Rock-Paper-Scissors, Viviparity, and Speciation: Links Between Climate Warming and Lizard Extinctions

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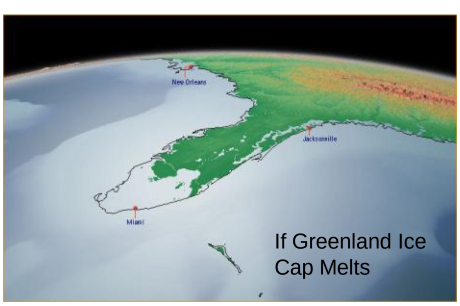
Outline

- **Climate Change & Global Warming – the Basics**
- Meet the "Lizards" (clade Squamata; grade "Sauria")
- The Rock-Paper-Scissors Dynamic, Speciation, & Viviparity
- Early Clues of Unexpected Lizard Declines
- Climate Change as a Driver of Lizard Extinctions

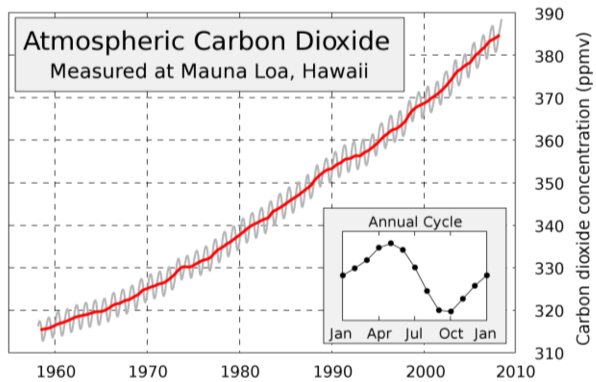


Key Climate Change Questions

1. Is climate changing in unusual ways? If it is, are humans the cause?

2. If climate is changing how large are the expected changes?

3. If climate change will cause significant damage, & is it too late, too difficult, or too expensive to correct or adapt to?



Route to a Scientific Consensus

- Heat-trapping gases & the Greenhouse Effect: Jean Fourier, 1824
- Global Warming: Svante Arrhenius, 1894; doubling CO_2 increases earth temperature 1.5 - 4.0° C
- CO_2 measurement: Roger Revelle, 1957 @ Mauna Loa, Hawaii
- The "Hockey Stick": Mann, Bradley, and Hughes, 1998 and 1999
- IPCC Reports (1990, 1995, 2001, 2007)
- Professional Scientific Societies

Atmosphere: Gasses With 3 or More Atoms will Trap/Hold Heat

Gas	% (Volume)	Source	Variability
~~Nitrogen~~	~~78.08~~	~~Biologic~~	~~permanent~~
~~Oxygen~~	~~20.95~~	~~Biologic~~	~~permanent~~
~~Argon~~	~~0.93~~	~~Radiogenic~~	~~permanent~~
Water (H_20)	0.4 (1-4% at surface)	Evaporation	variable
Carbon dioxide (CO_2)	0.039	Biological, industrial	increasing
Methane (CH_4)	0.00017	Biological	increasing
~~Helium~~	~~0.0005~~	~~Radiogenic~~	~~escaping~~
N_2O	0.00003	Bio/industrial	increasing

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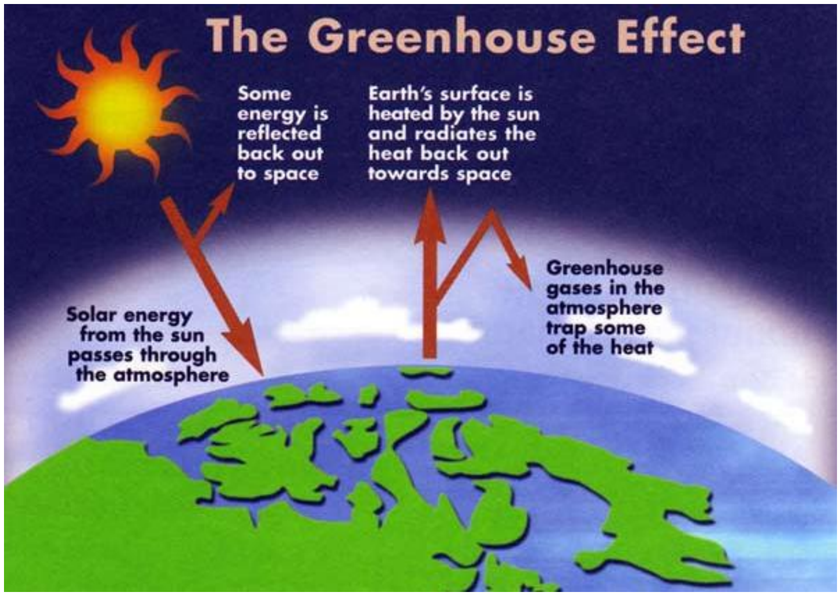
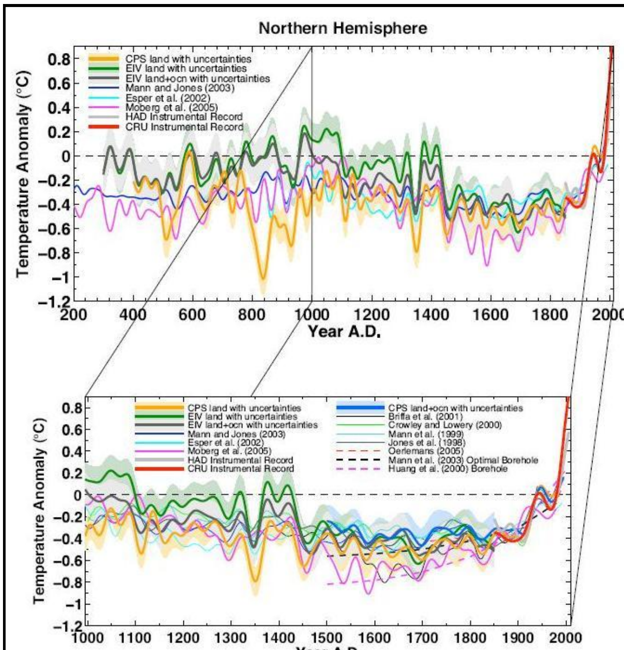
Greenhouse Effect – warming of earth's surface due to heat trapped by gases





2000 years of climate

Including records from:

◆tree-rings,
◆marine sediments,
◆speleothems,
◆lacustrine deposits,
◆ice cores,
◆coral, and
◆historical documentary series (weather records)

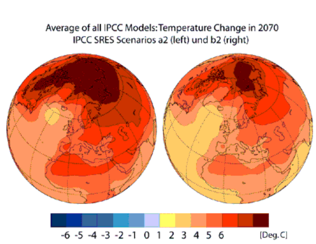
The "hockey stick"; Mann et al. (2008) PNAS 105: 13252-13257

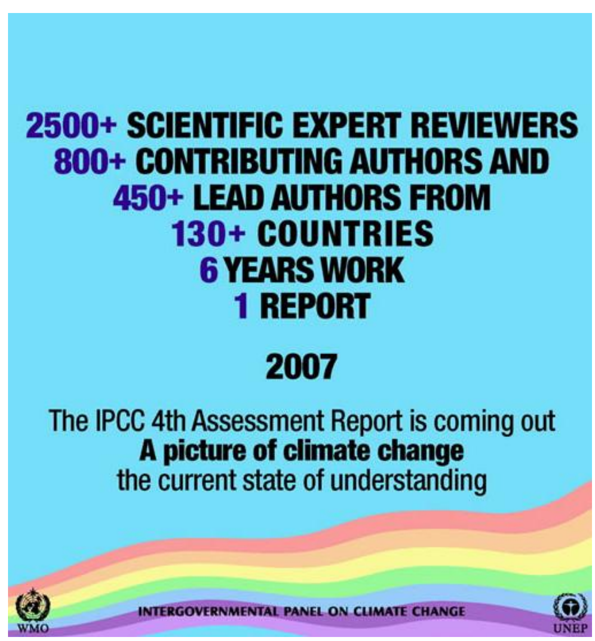
Intergovernmental Panels on Climate Change (IPCC)

- IPCC 1: 1990
- IPCC 2: 1995
- IPCC 3: 2001, Working Group 1: The Scientific Basis
  - 122 lead authors
  - 515 contributing authors
  - 420 independent reviewers
  - Several hundred government and other relevant reviewers
  - Consensus: **~ 65% probability of significant human impact**

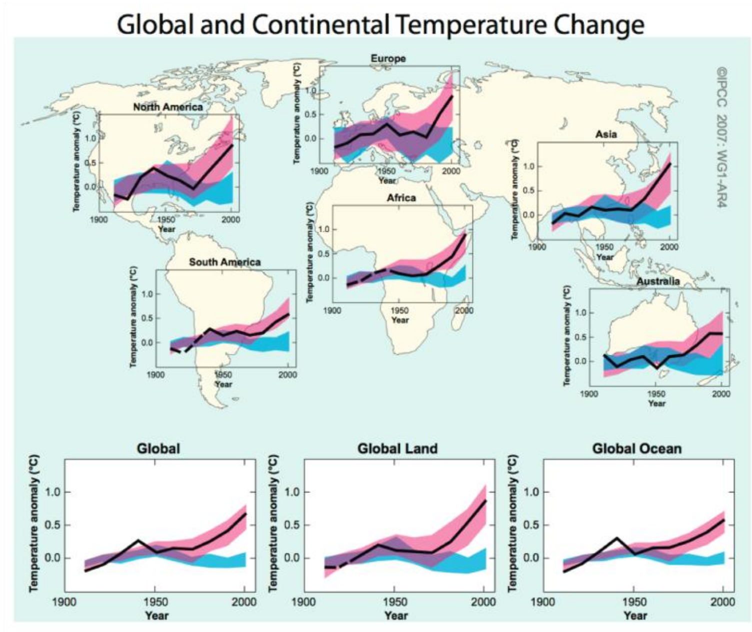
IPCC Timeline cont'd.

- IPCC 4: **90% probability of significant human impact**





Climate Models: **Observed**, **Predicted** and **Null** model (no anthropogenic effect)



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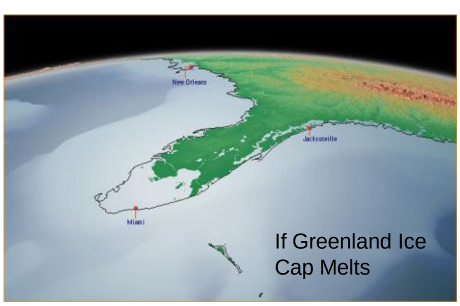
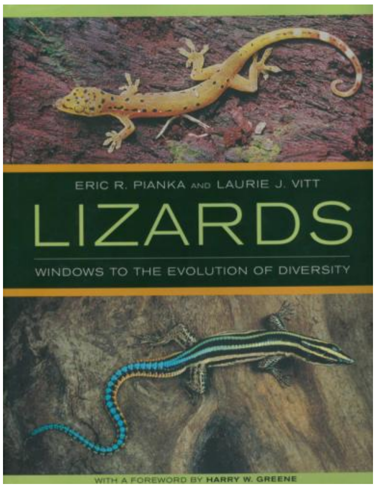
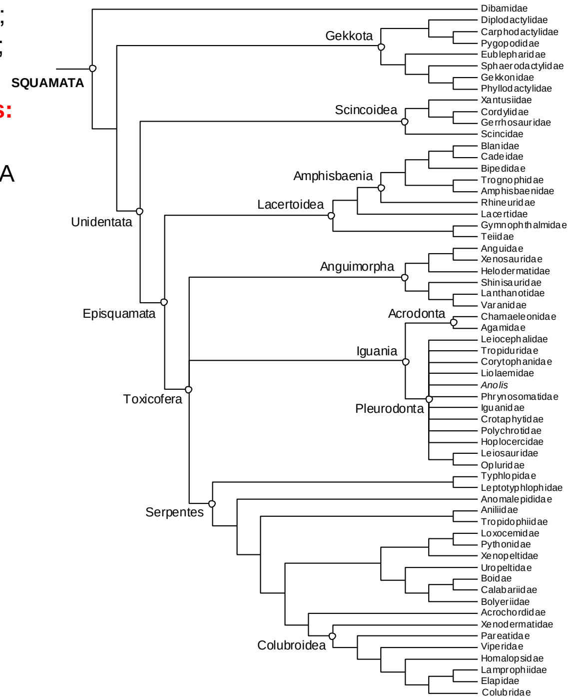


