud cover	Diurnal temp. range	Temp.	Temp. max.	Temp. min.	Vapor Pres.
1	0.685	3	0.253		0.859		0.764				
2	0.671	3		0.230	0.845		0.755				
3	0.644	3			0.857	-0.154	0.692				
4	0.643	3			0.804		0.788				0.212
5	0.640	3			0.807		0.738			0.177	
6	0.640	3			0.807		0.693	0.161			
7	0.640	3			0.807		0.649		0.157		
8	0.640	3			0.806			-2.350	2.453		
9	0.640	2			0.892		0.699				
10	0.640	3			0.806				1.306	-1.286	

results are similar using AIC

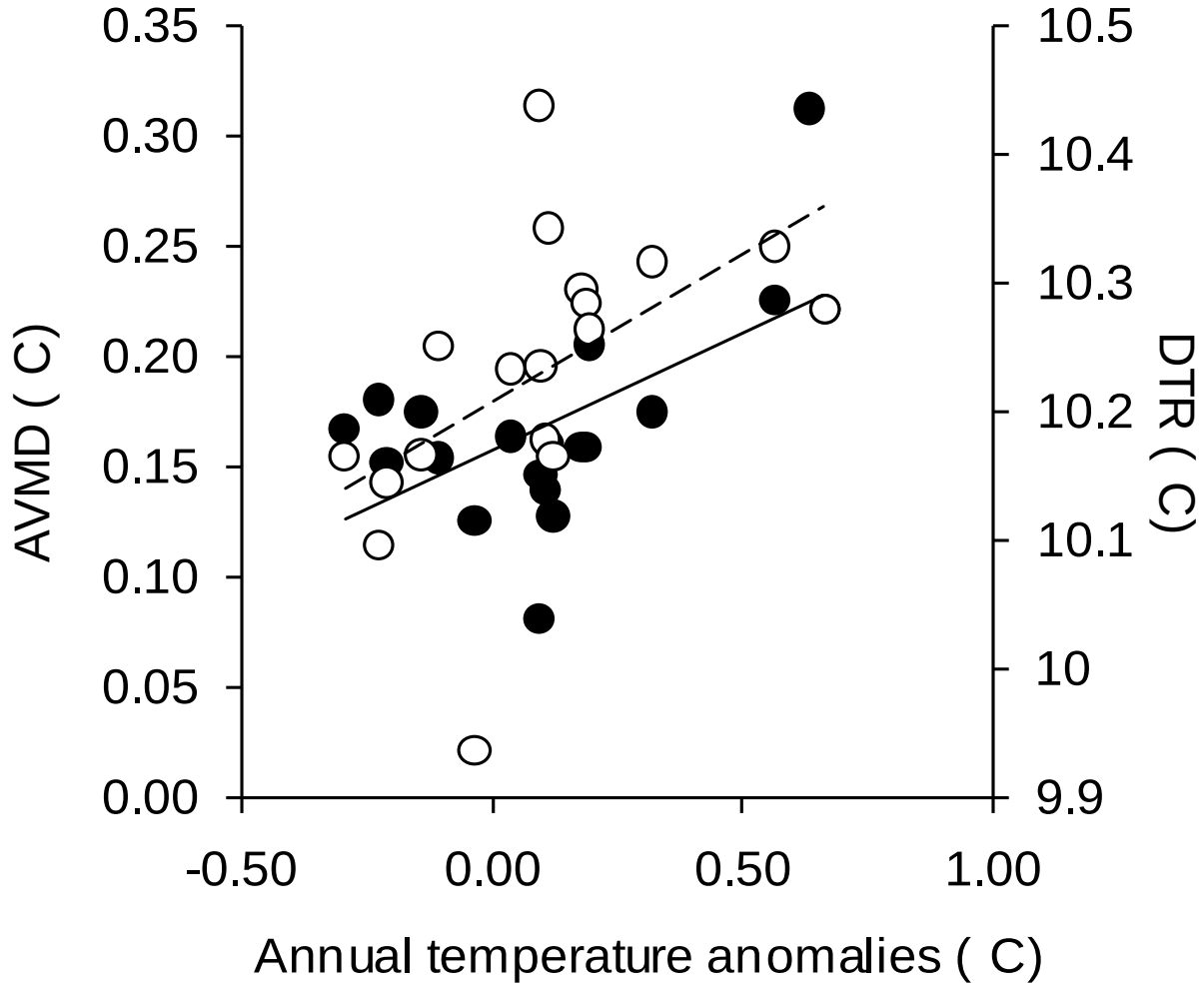
Can Monthly Temperature Variability Explain *Atelopus* Extinctions?



