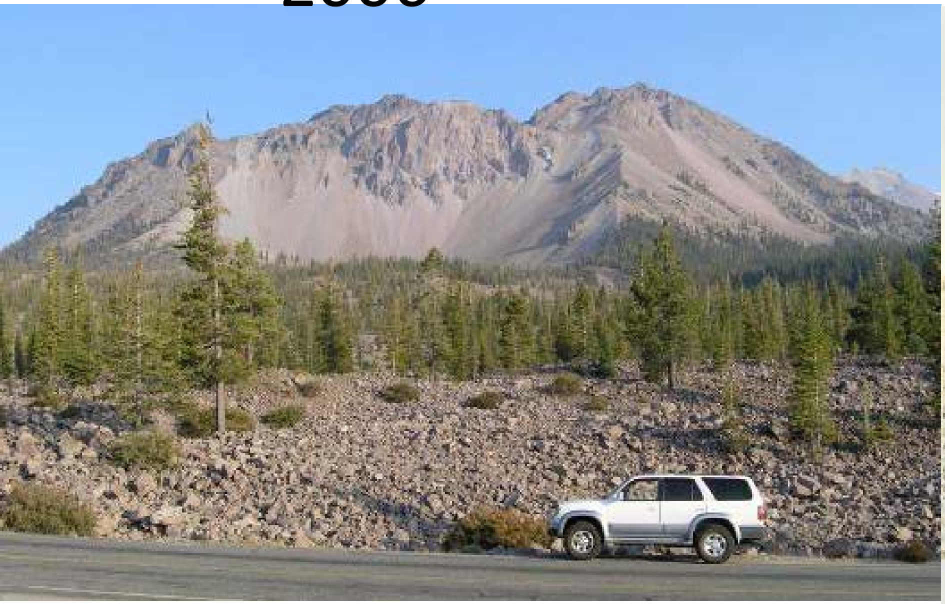
Detecting Diversity: Paradigm Shifts in Estimation of Species Distribution and Abundance

