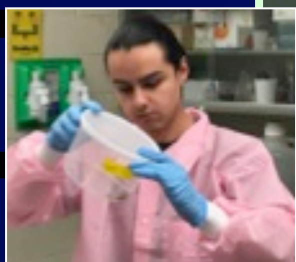
Skin Devouring Fungus:

The Next Threat to Salamanders and to Biodiversity

Matthew Gray, Davis Carter, Molly Bletz, Patrick Cusaac, Doug Woodhams, Laura Reinert, Louise Rollins-Smith, John Romansic, Jonah Piovia-Scott, Lori Williams, Pandy Upchurch, Priya Nanjappa, and Debra Miller

UTIA Center for Wildlife Health:

Department of Forestry, Wildlife, Fisheries



UTAgResearch
INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

UTIA East Tennessee Research & Education Center
(Dr. Bobby Simpson, Alex Anderson)

Skin Devouring Fungus:

BATRACHOCHYTRIUM SALAMANDRIVORANS (BSAL)

Science & Environment

Salamander threatened by skin-eating fungus

By Melissa Hogenboom
Science reporter, BBC News

2013

http://www.amphibians.org/news/watching-extinction-happen-origins-of-the-salamander-eater/

Emergence of Bsal

Salamandra salamandra

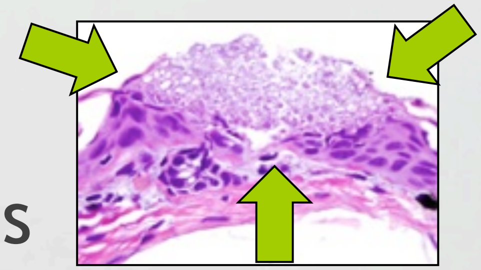
* 2010: 96% wild mortality in Netherlands
* 2013 & 2014: wild mortality in Belgium
* 2015: UK (trade) and Germany (captivity)
* 2016: Netherlands, Belgium, Germany (wild)
* Present in: **(Vietnam, Thailand, Japan, China)**
  * wild salamanders in Asia
  * museum records in Asia >150 yrs

Unknown to occur in North America

Martel et al. 2013, PNAS; Laking et al. 2017, Scientific Reports;
Martel et al. 2014. Science;
Cunningham et al. 2015, Veterinary Record;
Sabino-Pinto et al. 2015, Amphibia-Reptilia

PATHOLOGY

Necrotic Skin Ulcerations



"Skin devouring"

14 of 55 sites: 3 species

Ichthyosaura alpestris

Lissotriton vulgaris

Spitzen-van der Sluijs et al. (2016); EID

How *Bsal* will enter?

Port of Entry (LEMIS: 120,000 sal/year)

POLICY PERSPECTIVE

2018

WILEY Conservation Letters

Widespread occurrence of an emerging fungal pathogen in heavily traded Chinese urodelan species

Zhiyong Yuan[1,2] | An Martel[3] | Jun Wu[4] | Sarah Van Praet[3] | Stefano Canessa[3] | Frank Pasmans[3]

Trade in wild anurans vectors the urodelan pathogen *Batrachochytrium salamandrivorans* into Europe

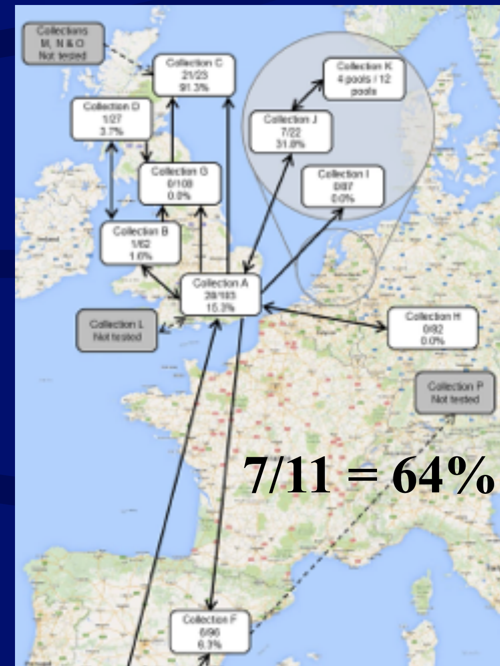
2017 (detected in German pet store; 3/36 = 8%)

Tao Thien Nguyen[1,2], Thinh Van Nguyen[2], Thomas Ziegler[3,4], Frank Pasmans[5], An Martel[5,*]

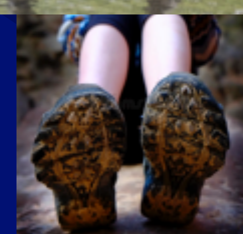
2.2M

3% Prevalence → 66,000 Bsal$^+$ newts ('08)