Rohr and Raffel 2010 *PNAS*

Amphibian extinctions have often occurred in warmer years, at higher elevations, and during cooler seasons.

Do Warmer Years Have Greater Variability in Temperature?



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Do High Elevations Have Greater Variability in Temp.?

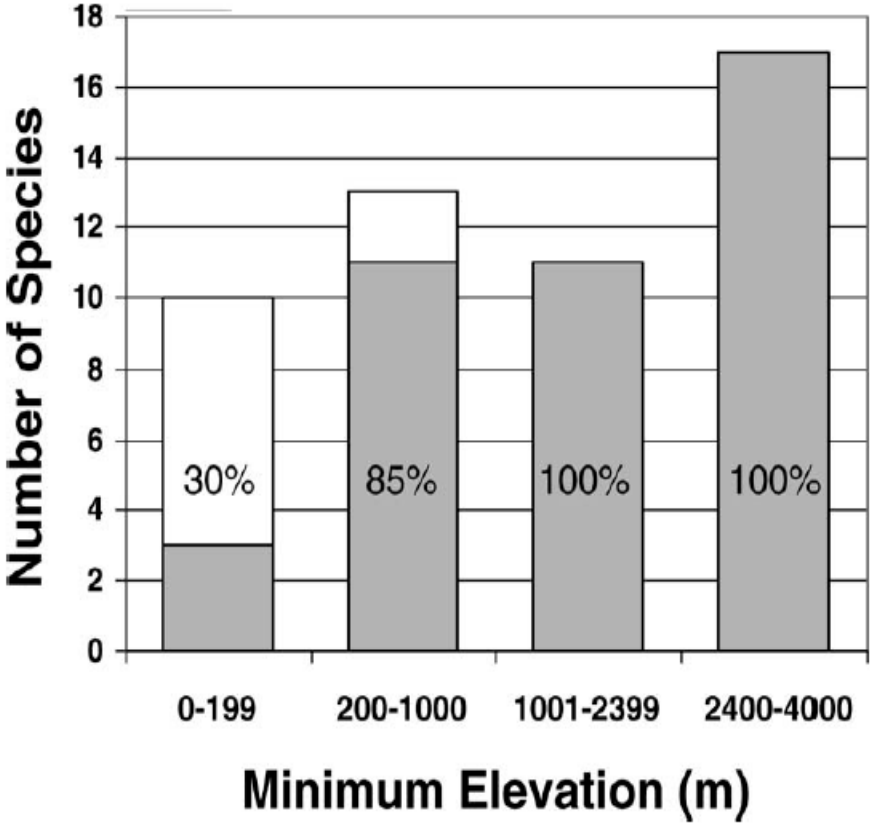
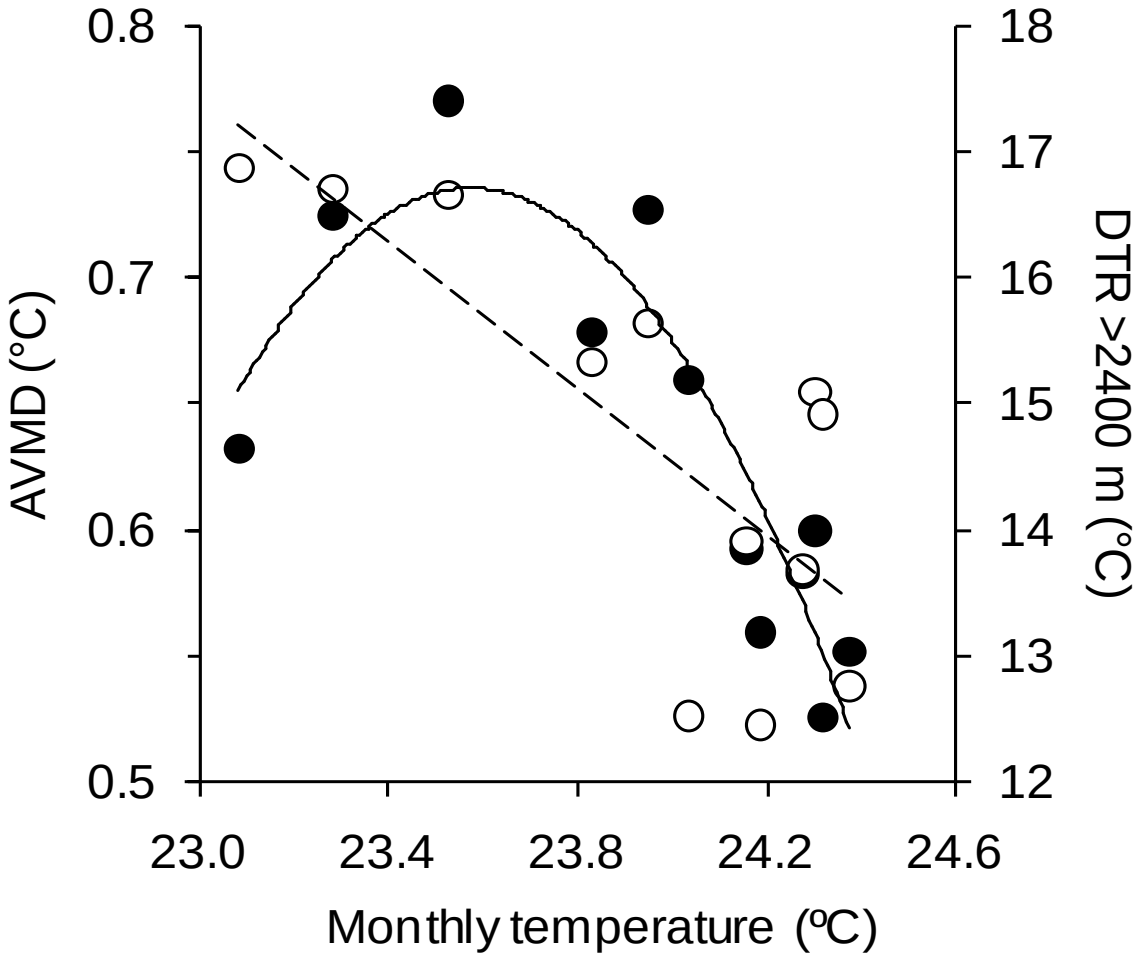


Figure 7. Percentage of *Atelopus* Species Declined or Extinct by Elevation in our Study Area

Bars show the number of species at each elevation category while gray depicts the number of species in decline and white depicts stable species. The percentage of species in decline is written on each bar. Total number of species included in the analysis was 51.

Do Cooler Months Have Greater Variability in Temp.?