Clade **SQUAMATA –** "scaly";
lizards, snakes, & amphisbaenians;

Most recent summary (Uetz et al., 2011), **> 9,000 species/61 families:**

Fig. at right – best estimate of phylogenetic relationships from DNA





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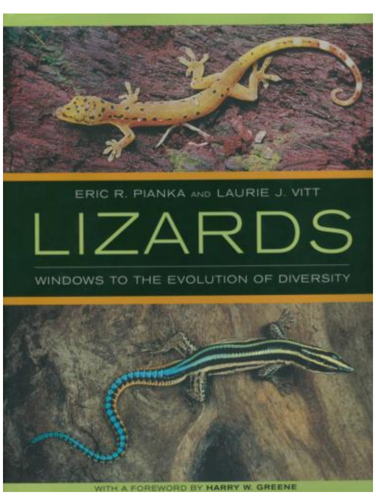
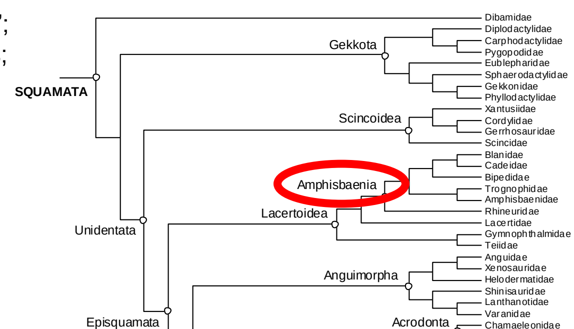
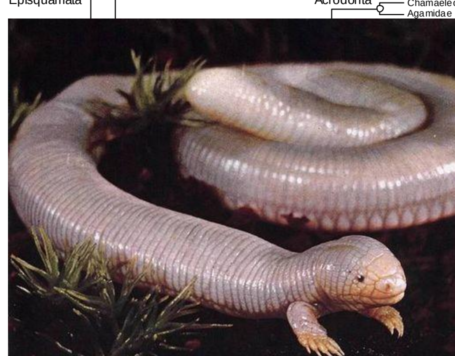
Amphisbaenians (~ 160 sp.)







Clade **SQUAMATA** – "scaly"; lizards, snakes, & amphisbaenians;

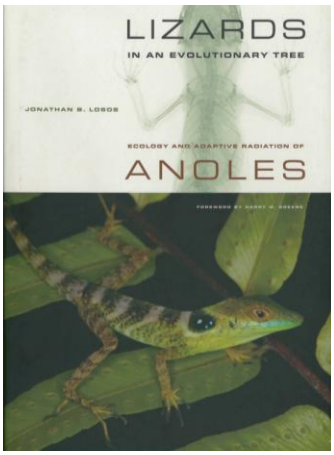
Most recent summary (Uetz et al., 2011) , > 9,000 species/61 families:

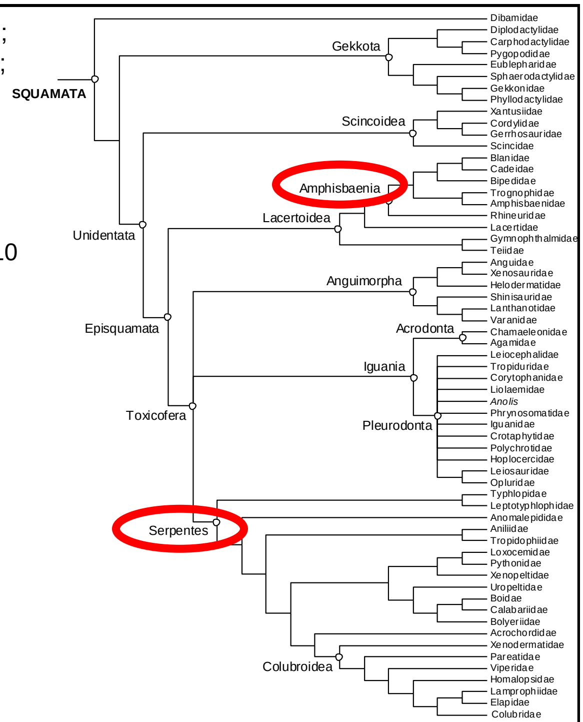
Amphisbaenians (~ 160 sp.)

Snakes (3,315 sp.)

Lizards (5,642 sp.); paraphyletic

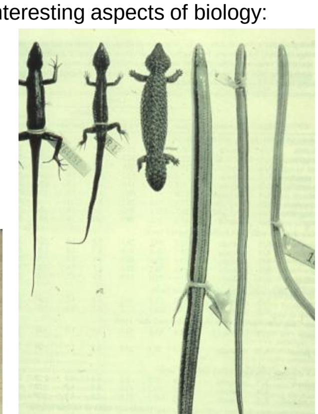
>100 new species described in 2010





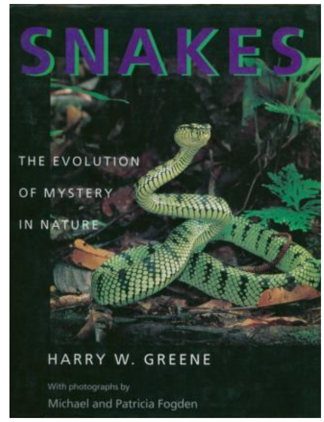
Clade **SQUAMATA** – **model systems** for studies of many interesting aspects of biology:

- ~150 independent origins of **toe fringes**
- ~ 107 independent origins of **viviparity**
- ~ 40 independent origins of **true parthenogenesis**
- ~ 25 independent transitions from 4-limbed lizard-like body form to **elongate limb-reduced/limbless snake-like body form**



Clade **SQUAMATA –** "scaly"; lizards, snakes, & amphisbaenians; general features of biology:

- multiple origins of **venoms & venom-delivery systems**



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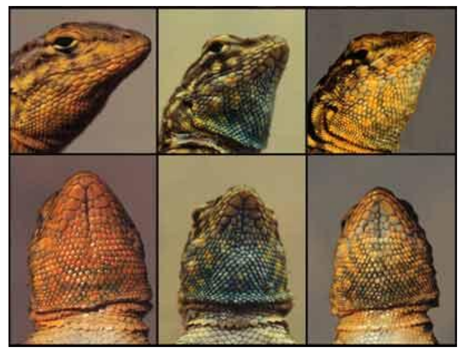
Family: **PHRYNOSOMATIDAE** - the cast of characters:**10 genera/~110+ species**; the games lizards play – the "rock-paper-scizzors" mating strategy in *Uta stansburiana*

Dr. Barry Sinervo (UCSC) - **orange, blue, and yellow-throated males**;

single gene locus (called OBY) controls this trait, with the **O and B alleles co-dominant to each other; both dominant to** Y;

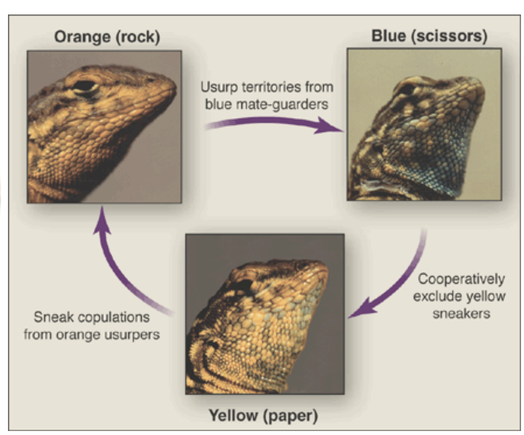
the three can co-exist because all have alternative mating strategies . . . .



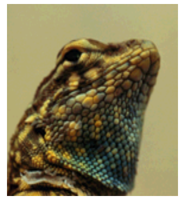
Strategy 1: Have a Lot of Territory – **O males** establish **<u>large territories</u>** occupied by several females, and here the more females present, the more often the male can mate;

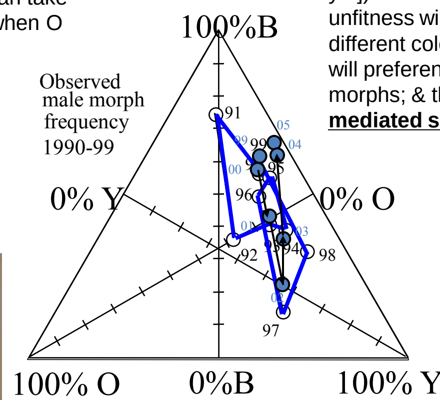
Strategy 2: Guard Your Mate – **B males** defend **<u>small territories</u>** holding just a few females, but because the territories are so small, males can more carefully guard their mates; or

Strategy 3: Be Sneaky – **Y males <u>mimic the markings and behavior of females</u>**, and can invade (undetected) the large territories of O males, and 'sneak' copulations (**= cuckoldry**)



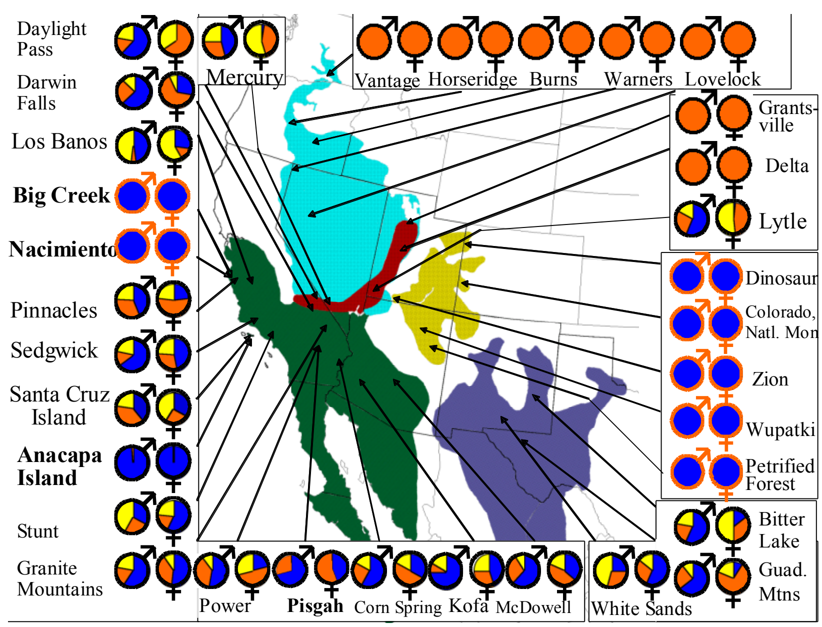
RPS cycle: classic example of **frequency-dependent selection**, each morph has a selective advantage when it is rare; O is common and can take territories from B males, but O is subject to invasion & **cuckoldry** by "sneaker males" when Y is rare; then B can take more territories from Y when O is rare, etc.