Fitzpatrick et al. 2018



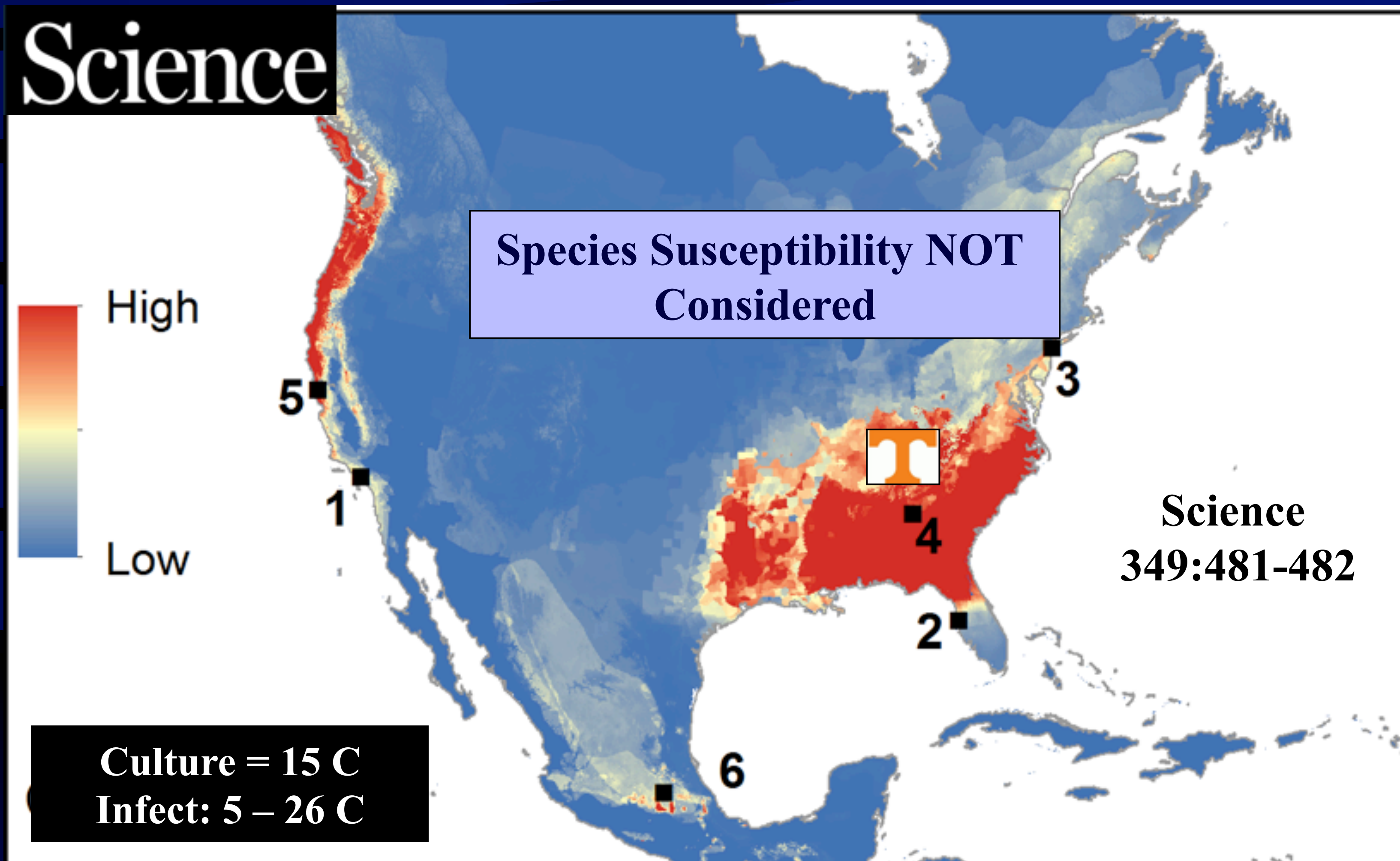
Fomites on Recreational Gear



2-3 days

Stegen et al. (2017)

Bsal Invasion Risk Model: Yap et al. (2015)



Final Risk Assessment Model

- Relative Risk = SpRich * Log ClimSuit Bsal

Initial *Bsal* Research in the USA

Test the susceptibility of various North American amphibian species to *Bsal*

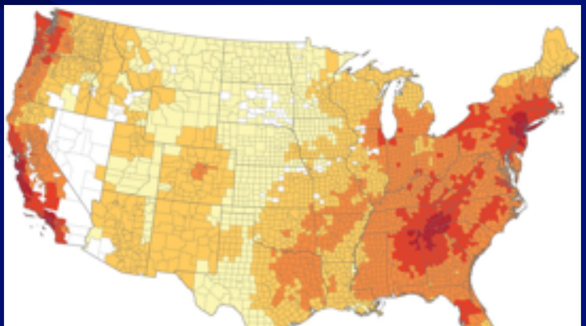
UMASS BOSTON
UT AGRESEARCH INSTITUTE OF AGRICULTURE THE UNIVERSITY OF TENNESSEE
The Center for Wildlife Health
UT CVM INSTITUTE OF AGRICULTURE THE UNIVERSITY OF TENNESSEE
VANDERBILT
Instituto de Biología UNAM
WASHINGTON STATE UNIVERSITY VANCOUVER

- Tested 24 salamander and 6 anuran species
- Susceptibility: infection, mortality, & disease generally across 4 *Bsal* doses (*n* = 5-10 / dose)

Robustly estimate Invasion RISK

→ Direct Surveillance and Response

(Yap et al. 2015:NA, Richgels et al. 2016: USA, Feldmeier et al. 2016: Europe)



Richgels et al. (2016)

Taxa Initially Tested

Salamanders (24; 5)