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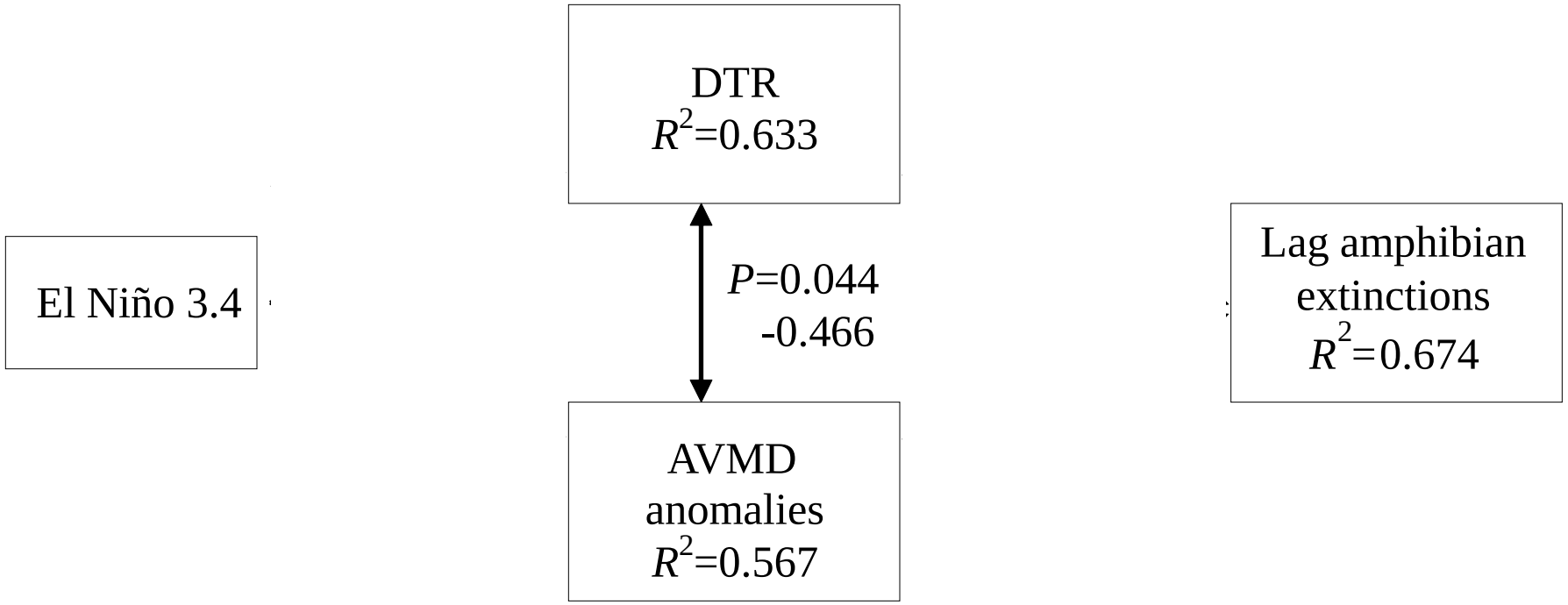
Results of Path Analysis