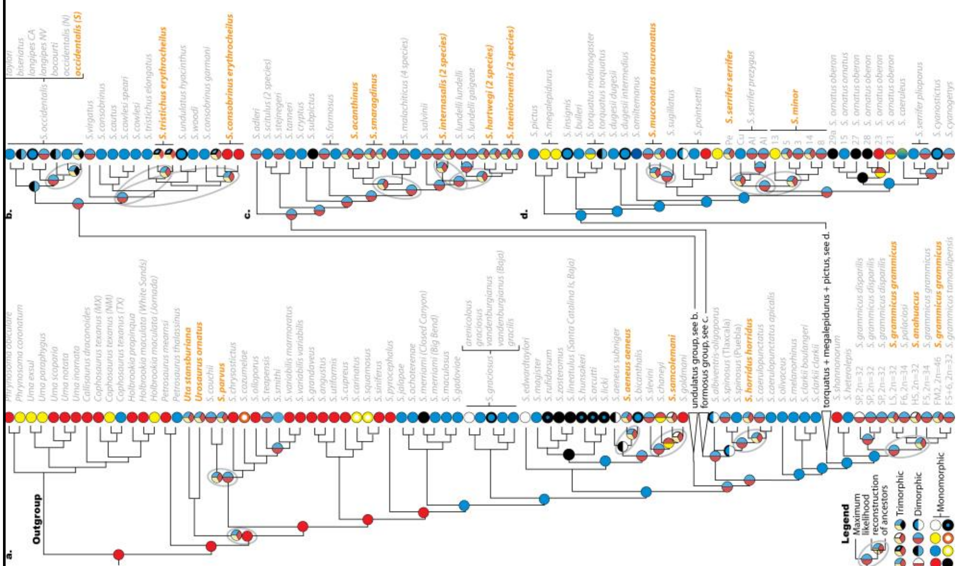


RPS cycle: **reproductive isolation can evolve within a polymorphic system like this**, given 2 other loci: one for mate choice, & one mediating social interactions (altruistic donation) – all present in *Uta* (based on gene mapping and field pedigree studies of > 7,700 lizards at Los Banos site [22 yrs]). Under some conditions hybrid unfitness will be generated when different color morphs meet – morphs will preferentially mate with their own morphs; & this **may lead to socially-mediated speciation**

Ammon Corl et al. PNAS (2010), Evolution (2009); variation in *U. stansburiana* RPS system; perhaps 15 - 20 species? (Mulcahy et al. in prep.)

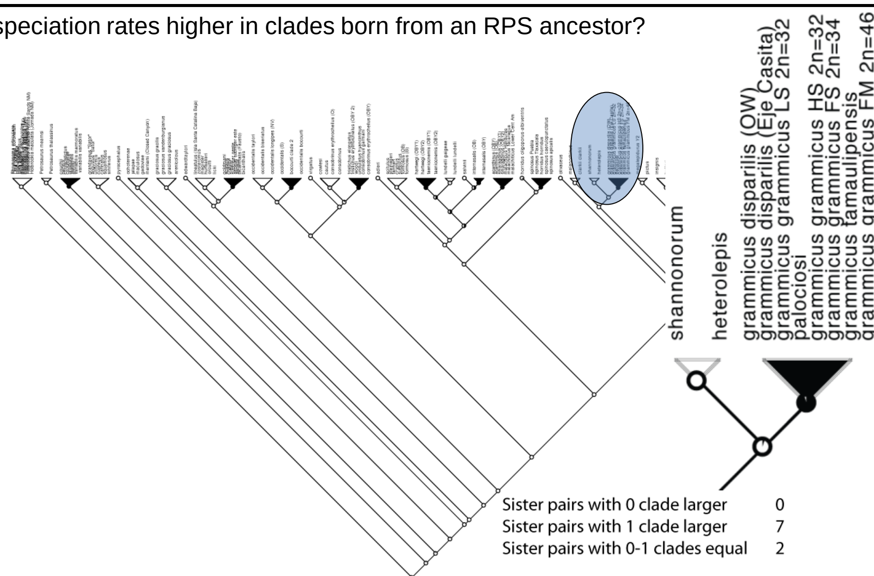


Phylogenetic history of RPS evolution in the Phrynosomatidae (Sinervo et al. in prep.)



RPS system arose at least 15 mya in *Uta*, and is associated with high speciation rates.

Are speciation rates higher in clades born from an RPS ancestor?



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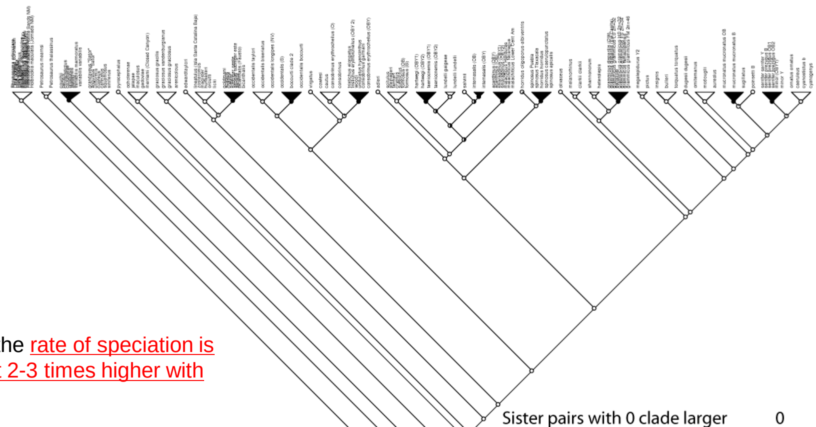
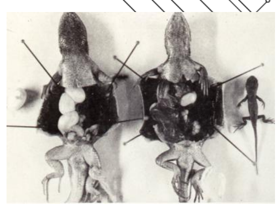


Yes, the rate of speciation is about 2-3 times higher with RPS;

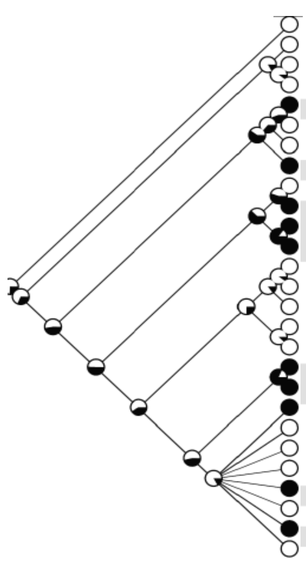
RPS dynamic drives a speciation process, and is **linked to the evolution of viviparity**



Sister pairs with 0 clade larger	0
Sister pairs with 1 clade larger	7
Sister pairs with 0-1 clades equal	2

Sister Diversification Binomial P= 0.0078125

Morphs, lizard families, & RPS speciation: not just *Uta* & Phrynosomatidae



Family	N Spp.	Mya	Rate of speciation		
Dibamidae	19	176.4	0.06	0	
Eublepharidae	20	75.7	0.26	0	
Pygopodidae	36	51.9	0.67	0	
Gekkonidae	1076	63.7	**13.74**	0	
Cordylidae	54	60.3	**0.70**	1	
Gerrhosauridae	32	60.3	0.58	0	
Xantusiidae	25	143.8	0.14	0	
Scincidae	1305	94.4	**0.70**	1	
Aniellidae	2	70	0.03	0	
Lacertidae	279	70	**3.99**	1	**RPS**
Teiidae	121	51	**2.45**	1	
Gymnophthalmidae	193	69	**2.32**	1	
Helodermatidae	2	99	0.02	0	
Anguidae	112	69	1.59	0	
Xenosauridae	7	101	0.04	0	
Lanthonotidae	1	65	0.02	0	
Varanidae	59	65	0.78	0	
Agamidae	381	78.5	**5.49**	1	
Chameleonidae	161	78.5	**1.66**	1	
Tropiduridae	309	74.5	1.21	0	
Hoplocercidae	11	74.5	0.13	0	
Iguanidae	36	74.5	0.46	0	
Opluridae	7	74.5	0.09	0	
Polychrotidae	393	74.5	**6.04**	**1**	
Crotophytidae	12	74.5	0.16	0	
Phrynosomatidae	125	74.5	**1.68**	1	**RPS**
Corytophanidae	9	74.5	0.13	0	

Speciation rate is **5 x higher** in polymorphic compared to monomorphic taxa

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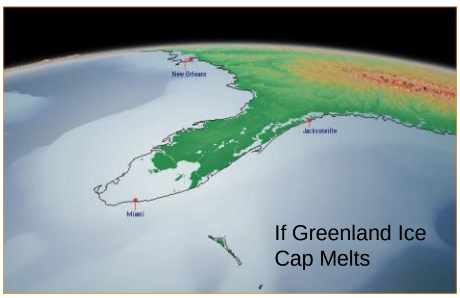
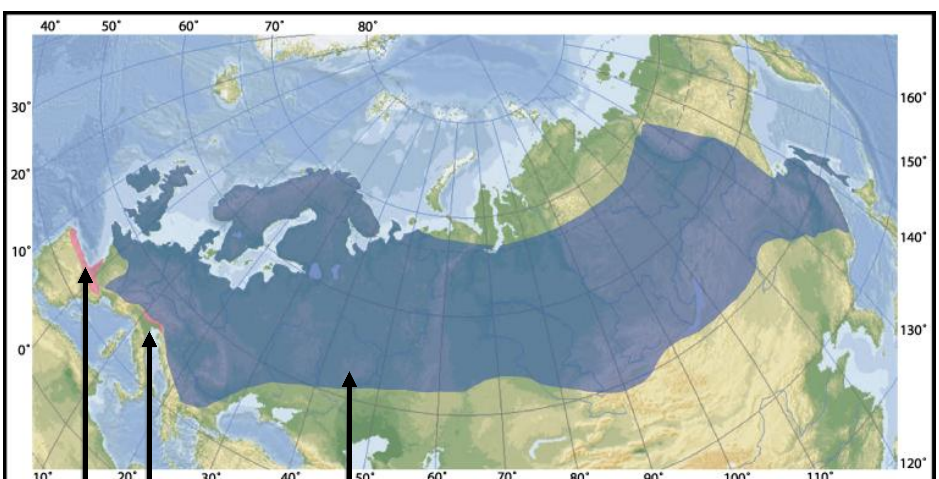
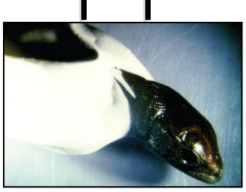
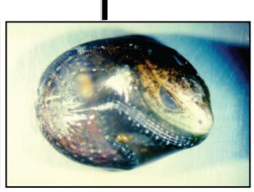
  - ***Lacerta*** **in Eurasia**
  - ***Sceloporus*** **in Mexico**
- Climate Change as a Driver of Lizard Extinctions



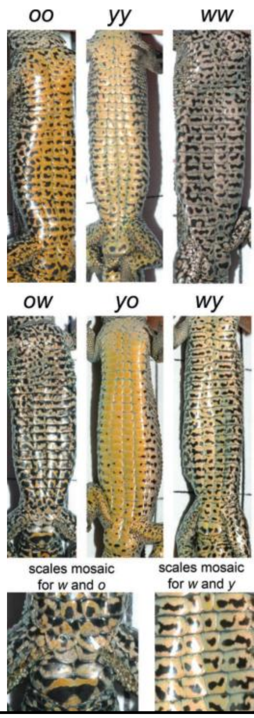






Sinervo off to Europe (2001) to study RPS system in*Lacerta vivipara*, the European Common lizard in which both parity modes are present