Family	Species
Ambystomatidae	*Ambystoma opacum*
	A. laterale *A. maculatum*
	A. mexicanum
Proteidae	*Necturus maculosus*
Cryptobranchidae	*Cyptobranchus alleganiensis*
Plethodontidae	*Hemidactylium scutatum*
	Aneides aeneus
	Aquiloeuryea cephalica
	Chiropterotriton spp.
	Desmognathus ocoee
	D. aeneus
	D. monticola
	Ensatina eschscholtzii (2 subspecies)
	Eurycea wilderae (3 populations)
	Eurycea lucifuga
	Plethodon shermani x P. teyahalee
	P. metcalfi
	Pseudotriton ruber
Salamandridae	*Notophthalmus perstriatus*
	N. meridionalis
	N. viridescens (6 populations and efts)
	Taricha granulosa, *T. torosa*

Frogs (6; 4)

Family	Species
Bufonidae	*Anaxyrus americanus*
Hylidae	*Hyla chrysoscelis*
Ranidae	*Lithobates sylvaticus*
	L. chiricahuensis
	L. catesbeianus
Scaphiopodidae	*Scaphiopus holbrookii*






Methods

North American Bsal Task Force:

Research Working Group

https://ag.tennessee.edu/fwf/bsalproject/

University of Tennessee IACUC Protocols 2395 and 2623

BSL-2 Containment Practices

Results

Of the 30 species tested (>1,000 animals), 75% became infected and 9 species (30%) developed *Bsal* chytridiomycosis

Spelerpinae
(42 endemic spp)

Plethodontidae

1) *Eurycea wilderae*
2) *Pseudotriton ruber*
3) *Ensatina e. klauberi*
4) *Aquiloeurycea cephalica*
5) *Chiropterotriton* spp.

Salamandridae

1) *Notophthalmus perstriatus**
2) *N. meridionalis**
3) *N. viridescens*
4) *Taricha granulosa*

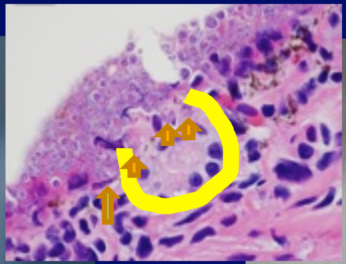
NORTH CAROLINA Wildlife RESOURCES COMMISSION

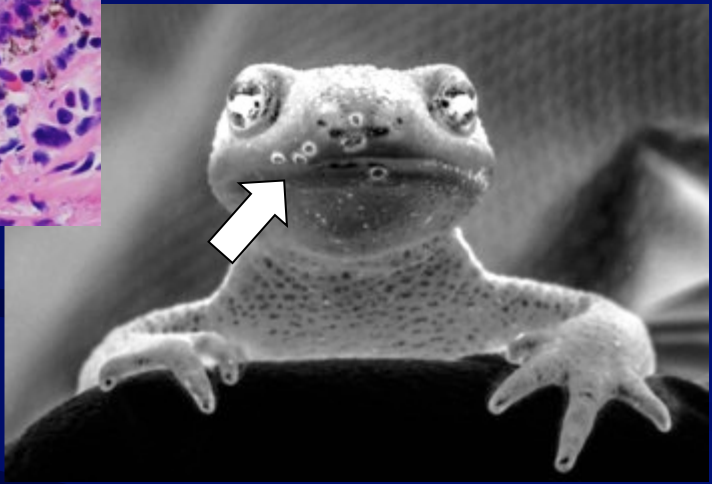
BAND

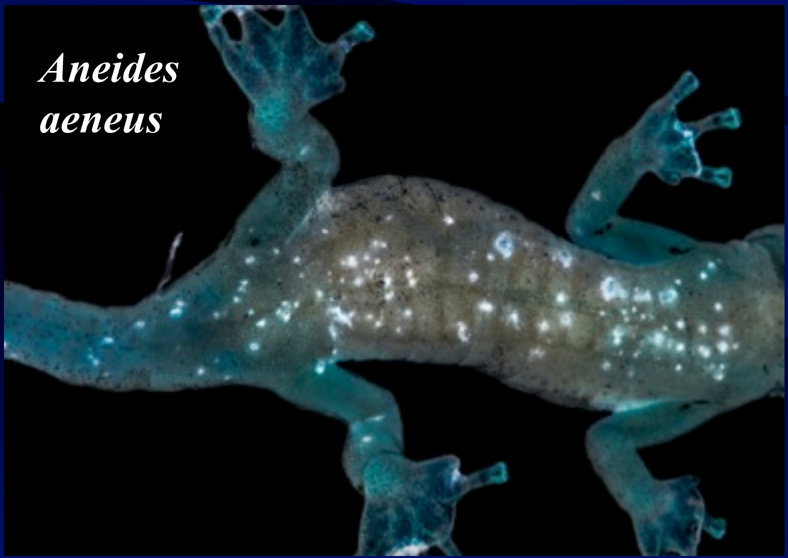
ASSOCIATION of FISH & WILDLIFE AGENCIES

TENNESSEE WILDLIFE RESOURCES AGENCY

Gross Signs: Bsal Chytridiomycosis







Pathogenesis of Bsal Chytridiomycosis

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Convulsions, lethargy, loss of righting reflex, paralysis

D. Miller, A. Grzelak

Notophthalmus perstriatus

Hypothesis

Epidermal Destruction resulting in….