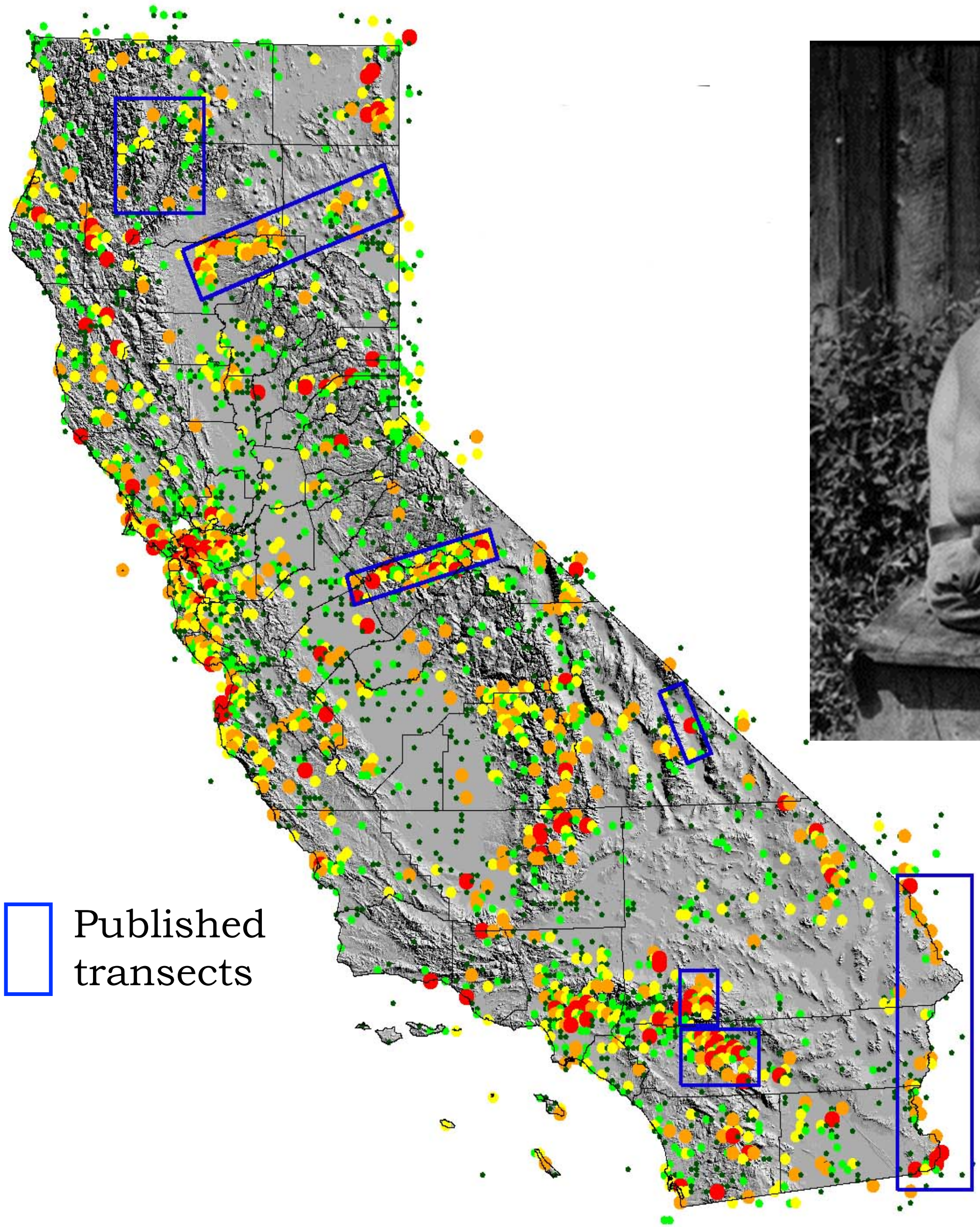
2006

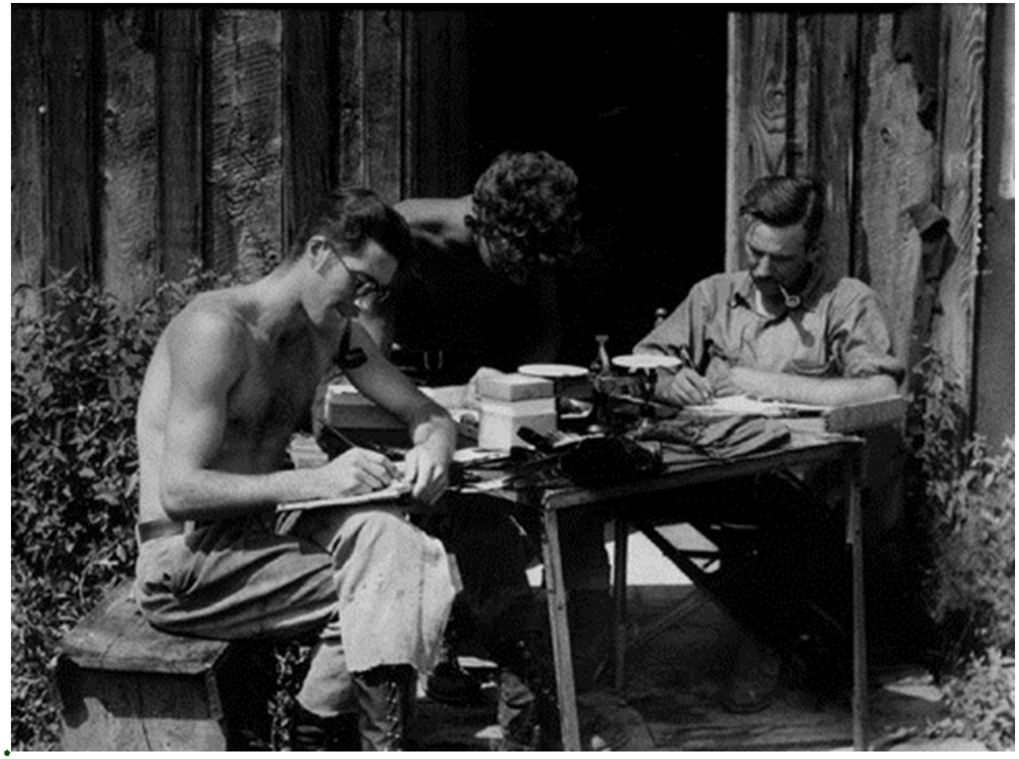


1930

Steve Beissinger
Dept. of Environmental Science, Policy & Management
& Museum of Vertebrate Zoology
U.C. Berkeley