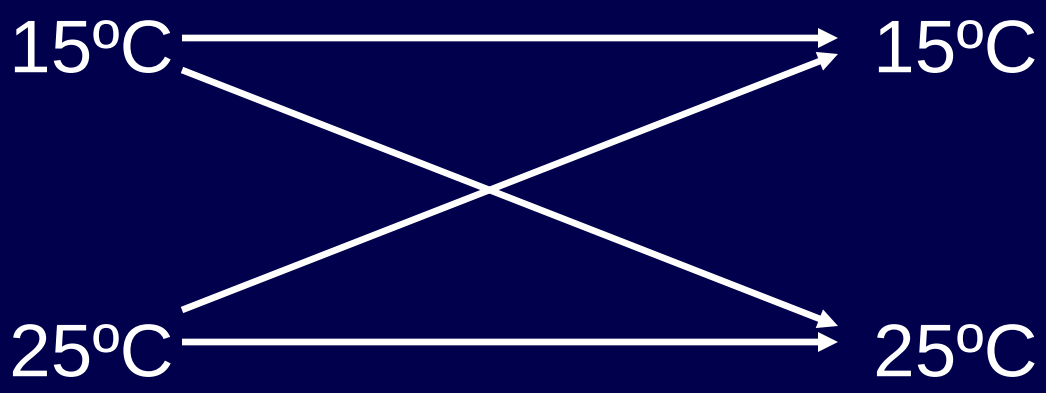


Rohr and Raffel 2010
PNAS

We Weren't Convinced

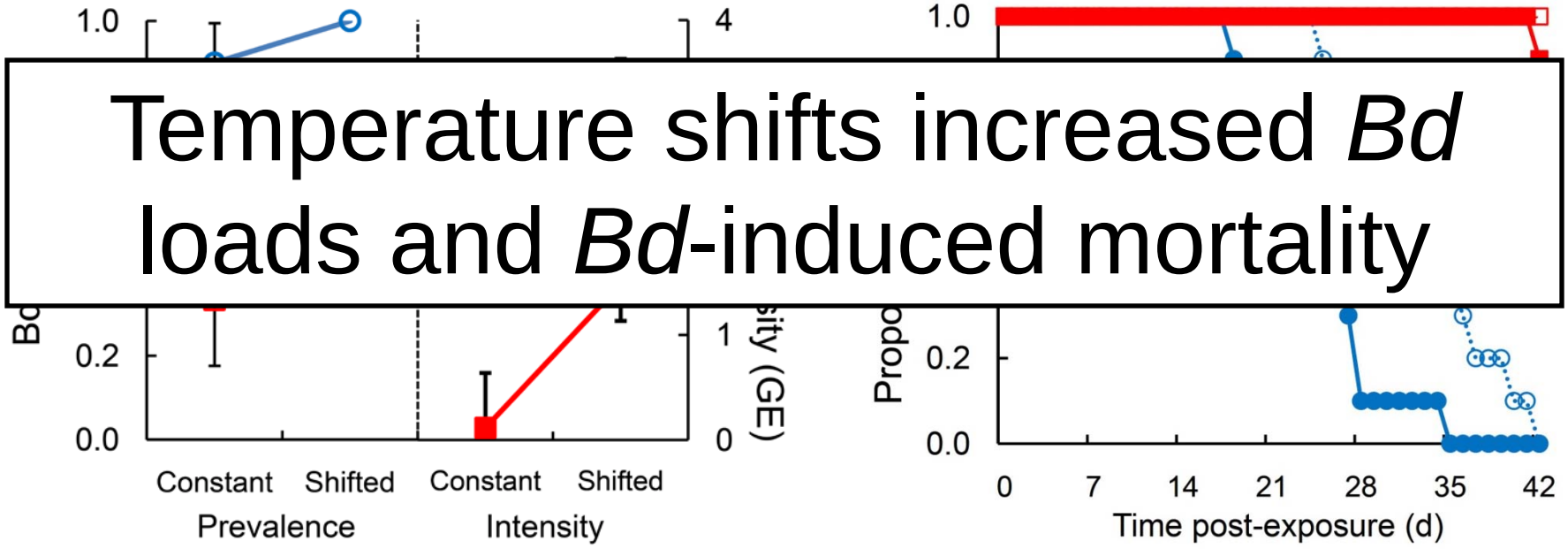
Experimental Test

- Acclimated Cuban tree frogs to 15 or 25º C for four weeks
- Challenged with *Bd* at start of week five
- Quantified survival and *Bd* loads on frogs and *Bd* in culture




49
40
41

Does Temperature Variability Increase *Bd* Loads on Frogs?