Impaired osmoregulation…

Electrolyte imbalance?

Actin-myosin cross-bridge cycle:

Muscle contraction – lead to paralysis

Bsal Infection Tolerance Rank

Low Tolerance ← → **High Tolerance**

High Risk — **Low Risk**

Epidemiological Role:

Amplification (Risk = 3; high)	Carrier (Risk = 2; moderate)	Carrier (Risk = 1; low)	Resistant (Risk = 0; no)
*Notophthalmus perstriatus**	*N. viridescens (adults)**	*Aneides aeneus**	*Hemidactylium scutatum**
*N. meridionalis**	*Taricha granulosa**	*Eurycea lucifuga**	*D. aeneus**
*N. viridescens (efts)**	*Taricha torosa**	*Desmognathus ocoee*	*D. monticola**
Ensatina e. klauberi	*Eurycea wilderae**	*Plethodon metcalfi*	*P. shermani x P. teyahalee*
Aquiloeurycea cepahalica	*Pseudotriton ruber**	*Cryptobranchus alleganiensis**	*Necturus maculosus**
Chiropterotriton sp.		*Ambystoma mexicanum*	*Ambystoma opacum*
		*Anaxyrus americanus**	*A. laterale**
		*Hyla chrysoscelis**	*A. maculatum**
		*L. chiricahuensis**	*Lithobates sylvaticus**
		*Scaphiopus holbrooki**	*L. catesbeianus*
3=high mortality; high infection	**2=low – mod mortality; high infection**	**1= No mortality; low infection**	**0=No mortality; No to low infection**

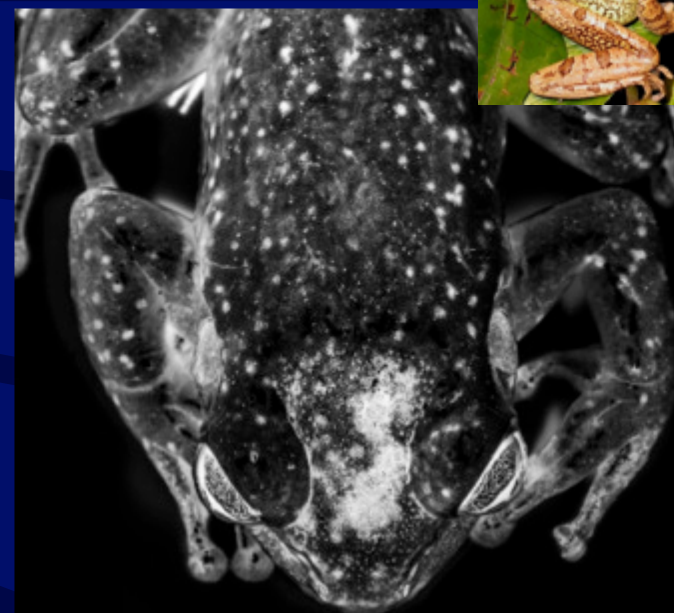
*** = SWAP Species of Greatest Conservation Need**

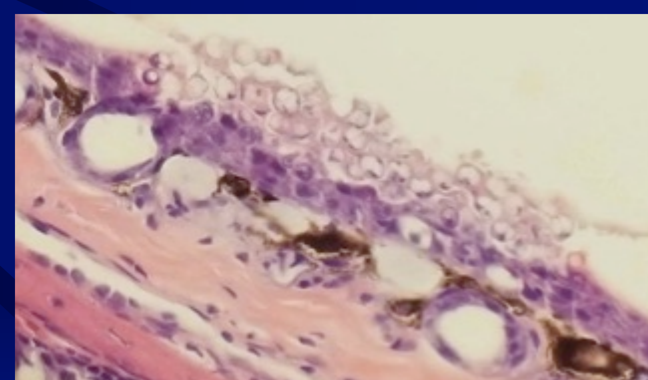
14/21 SGCN (infected)
7/21 (chytridiomycosis)