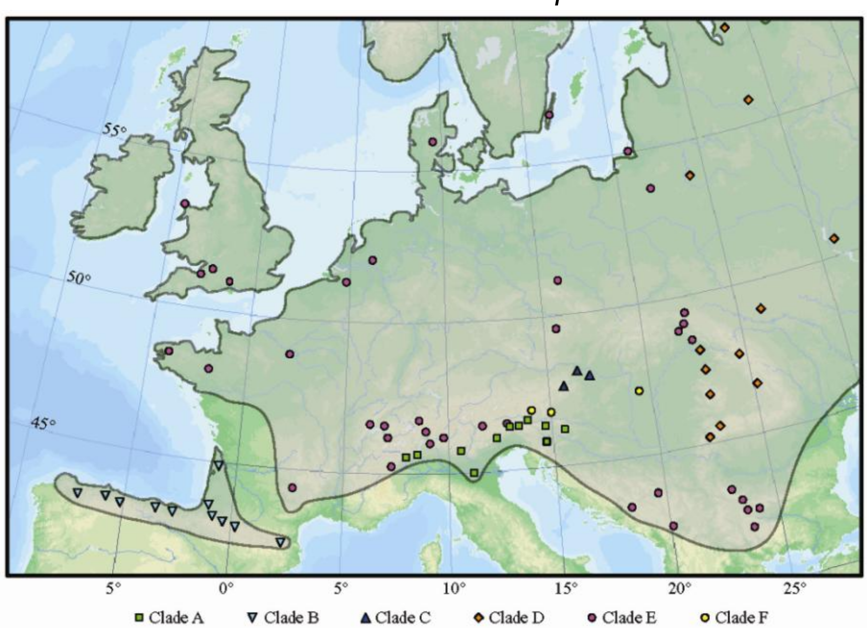
Collaborators: Benoit Heulin and Jean Clobert



RPS in *Lacerta vivipara* parallel to *Uta stansburiana*

- Resampled sites visited by B. Heulin (1980s); 100+ sites across Europe (N=117 and counting)
- J. Clobert and Sinervo had started a global climate change project in France (focused on the Massif Central and the Pyrenees of France); a goal was to quantify adaptation of lizard populations to warming at these sites
- They immediately discovered 6 “species” (well-supported clades defined by sequence data) likely due to RPS speciation processes

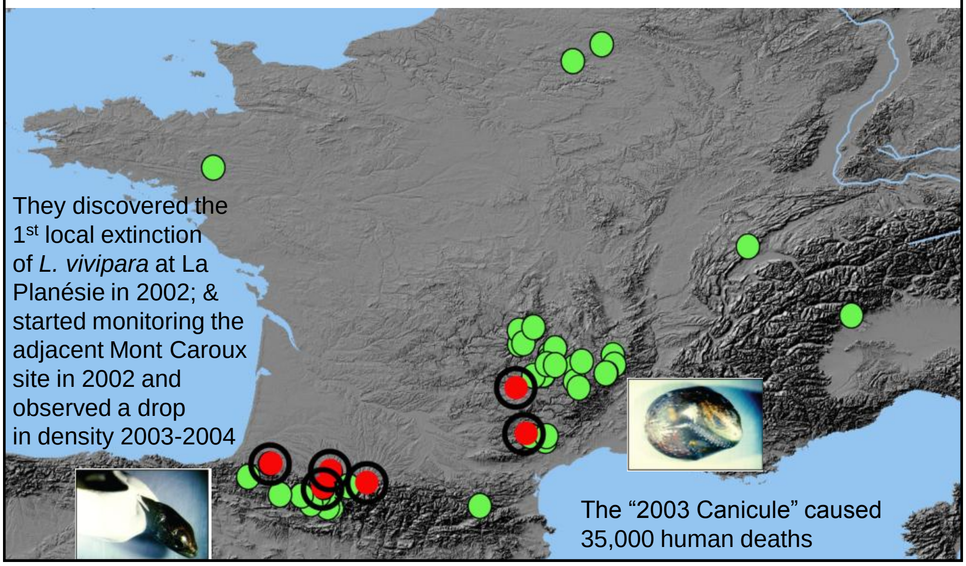
6 Clades of *Lacerta vivipara*

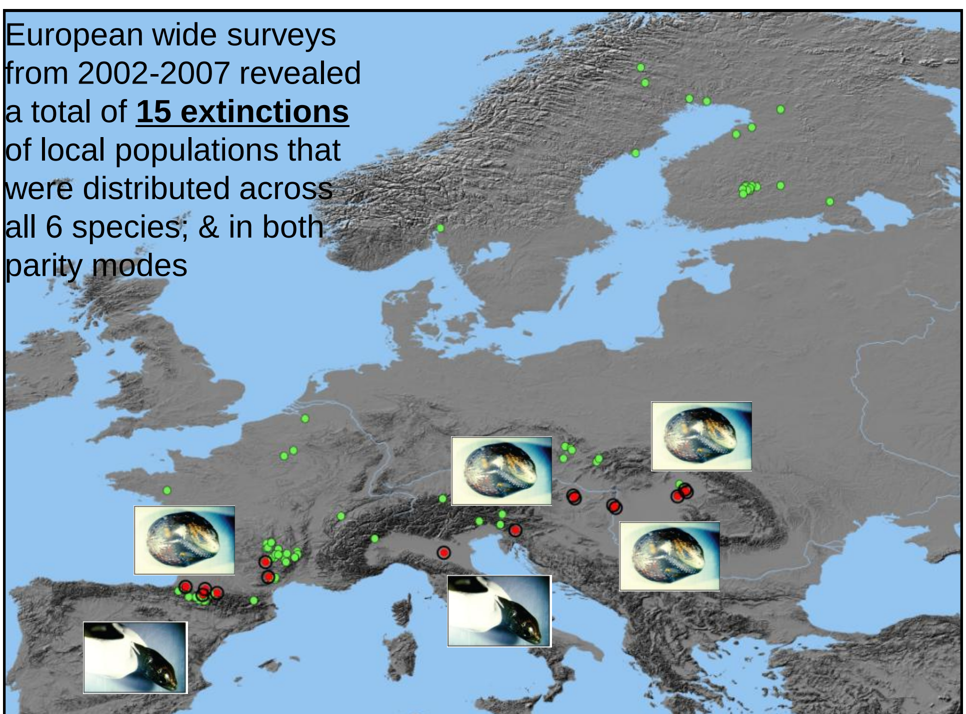


Surget-Groba et al. 2001, 2006

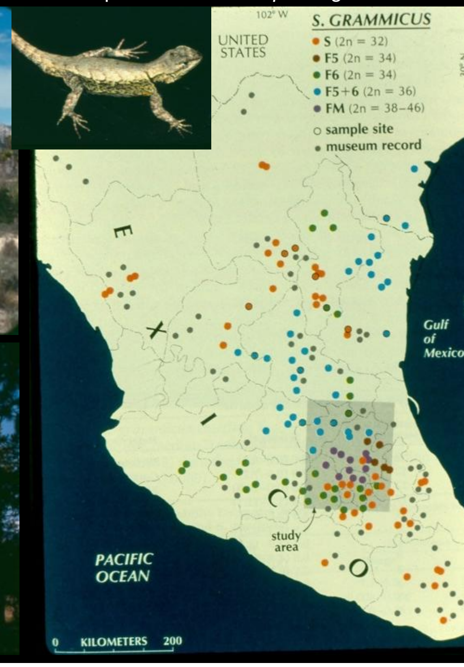
Massif Central: Sinervo located about 20 populations in the Massif Central, which he & J. Clobert started surveying every 2 years (with Virginie Lepetz and Don Miles)

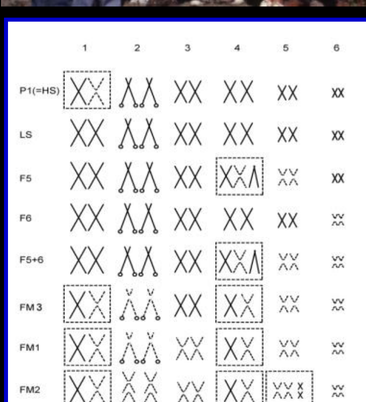
Pyrenees: B. Heulin and Sinervo started detailed demographic studies in 2004 of 5 populations in the Pyrenees, and they have resurveyed 20 populations in total

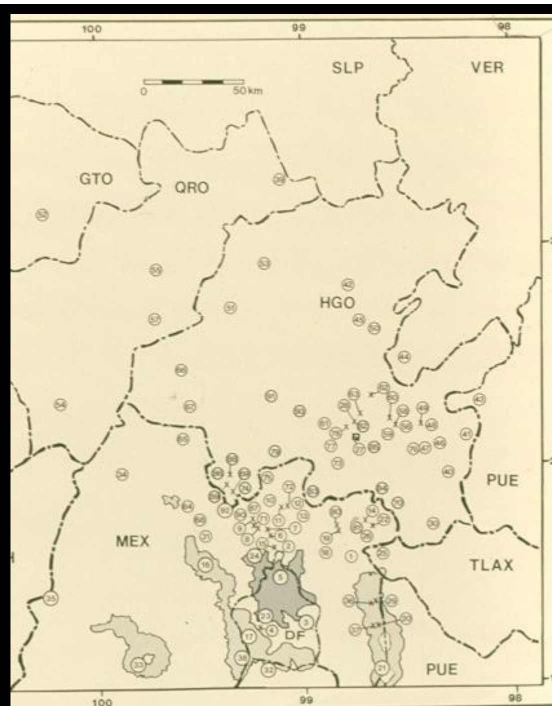




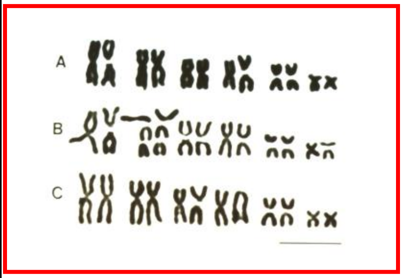
Family: **PHRYNOSOMATIDAE**; J. Sites' early studies (started in1977) of chromosomal polymorphism/speciation potential in the viviparous Mesquite Lizard: *Sceloporus grammicus*







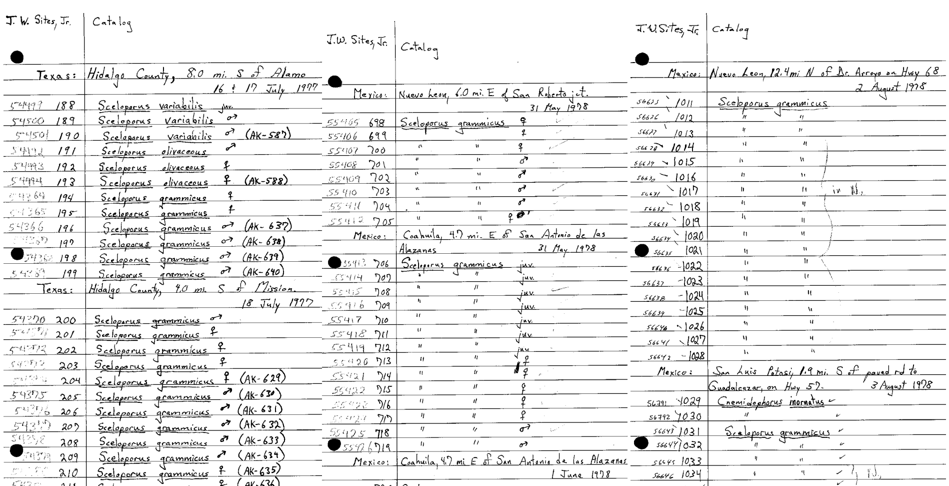
Sceloporus grammicus complex – a model in speciation research



2N = 32 – 46 (females)

- **Hall (1973)**
- **Sites (1983)**
- **Porter & Sites (1986)**
- **Arévalo et al. (1991)**

Sceloporus grammicus complex – a case of disappearing populations



J. W. Sites, Jr. | Catalog

Texas: Hidalgo County, 8.0 mi. S of Alamo, 16 & 17 July 1977

[illegible]	188	Sceloporus variabilis	juv.	
54500	189	Sceloporus variabilis	♂	
54501	190	Sceloporus variabilis	♂	(AK-587)
[illegible]	191	Sceloporus olivaceous	♂	
54493	192	Sceloporus olivaceous	♀	
[illegible]	193	Sceloporus olivaceous	♀	(AK-588)
[illegible]	194	Sceloporus grammicus	♀	
[illegible]	195	Sceloporus grammicus	♀	
54366	196	Sceloporus grammicus	♂	(AK-637)
[illegible]	197	Sceloporus grammicus	♂	(AK-638)
[illegible]	198	Sceloporus grammicus	♂	(AK-639)
[illegible]	199	Sceloporus grammicus	♂	(AK-640)