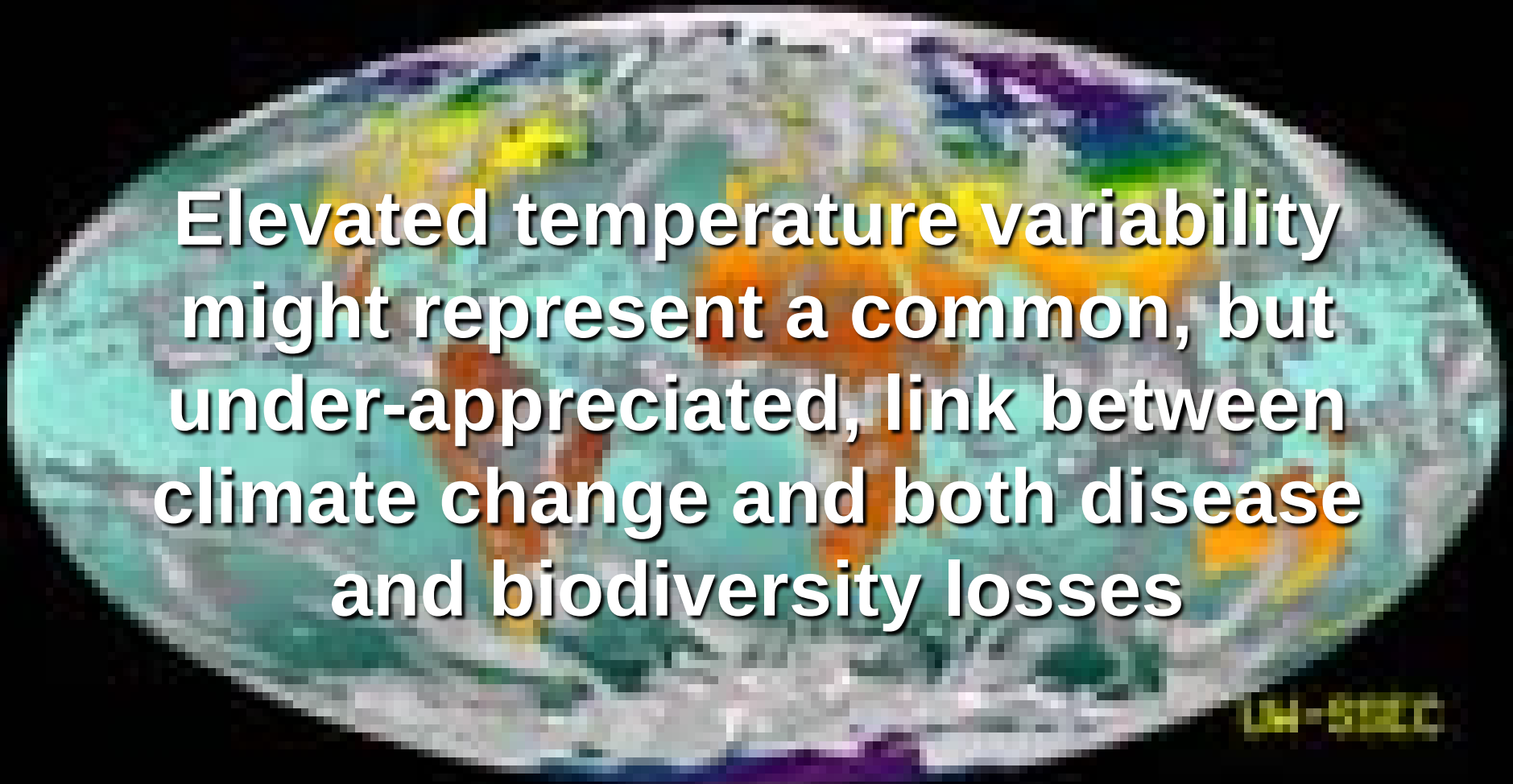
Temperature shifts increased *Bd* loads and *Bd*-induced mortality

Raffel et al. in review *Science*

Conclusions

Temperature, temperature variability, and Central Pacific El Niño events are increasing in tropical and subtropical regions because of climate change; thus, global climate change might be contributing to enigmatic amphibian declines, by increasing disease risk

Conclusions (cont.)