Results

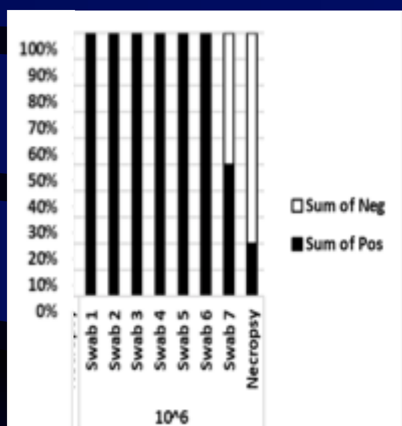
Susceptibility of Frogs

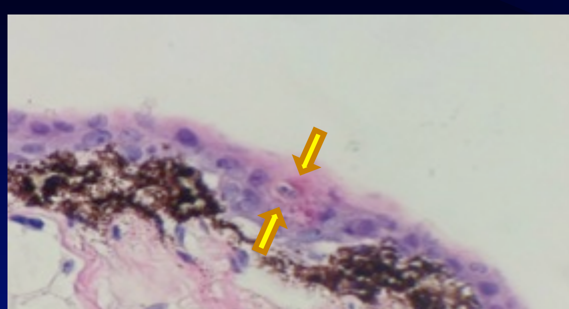
Cuban treefrog



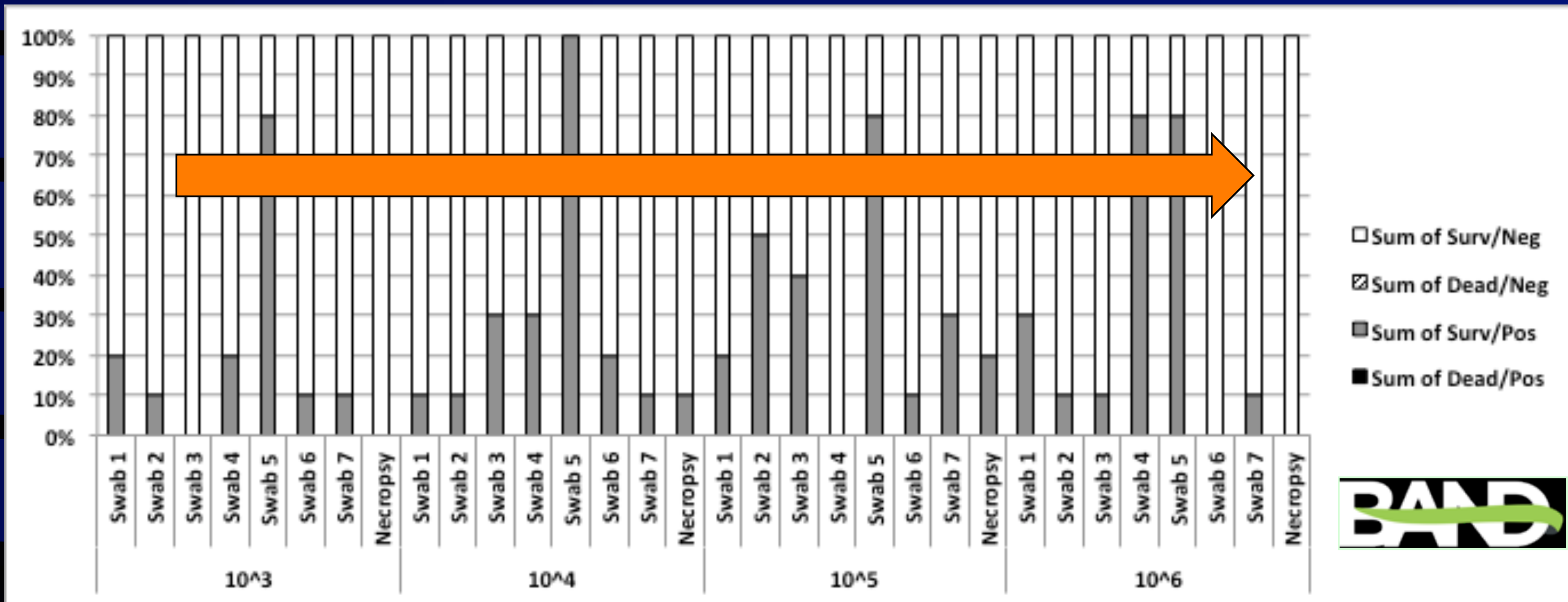


Eastern spadefoot





Mexican Axolotl:
Carrier Species



Infected at all doses and maintained low-grade infections throughout duration of experiment (6 weeks).

Biomedical and Pet Trade

Pathogen Spillover

Initial Evidence

- **Most North American amphibian assemblages will be composed of suitable hosts (75%) with different tolerances to Bsal infection**

USA 4.5x spp. > Europe → **Ample susceptible hosts to facilitate Bsal emergence and persistence**

- **Four of six frog species tested were suitable hosts**

Anurans: 95% of trade → **Host range of Bsal is greater than expected, which increases the likelihood of entry through trade**

- **Significant conservation threat: 30% disease**

→ **Representative sample: potentially 60 species**

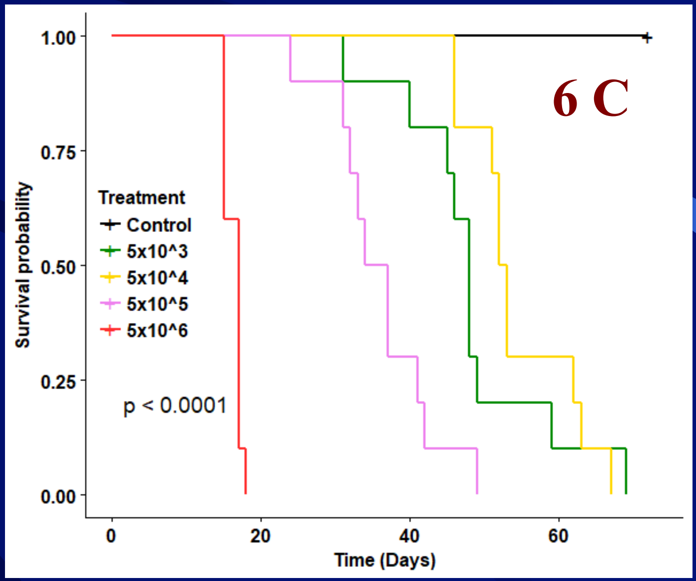
The combination of amplification and carrier species and *suitable environmental conditions* exist in the USA create the "perfect storm" for Bsal emergence.