Texas: Hidalgo County, 4.0 mi. S of Mission, 18 July 1977

[illegible]	200	Sceloporus grammicus	♂	
[illegible]	201	Sceloporus grammicus	♀	
[illegible]	202	Sceloporus grammicus	♀	
[illegible]	203	Sceloporus grammicus	♀	
[illegible]	204	Sceloporus grammicus	♀	(AK-629)
54375	205	Sceloporus grammicus	♂	(AK-630)
[illegible]	206	Sceloporus grammicus	♂	(AK-631)
[illegible]	207	Sceloporus grammicus	♂	(AK-632)
[illegible]	208	Sceloporus grammicus	♂	(AK-633)
[illegible]	209	Sceloporus grammicus	♂	(AK-634)
[illegible]	210	Sceloporus grammicus	♀	(AK-635)
[illegible]	211	Sceloporus grammicus	♀	(AK-636)

J.W. Sites, Jr. | Catalog

Mexico: Nuevo Leon, 6.0 mi. E of San Roberto jct., 31 May 1978

55405	698	Sceloporus grammicus	♀
55406	699		♀
55407	700	" "	♀
55408	701	" "	♂
55409	702	" "	♂
55410	703	" "	♂
55411	704	" "	♂
55412	705	" "	♀

Mexico: Coahuila, 4.7 mi. E of San Antonio de las Alazanas, 31 May 1978

55413	706	Sceloporus grammicus	juv.
55414	707	" "	juv.
55415	708	" "	juv.
55416	709	" "	juv.
55417	710	" "	juv.
55418	711	" "	juv.
55419	712	" "	juv.
55420	713	" "	♀
55421	714	" "	♀
55422	715	" "	♀
[illegible]	716	" "	♀
[illegible]	717	" "	♀
55425	718	" "	♂
55426	719	" "	♂

Mexico: Coahuila, 4.7 mi E of San Antonio de las Alazanas, 1 June 1978

55427	720	Sceloporus grammicus	juv.

J. W. Sites, Jr. | Catalog

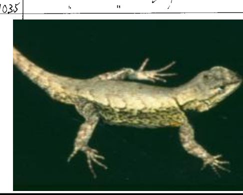
Mexico: Nuevo Leon, 12.4 mi N of Dr. Arroyo on Hwy 68, 2 August 1978

56625	1011	Sceloporus grammicus
56626	1012	" "
56627	1013	" "
56628	1014	" "
56629	1015	" "
56630	1016	" "
56631	1017	" " in N.
56632	1018	" "
56633	1019	" "
56634	1020	" "
56635	1021	" "
56636	1022	" "
56637	1023	" "
56638	1024	" "
56639	1025	" "
56640	1026	" "
56641	1027	" "
56642	1028	" "

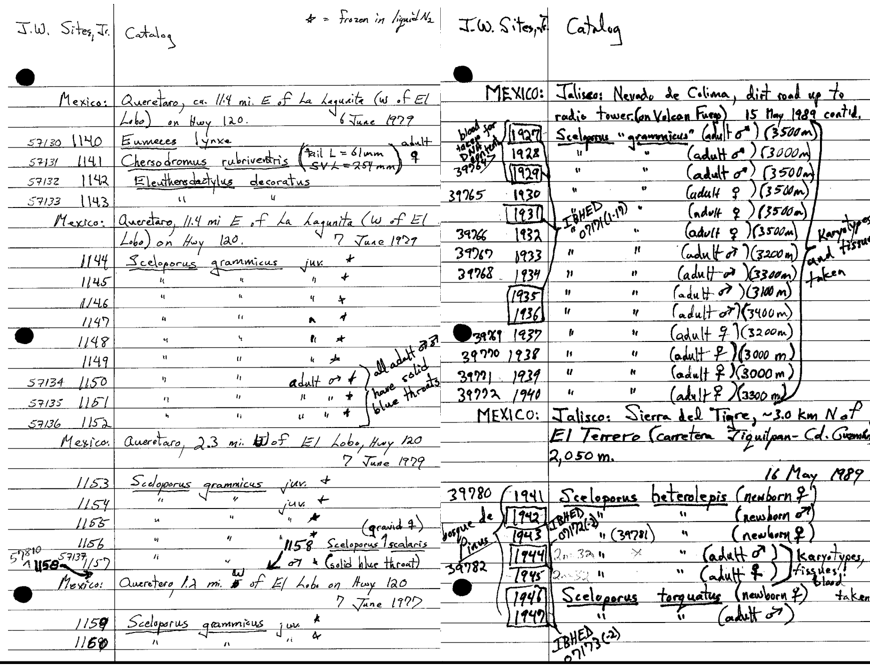
Mexico: San Luis Potosi, 1.9 mi. S of paved rd to Guadalcazar, on Hwy 57. 3 August 1978

56791	1029	Cnemidophorus inornatus
56792	1030	"
56643	1031	Sceloporus grammicus
56644	1032	" "
56645	1033	" "
56646	1034	" "
56647	1035	" "

Samples of J. Sites' field catalog for sampling in southern Texas & several localities in north-central Mexico (1977 – 1978)



Documenting extinctions: 2006 – 08; B. Sinervo & F. Mendez re-survey of **48 *Sceloporus* @ 200 localities in Mexico; originally sampled 1975-95**; 12% of these showed local extinctions by 2009


J.W. Sites, Jr. | Catalog | * = frozen in liquid N_2

Mexico: Queretaro, ca. 11.4 mi. E of La Laguinita (W of El Lobo) on Hwy 120. 6 June 1979

57130 1140 Eumeces lynxe adult

57131 1141 Cherodromus rubriventris (tail L = 61mm, SVL = 25 mm) ♀

57132 1142 Eleutherodactylus decoratus

57133 1143 "

Mexico: Queretaro, 11.4 mi E of La Laguinita (W of El Lobo) on Hwy 120. 7 June 1979

1144 Sceloporus grammicus juv. *

1145 – 1149 " " " *

57134 1150 " " adult ♂ * (all adult ♂♂ have solid blue throats)

57135 1151 " " " *

57136 1152 " " " *

Mexico: Queretaro, 2.3 mi. W of El Lobo, Hwy 120. 7 June 1979

1153 Sceloporus grammicus juv. *

1154 " " juv. *

1155 " " " *

1156 " " " (gravid ♀)

57137 1157 " " ♂ * (solid blue throat)

57810 1158 Sceloporus scalaris

Mexico: Queretaro 1.2 mi. W of El Lobo on Hwy 120. 7 June 1979

1159 Sceloporus grammicus juv. *

1160 " " " *

J.W. Sites, Jr. | Catalog

MEXICO: Jalisco: Nevado de Colima, dirt road up to radio tower (on Volcan Fuego) 15 May 1989 cont'd.

1927 Sceloporus "grammicus" (adult ♂) (3500m)

1928 " " (adult ♂) (3000m)

39764 1929 " " (adult ♂) (3500m)

39765 1930 " " (adult ♀) (3500m)

1931 " " (adult ♀) (3500m)

39766 1932 " " (adult ♀) (3500m)

39767 1933 " " (adult ♂) (3200m)

39768 1934 " " (adult ♂) (3300m)

1935 " " (adult ♂) (3100m)

1936 " " (adult ♂) (3400m)

39769 1937 " " (adult ♀) (3200m)

39770 1938 " " (adult ♀) (3000 m)

39771 1939 " " (adult ♀) (3000 m)

39772 1940 " " (adult ♀) (3300 m)

(blood for tissue DNA taken; IBHED 07171(1-11); Karyotypes and tissue taken)

MEXICO: Jalisco: Sierra del Tigre, ~3.0 km N of El Terrero (carretera Tiquilpan - Cd. Guzmán) 2,050 m. 16 May 1989

39780 1941 Sceloporus heterolepis (newborn ♀)

1942 " " (newborn ♂)

1943 " (39781) " (newborn ♀)

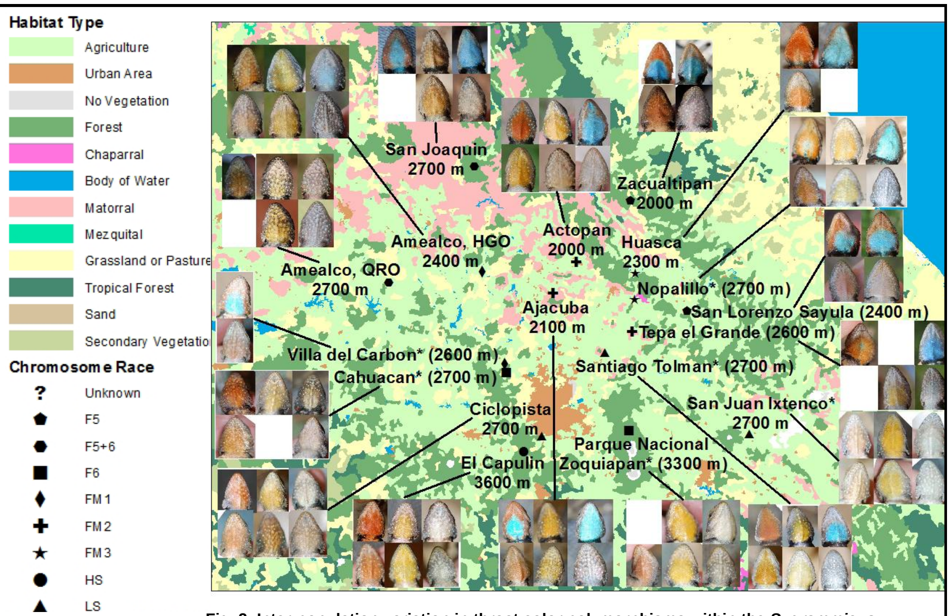
1944 " " (adult ♂)

39782 1945 " " (adult ♀)

1946 Sceloporus torquatus (newborn ♀)

1947 " " (adult ♂)

(bosque de Pinus; IBHED 07172(1-3); IBHED 07173(1-2); Karyotypes, tissues, blood taken)



E. Bastiaans; F. Mendez, & B. Sinervo

Fig. 2: Inter-population variation in throat color polymorphisms within the *S. grammicus* complex in northern (above) and central México. Colors denote habitat types, while the shape of the marker at each population corresponds to the chromosome race present there (shown in key at left). Lizard photos are arranged with male morphs above female morphs. At Cerro Peña Nevada and San Antonio de las Alazanas, morphs varied by elevation.