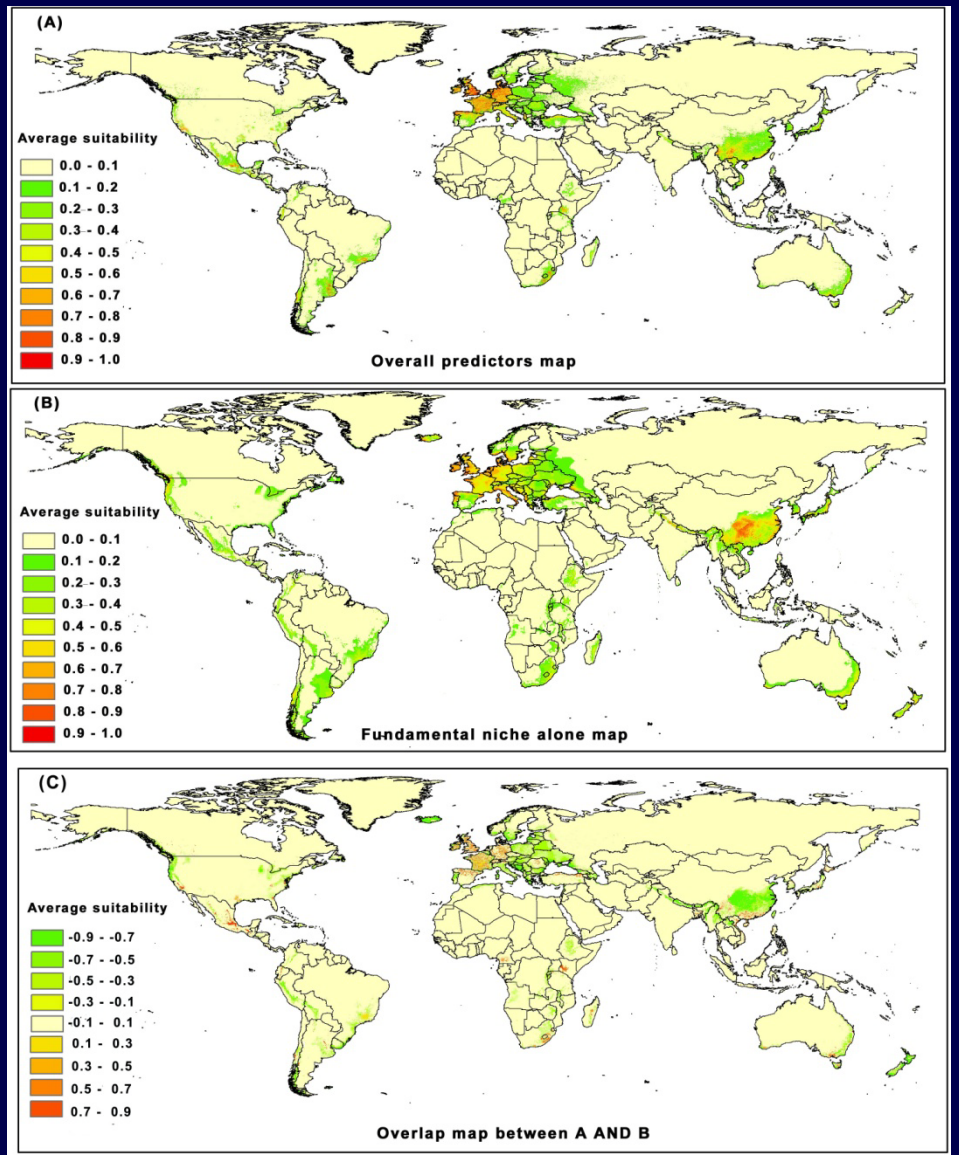


Elevated temperature variability might represent a common, but under-appreciated, link between climate change and both disease and biodiversity losses

Present and Future Research

- How do hosts and parasites respond to predictable climatic variability and climatic variability on various time scales?
- Are our results general across pathogens and hosts, including zoonotic pathogens?
- How do combinations of climatic factors (e.g. moisture and temp.) affect disease?
- How important is climate and climate change globally relative to other factors facilitating the spread of invasive parasites?