Temperature Influences Pathogenicity

- **22 C: No infection or disease**
- **14 C: Infection and disease**
  - **Final Mortality = 95%**
  - ***Median survival duration = 18 d**
- **6 C: Infection and disease**
  - **Final Mortality = 100%**
  - ***Median survival duration = 38 d**
  - ***Died at 6X lower infection loads**

Eastern newt, *N. viridescens*

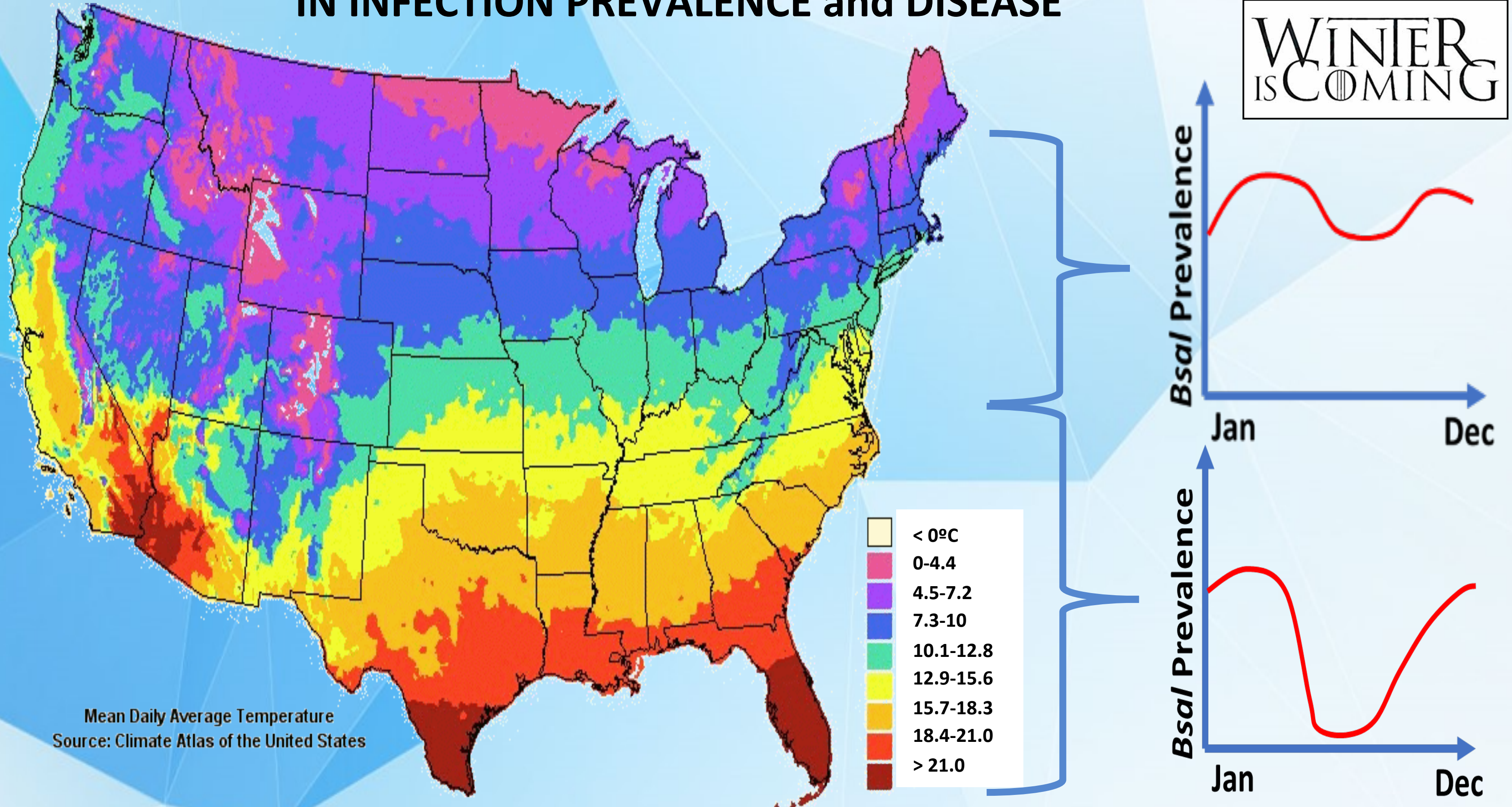
Division of Environmental Biology
Ecology of Infectious Disease Program
Grant #1814520