Sceloporus chaneyi (dimorphic with respect to alleles), in *S. aeneus* group

male morphs | female morphs

yy

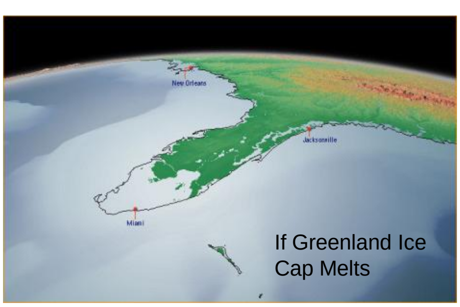
yo

oo

Beth Bastiaans resurveyed many of the 2007 sites for *S. chaneyi*, and has found new extinctions. The related *S. goldmani* (viviparous) will almost certainly be totally extinct within 10 years

Outline

- Climate Change & Global Warming – the Basics
- Meet the "Lizards" (clade Squamata; grade "Sauria")
- The Rock-Paper-Scissors Dynamic, Speciation, & Viviparity
- Early Clues of Unexpected Lizard Declines
- **Climate Change as a Driver of Lizard Extinctions**



Global climate change (GCC) affects organisms in all biomes & ecosystems; with sufficient time/dispersal capability, species may adjust by:

- shifting distributions to more favorable thermal environments
- adapting to modified local environments by behavioral/physiological plasticity, or via directional selection (given sufficient h^2); or
- failing to do these things → demographic collapse & extinction

Science AAAS

Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches

Barry Sinervo,[1,15]* Fausto Méndez-de-la-Cruz,[2] Donald B. Miles,[3,15] Benoit Heulin,[4] Elizabeth Bastiaans,[1] Maricela Villagrán-Santa Cruz,[5] Rafael Lara-Resendiz,[2] Norberto Martínez-Méndez,[2] Martha Lucía Calderón-Espinosa,[6] Rubi Nelsi Meza-Lázaro,[2] Héctor Gadsden,[7] Luciano Javier Avila,[8] Mariana Morando,[8] Ignacio J. De la Riva,[9] Pedro Victoriano Sepulveda,[10] Carlos Frederico Duarte Rocha,[11] Nora Ibargüengoytía,[12] César Aguilar Puntriano,[13] Manuel Massot,[14] Virginie Lepetz,[15]† Tuula A. Oksanen,[16] David G. Chapple,[17] Aaron M. Bauer,[18] William R. Branch,[19] Jean Clobert,[15] Jack W. Sites Jr.[20]

It is predicted that climate change will cause species extinctions and distributional shifts in coming decades, but data to validate these predictions are relatively scarce. Here, we compare recent and historical surveys for 48 Mexican lizard species at 200 sites. Since 1975, 12% ofl ocal populations have gone extinct. We verified physiological models of extinction risk with observed local extinctions and extended projections worldwide. Since 1975, we estimate that 4% ofl ocal populations have gone extinct worldwide, but by 2080 local extinctions are projected to reach 39% worldwide, and species extinctions may reach 20%. Global extinction projections were validated with local extinctions observed from 1975 to 2009 for regional biotas on four other continents, suggesting that lizards have already crossed a threshold for extinctions caused by climate change.

Current forecasting models are not calibrated with actual extinction events (range shifts, species/area relationships, etc.); **empirical validation of global extinction forecasts requires three forms of evidence:**

- **1 – actual extinctions should be linked to <u>macroclimate patterns</u> and validated to biophysical thermal causes arising from <u>microclimate</u>.**
- 2 – the pace of climate change should compromise thermal adaptation, such that evolutionary rates lag behind global warming due to constraints on thermal physiology.
- 3 – extinctions due to climate should be global in extent spanning continents, *but the models should also be able to predict extinctions at precise local scales.*

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1 – actual extinctions should be linked to macroclimate and validated to biophysical thermal causes arising from microclimate

Many lizards are **heliotherms**, but **preferred body temperature** (T_b) cannot >> **critical thermal maximum** (T_{max}); = **lethal**

lizards retreat to cool places, but **hours of restriction** (h_r) **limit foraging, etc., → constrain growth, maintenance, & reproduction → undermining population growth rates**

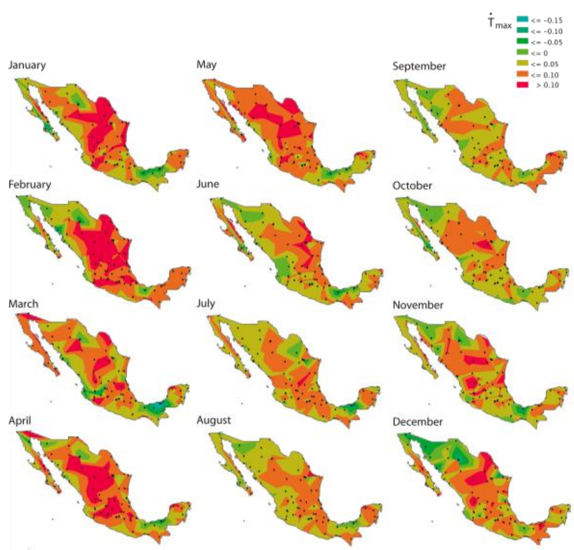
Rate of change in maximum ambient air temperature (ΔT_{max}) data from 99 Mexican weather stations, to construct climate surfaces for 1973 – 2008; results:

Red = areas where ΔT = 3.5°C from1975 – 2010, but at some sites during breeding ΔT has increased by 4 - 7°C;

Note that:

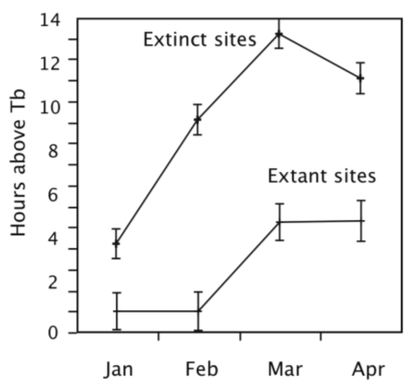
- ΔT highest for Jan – May
- fastest rates in central & northern MX, & high elevation
- significant **correlation** between ΔT_{max} during W/S breeding, & **extinctions** of local *Sceloporus* populations

= **"macroclimate pattern"**

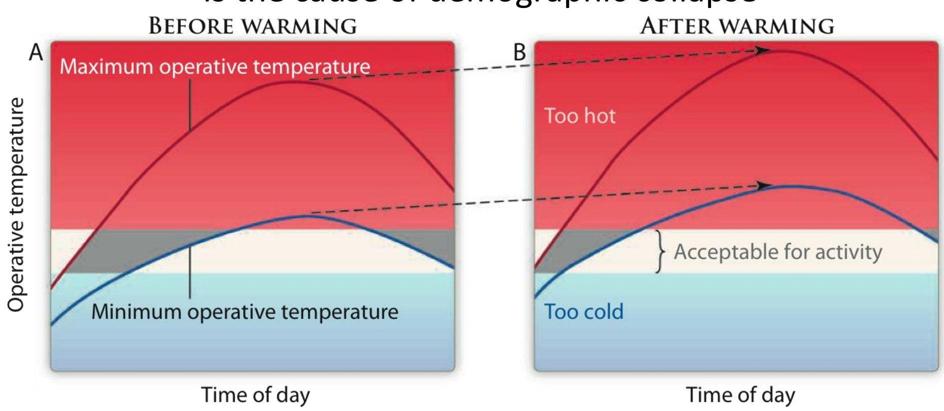


Yucatan ground truth study (Dec 2008-Apr 2009):

- Deploy lizard models hooked up to Hobotemps
- Measure the number of hours T_b is above $T_{preferred}$ at two extinct and two persistent sites (*Sceloporus serrifer*; viviparous, Yucatan)
- Linear relationship can be used to predict $h_{restriction}$: $h_r [T_b > T_{preferred}] = slope \times (T_{max} - T_{preferred}) + intercept$
- **h_r significantly higher in Mar-April at extinction vs extant sites**; (t = 9.26; P < 0.0001)



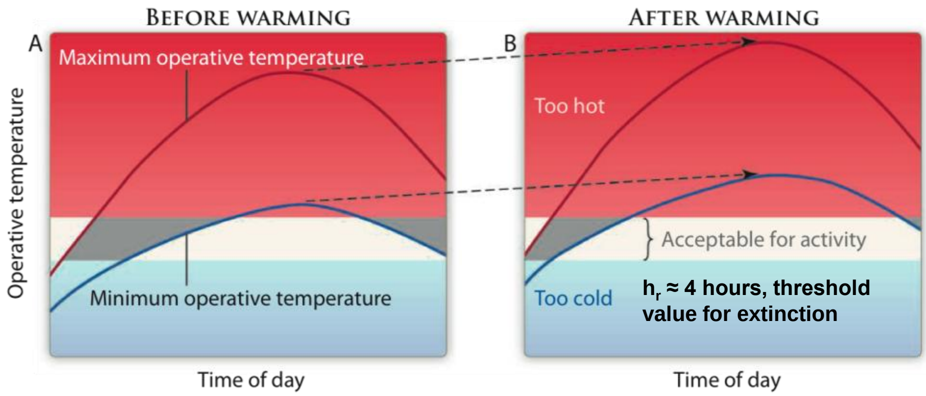
Hypothesis: Hours of restriction (h_r) During Breeding is the cause of demographic collapse



With warming, **restriction on activity is so severe** that lizards have to retreat shortly after emergence; **insufficient time to accumulate enough calories to develop a clutch**

Figure from: Huey et al. (2010) Are Lizards Toast? Science 325. Photo: Dr. Fausto Mendez De la Cruz

S. serrifer: relationship between h_r as a function of T_{max} provides a **general formula** [$h_r = 6.12 \times 0.74(T_{max} - T_b)$] **for predicting extinctions**



Best fit: observed vs predicted extinctions for Mexican *Sceloporus*; $h_r > 3.85$ hours

Significant for both parity modes: **Oviparous – $\chi^2 = 49.0$; $P < 0.001$**

Viviparous – $\chi^2 = 4.2$; $P < 0.04$

What approach should be used? Empirical validation of global extinction forecasts requires three forms of evidence:

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Lizards cannot evolve rapidly enough to track pace of regional climate change:

- PIC test shows that T_b and T_{max} are correlated, which constrains adaptation;
- Phynosomatidae – **shift in T_b of 1°C yields only a 0.5°C correlated response in T_{max};**
- the latter attribute **(T_{max}) <u>will not evolve fast enough</u> to keep pace with selection for higher T_b**

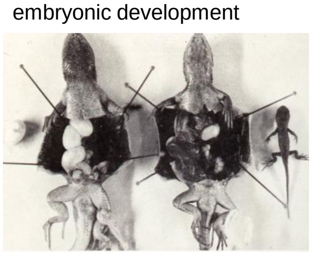
Selection: R = h^2s; where **h^2 = ~ 0.17** in *S. occidentalis* (T_b heritability)

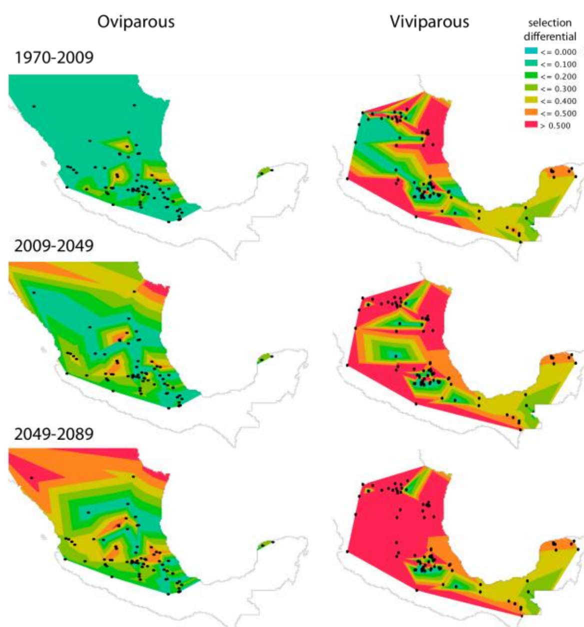
Maps - **sustained selection differentials** needed per year **for T_b to keep pace with warming;**

adaptation in T_b is not likely due to low h^2

oviparous – warming alters hydric soil environments, clutches overheat

viviparous – heat loads to adults compromises behavioral strategies for maintaining body temperature suitable for embryonic development