“Climate, introduced hosts, trade and human footprint shape a global wildlife pandemic”



Liu, Rohr, Li in review *PNAS*

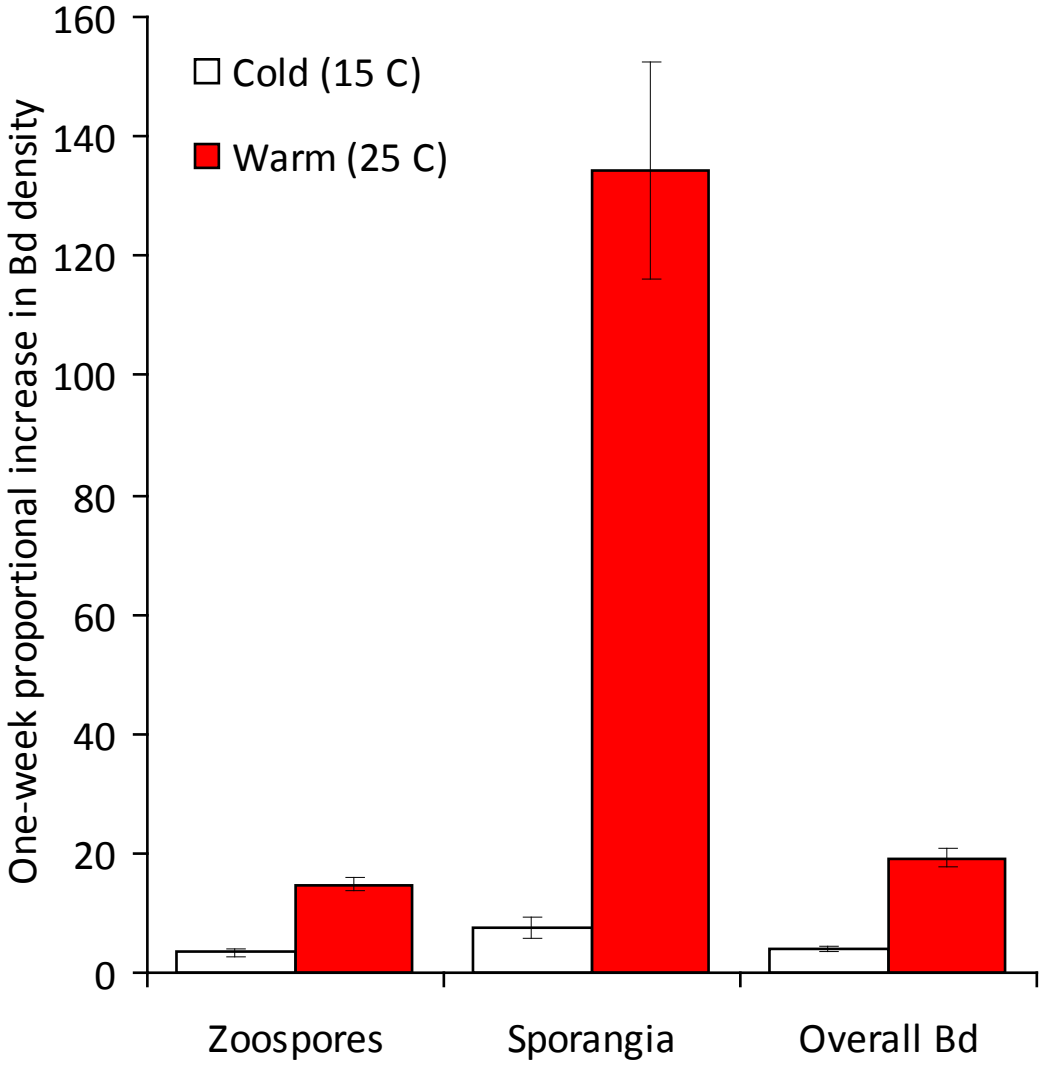
Acknowledgements

FUNDING AGENCIES

Environmental Protection Agency

Various colleagues, co-authors, and research assistants.

In culture, *Bd* grew better at 25C than 15C



On the frog, *Bd* grew best and was most deadly at 15C