"White Walker" Effect

Possible Role of Temperature in Bsal Invasion Potential

LATITUDINAL/ALTITUDINAL and SEASONAL DIFFERENCES IN INFECTION PREVALENCE and DISEASE

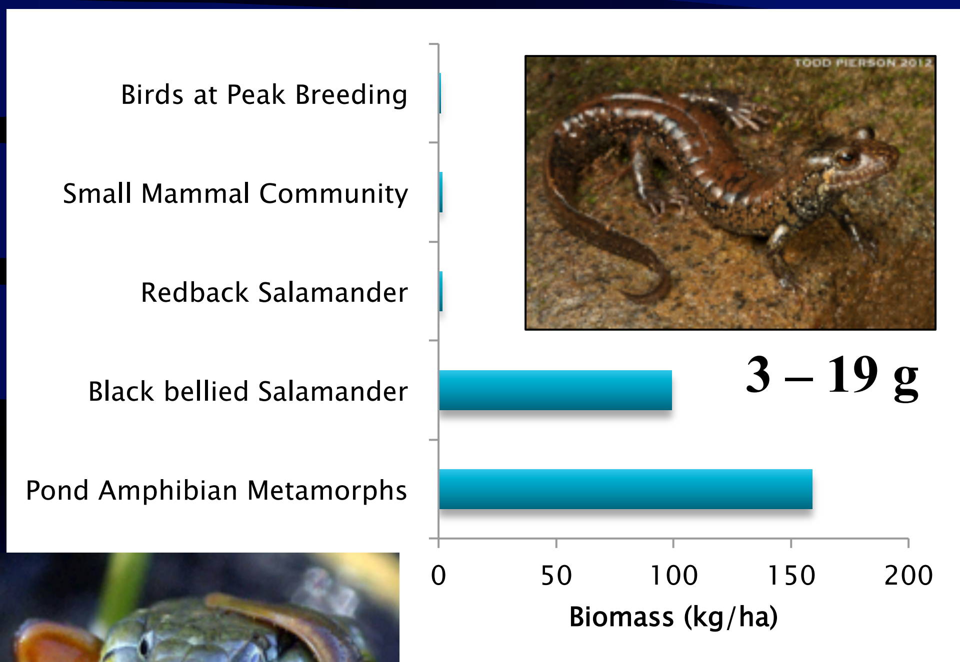


Why Do We Care?

ECOSYSTEM SERVICES OF AMPHIBIANS

1) Ecological and Environmental Benefits

Massive Biomass



- Carbon Sequestration
- Nutrient Cycling
- Food Web Reliance

Why Do We Care?

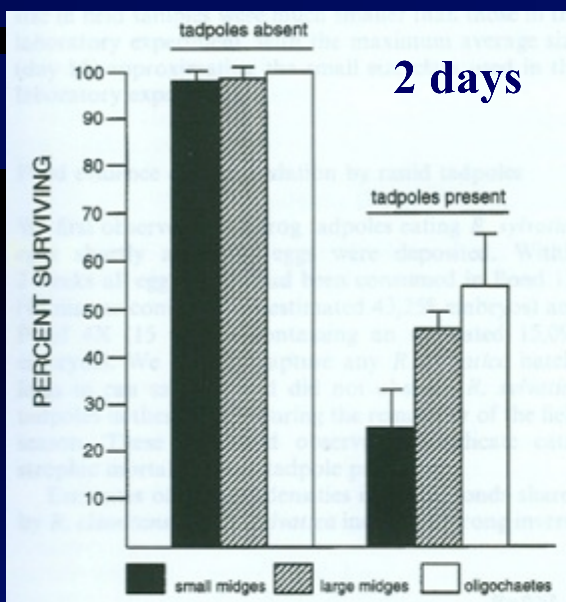
Ecosystem Services of Amphibians

2) Insect Control:

❖ **1000 cricket frogs eat 5 million insects per year:** J. Herpetology 10:63-74

Zoonotic pathogens (malaria, dengue, Zika, WNV, encephalitis)

Macrophagus Predators



Oecologia 120:621-631

Louise Rollins-Smith
(Vanderbilt)

Why Do We Care?

Ecosystem Services of Amphibians

J. Virology 79:11598-11606, Peptides 71:296-303, J Am Chem Soc 114:3475-78, Regeneration 2:54-71, Trends in Genetics 33:553-565

John W. Daly
(NIH)

3) Biomedical Potential:

Antimicrobial Peptides

- Caerin 1.2, 1.9, 1.10, 1.20
- Inhibition of HIV
- Prevent T-cell infection
- Prevent dendritic cell transfer of HIV to T-cells

Skin Toxins: Analgesics

- Epibatidine, dermorphin
- Nicotinic, Opioid receptors
- 20 – 40 X more potent than morphine & not addictive

Limb Regeneration

- Axolotl (*Ambystoma mexicanum*)
- Cell Memory: skin, muscle, connective tissue
- Blastema: undifferentiated cells (stem cells)

Why Do We Care?

ECOSYSTEM SERVICES OF AMPHIBIANS

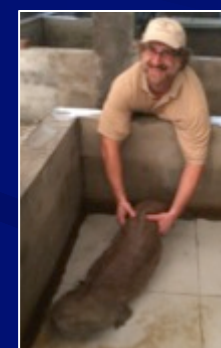
3) Other Biomedical Potential

Trials in rats show possible applications for weight loss, blood pressure regulation, cancer treatment, congestive heart failure, drug addiction

4) Food, Pets, Cultural/Spiritual

23-72 metric tons

Albany, NY



5) Ecological Indicators

Herpetological Conservation and Biology 9(1):1−17.
Submitted: 19 December 2013; Accepted: 25 February 2014; Published: 13 July 2014.