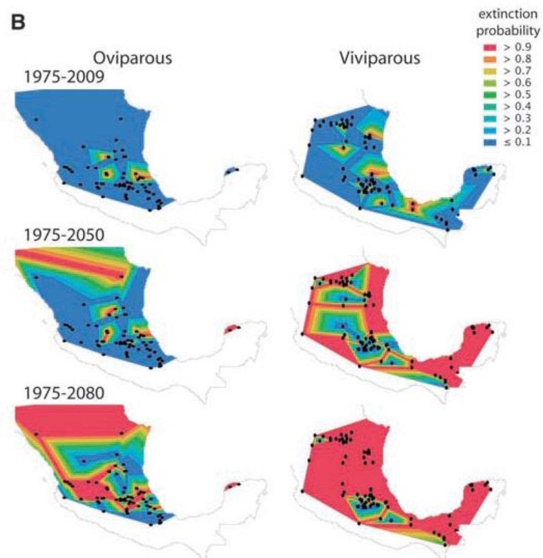
Selection: $R = h^2 s$; where $h^2 = \sim 0.17$ in *S. occidentalis* (T_b heritability)

Maps – extinction surfaces:

Viviparous: 56% population extinctions by 2050; 66% by 2080

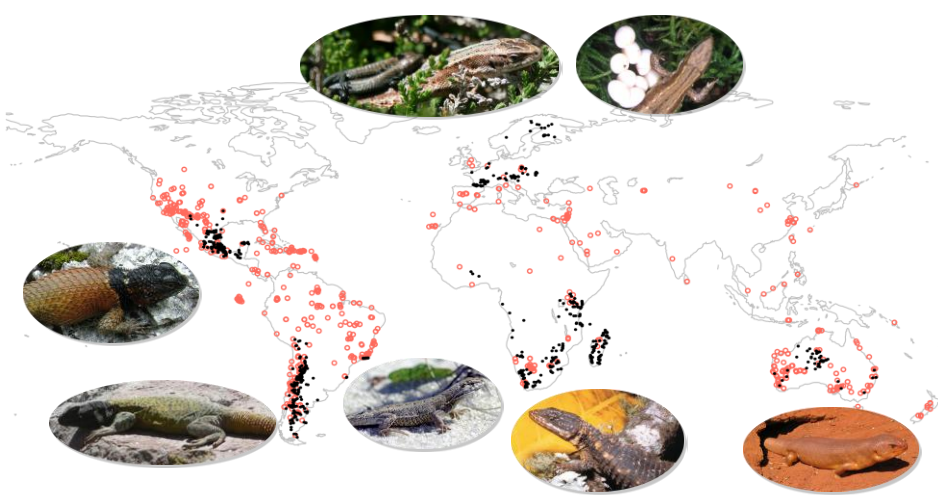
Oviparous: 46% and 61% population extinctions by 2050 and 2080, respectively

Combined: 58% population extinctions of Mexican *Sceloporus* by 2080



The Global Extinction Model:

1) T_{max} from WorldClim.org at 10 arc-sec resolution
2) **T_b parameterized from N=1216 georeferenced sites**, red dots
3) T_b (simulated, climate envelope for high range)
4) $h_r = 4.55$, average across all lizard families
5) **h_r fitted for each of 34 families from 1975 distribution limits**
6) local extinctions validated for 6 families on 5 continents, **black** dots



Reliability of predicted vs. observed contemporary extinctions: **72 % accurate** (weighted R^2)

Region/Taxon	R-Squared	N sites
Africa (167 sites)+Madagascar (2 sites): Gerrhosauridae, Cordylidae, Chamaeleonidae, Scincidae, Gekkonidae	0.98	169
Europe: Lacertidae, *Lacerta vivipara*	0.53	46
South America: Liolaemidae, *Liolaemus* and *Phymaturus* spp.	0.53	128
Australia: Scincidae, *Liopholis spp.*	1.00	23
Australia: Scincidae, *Liopholis kintorei*	0.19	29

1. Where we see errors, drought due to climate warming has caused extinctions not explained by temperature
1. Also ¼ of Mexican extinctions were not predicted by thermal extinction, but in 6 of 8 cases a competitor had expanded its range upwards due to climate warming

What approach should be used? Empirical validation of global extinction forecasts requires three forms of evidence:

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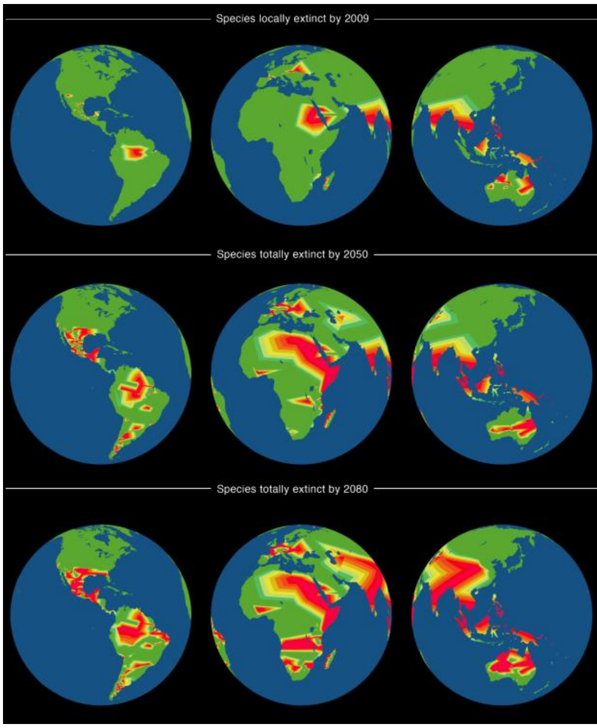


Extrapolating to the total number of lizard species:

2009
- 4% local extinction
- 60% in some areas

2050
- 6% species extinction
- 100% in some areas

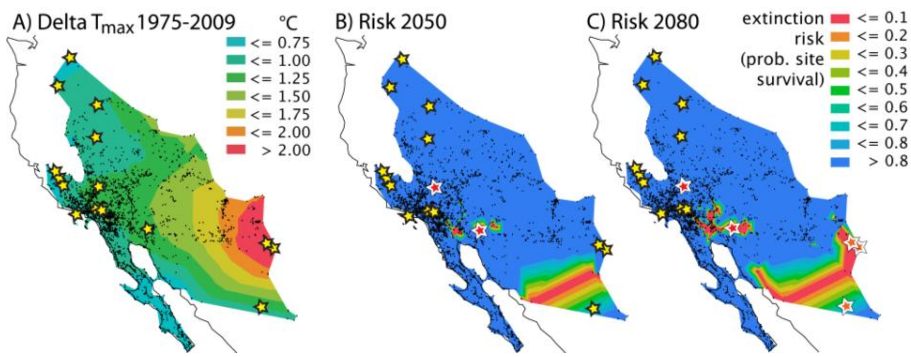
2080
- 20% species extinction
- 100% in many areas

Research at demographic timescales

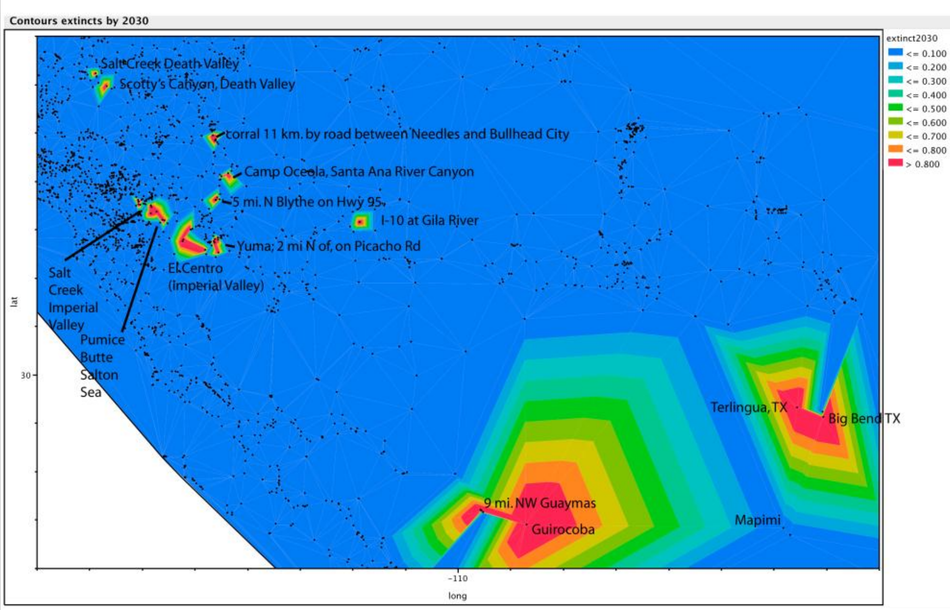
- *Uta stansburiana*: Can lizards evolve out of the frying pan: Evolution of T_b unlikely, maybe habitat preference?
- *Urosaurus graciosus*: Very high local extinction in 2010, Donald Miles, Sinervo unpub. data.
- *Lacerta vivipara*: tracking the progress of extinctions (periodic resurveys from 1992-2010)
- *Iberolacerta* spp in Europe: ongoing extinctions in endemic montane species that we are tracking
- We are also tracking the extinctions in Mexico

Uta stansburiana:

1. Sample 15 sites across the west
2. Estimate climate change evolution at Los Banos (N=32,000, pedigree 1989-2010) to estimate $R=h^2s$
3. Survey extinctions. We have verified predicted extinctions at Death Valley and Pilot Knob. Others:TX and Mexico are currently being surveyed

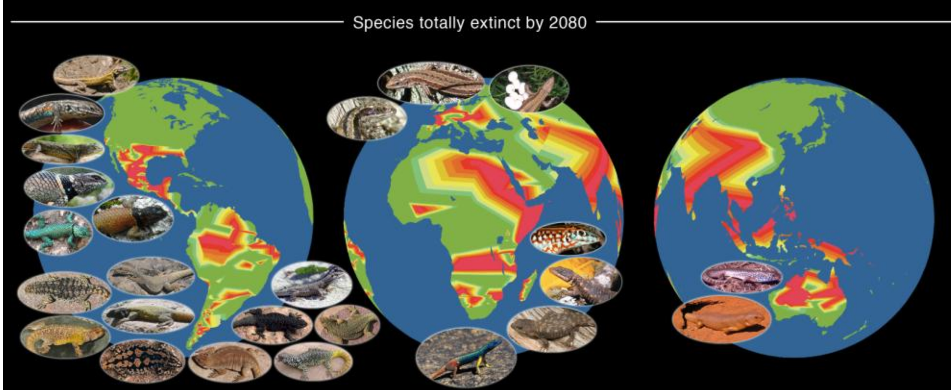


Uta stansburiana predicted extinctions 2010-2030

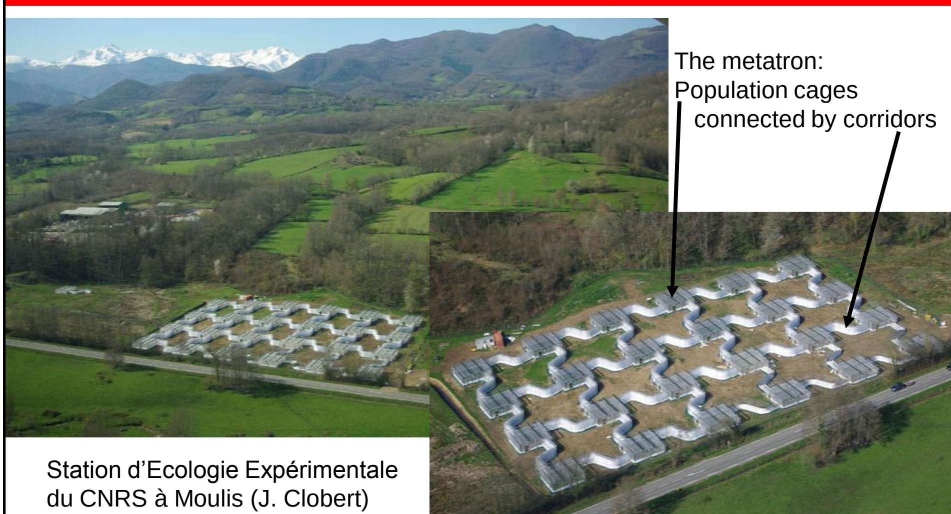


More detailed Global surveys are underway:

1) a, Luciano Javier Avila, Mariana Morando
2)Brazil: Carlos Frederico Duarte Rocha
3)Australia: David G. Chapple; Steve McAlpin, during my sabbatical
4)Namibia, South Africa: Christy Hipsely, D. Miles, Aaron Bauer, Bill Branch
5)Madagascar Bauer & Branch and during sabbatical year
6)Malaysia and Indonesia survey during my sabbatical next year



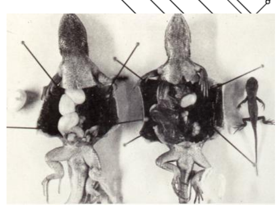
A proposed experimental set up to study the interplay between temperature, humidity and extinctions due to demographic collapse



Station d'Ecologie Expérimentale du CNRS à Moulis (J. Clobert)

Are speciation rates higher in clades born from an RPS ancestor?