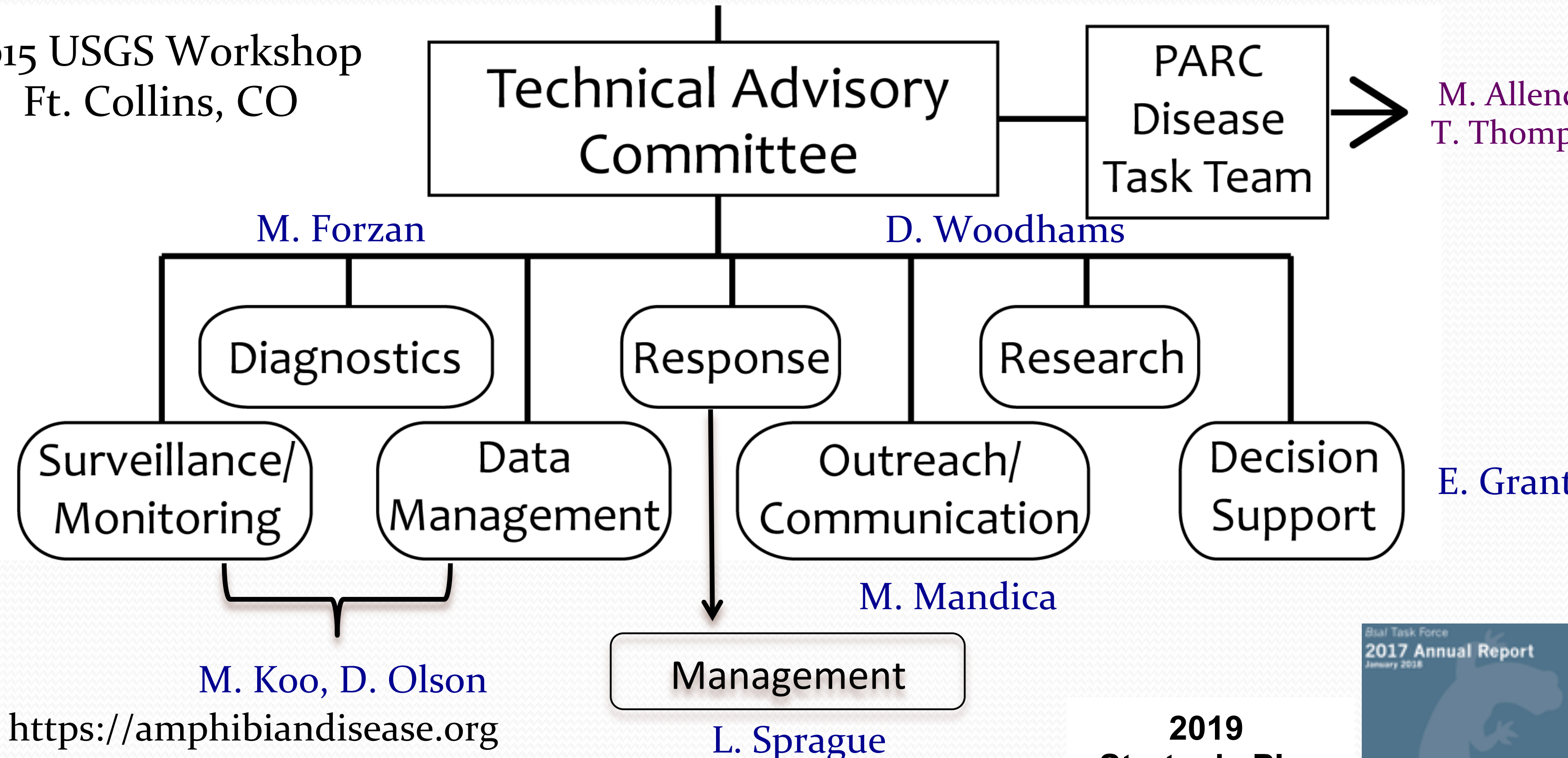
AMPHIBIAN CONTRIBUTIONS TO ECOSYSTEM SERVICES

DANIEL J. HOCKING[1, 2] *AND KIMBERLY J. BABBITT*[1]

North American Bsal Task Force

Jake Kerby, Matt Gray; Chairs

2015 USGS Workshop
Ft. Collins, CO



https://amphibiandisease.org

Salamanderfungus.org

2019 Strategic Plan

2018 Response Plan

What Can You Do?

Facilitating Early Detection and Rapid Response

AN ALERT SYSTEM TO COMBAT EMERGING HERPETOFAUNAL DISEASES

By Matthew J. Gray, Matthew C. Allender, Katherine H. Haman, Reid N. Harris and Deanna H. Olson

http://parcplace.org/resources/parc-disease-task-team/

How to Submit a Report

Anyone who finds an amphibian or reptile with suspicious lesions or observes an unusual die-off event can report it to the Herpetofaunal Disease Alert System. Send an email to herp_disease_alert@parcplace.org with the following information:

1. Name and e-mail address of the observer.
2. Date of observation.
3. What was seen.
4. Where it was seen, ideally latitude-longitude coordinates.
5. The types of animals involved, including species if certain of the identification and life stage, e.g., eggs, larvae, sub-adults or adults.
6. Photos of dead or decayed animals or live, sick-looking animals.
7. Photos of any other relevant information.

Credit: Matthew Niemiller

▲ **Reports of die-offs of amphibians and reptiles such as this one of larval marbled salamanders (*Ambystoma opacum*) in the Great Smoky Mountains National Park help monitor the incidence of herpetofaunal diseases.**

tiny.utk.edu/bsal

Bsal Rap

CENTER FOR WILDLIFE HEALTH
UTIA INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

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Questions?

https://ag.tennessee.edu/fwf/bsalproject/

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