Yes, the rate of speciation is about 2-3 times higher; if linkage to the origin of viviparity is further corroborated, does socially-mediated speciation lock lizards into inflexible heat tolerance if they are viviparous?



Sister pairs with 0 clade larger	0
Sister pairs with 1 clade larger	7
Sister pairs with 0-1 clades equal	2

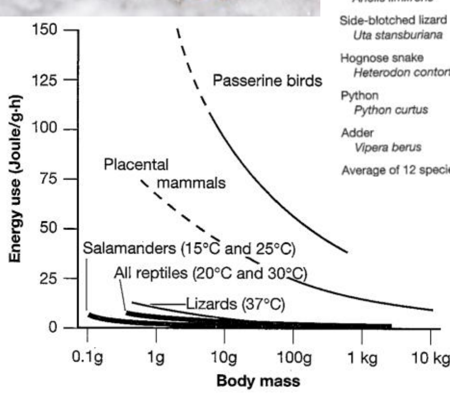
Sister Diversification Binomial P= 0.0078125

Ecological Consequences of Lizard Declines

Lizards are "energy capacitators" – they can attain very high densities relative to endotherms due to:

(1) much lower metabolic rates (ectotherms);

(2) ability to exploit very tiny prey (arthropods) that for energetic reasons birds & mammals cannot eat

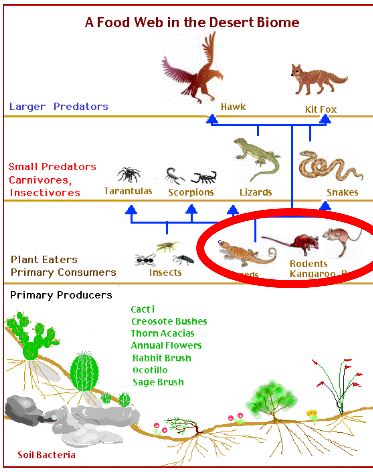


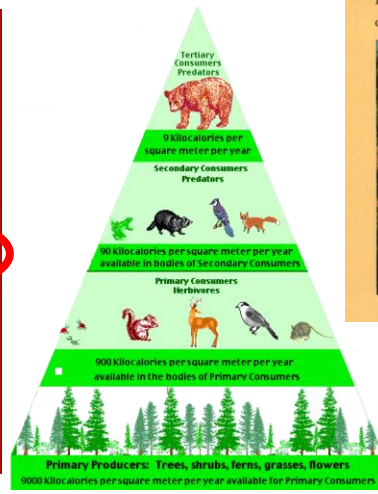
Ectotherms		Endotherms	
Species	Efficiency	Species	Efficiency
Red-backed salamander *Plethodon cinereus*	48	Kangaroo rat *Dipodomys merriami*	0.8
Mountain salamander *Desmognathus ochrophaeus*	76–98	Field mouse *Peromyscus polionotus*	1.8
Panamanian anole *Anolis limifrons*	23–28	Meadow vole *Microtus pennsylvanicus*	3.0
Side-blotched lizard *Uta stansburiana*	18–25	Red squirrel *Tamiasciurus hudsonicus*	1.3
Hognose snake *Heterodon contortrix*	81	Least weasel *Mustela rixosa*	2.3
Python *Python curtus*	6–33	Savanna sparrow *Passerculus sandwichensis*	1.1
Adder *Vipera berus*	49	Marsh wren *Telmatodytes palustris*	0.5
Average of 12 species	50	Average of 19 species	1.4

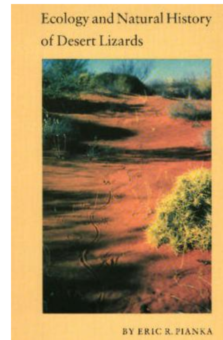
Ecological Consequences of Lizard Declines

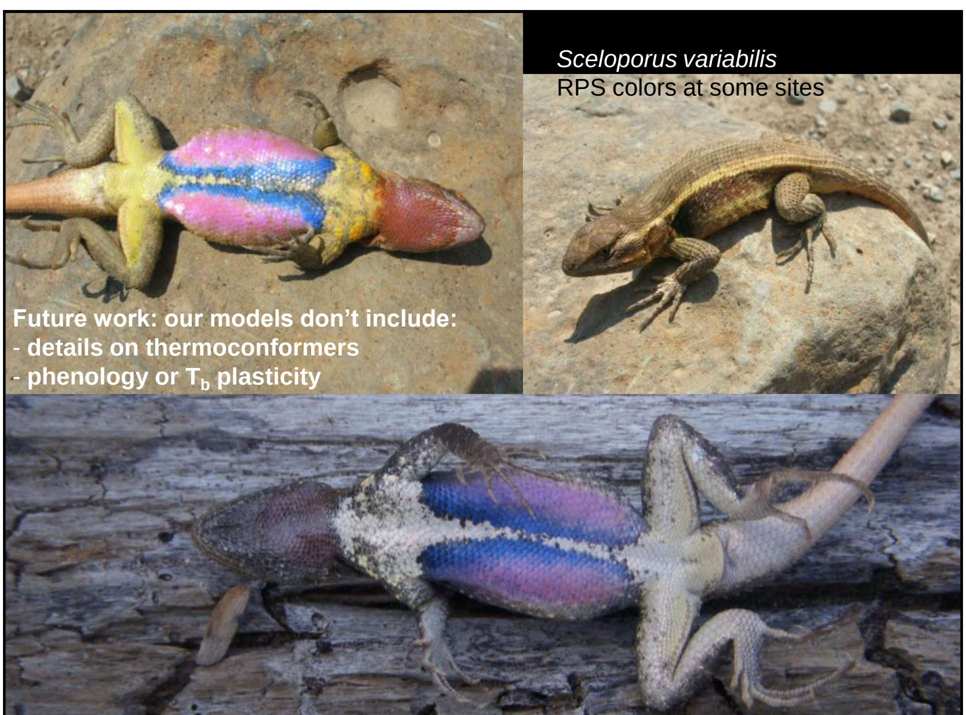
Lizards are "energy capacitators" – they can attain very high densities relative to <u>endotherms</u> due to:

(1) much lower metabolic rates (ectotherms);
(2) ability to exploit very tiny prey (arthropods) that for energetic reasons birds & mammals cannot eat
(3) more efficient at conversion of plant or insect biomass into new lizard biomass (up to 50% vs < 2% in a bird or mammal of equal body mass; vs 2-3%)



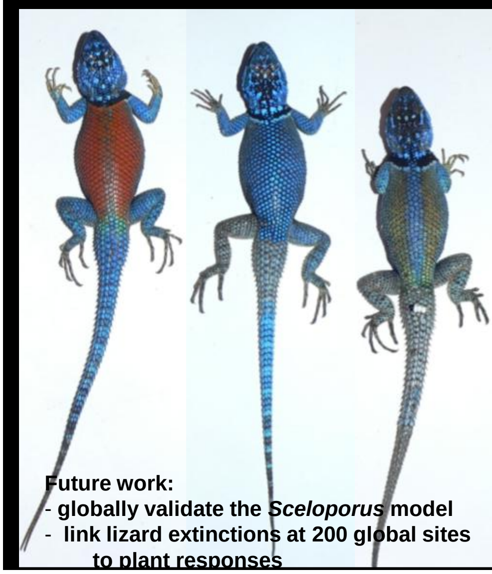






Sceloporus minor
(Barry Stephenson et al.)

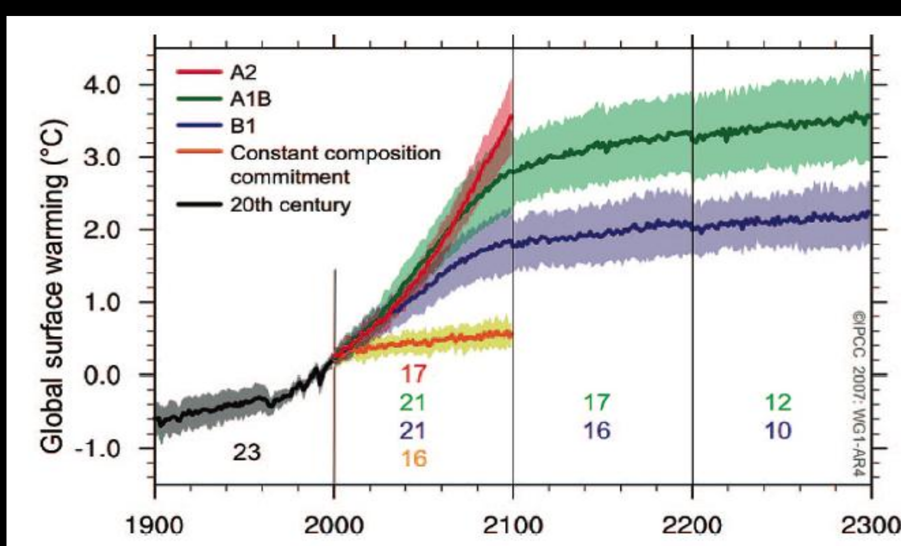
oo bb by

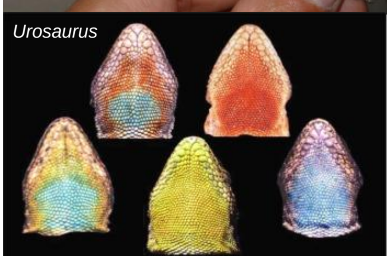


Future work:
- **globally validate the *Sceloporus* model**
- **link lizard extinctions at 200 global sites to plant responses**

Liolaemus sp.; Santa Cruz Province, Argentina (2007)

If we bend the CO_2 curve (B1) we limit extinctions to 5% (2050 levels), not the 20% of species extinctions predicted for 2080 (A2).





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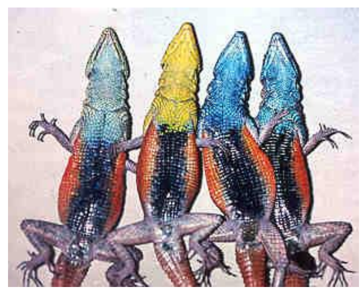
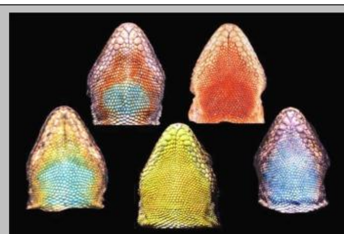
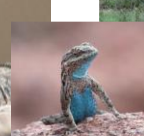


Platysaurus broadleyi, Africa

Urosaurus ornatus mating system - males

- Throat color morphs
  - Orange
  - Blue
  - Yellow
- Social Status
  - Territorial
  - Satellite
  - Floater/Sneaker
- Mating System
  - Polygynous
  - Monogamous





Change in Operative Temperature between wet and drought years