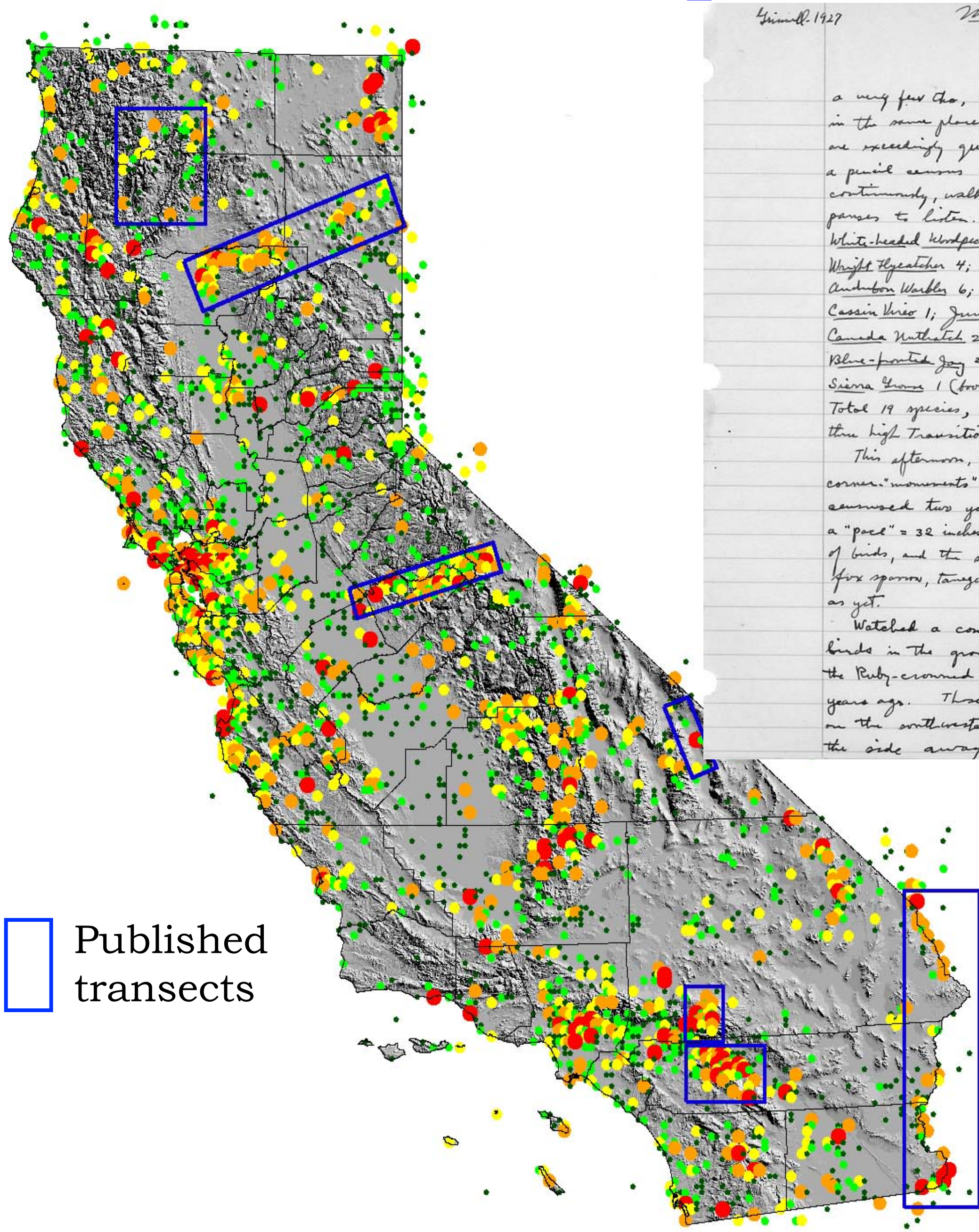
Pre-1940 MVZ Specimen Locality Records

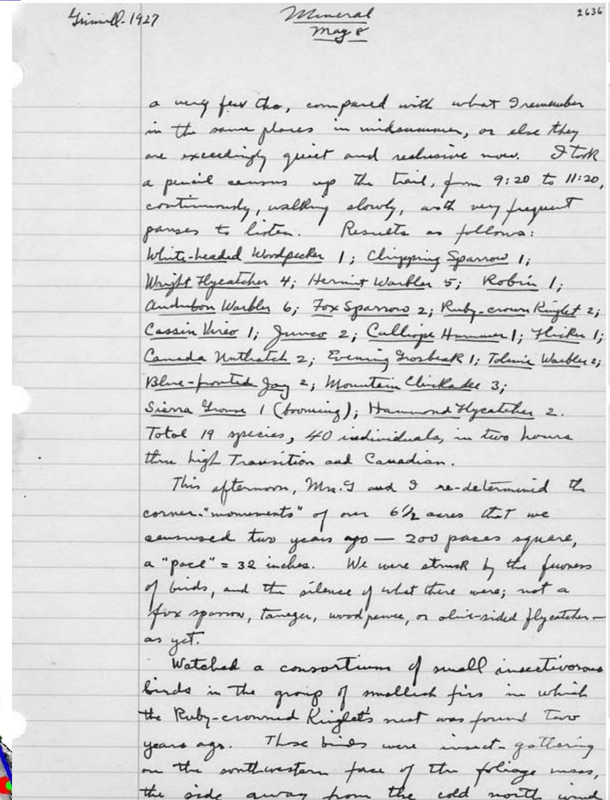




Joseph Grinnell and students collecting birds and mammals, and writing field notes

Pre-1940 MVZ Specimen Locality Records





Grinnell 1927

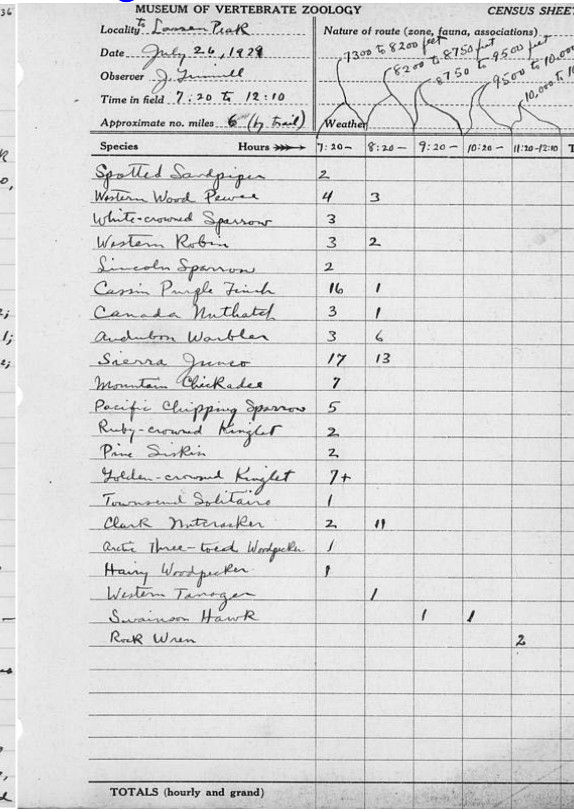
Mineral
May 8

2636

a very few tho, compared with what I remember in the same places in midsummer, or else they are exceedingly quiet and reclusive now. I took a pencil census up the trail, from 9:20 to 11:20, continuously, walking slowly, with very frequent pauses to listen. Results as follows: White-headed Woodpecker 1; Chipping Sparrow 1; Wright Flycatcher 4; Hermit Warbler 5; Robin 1; Audubon Warbler 6; Fox Sparrow 2; Ruby-crown Kinglet 2; Cassin Vireo 1; Junco 2; Calliope Hummer 1; Flicker 1; Canada Nuthatch 2; Evening Grosbeak 1; Tolmie Warbler 2; Blue-fronted Jay 2; Mountain Chickadee 3; Sierra Grouse 1 (booming); Hammond Flycatcher 2. Total 19 species, 40 individuals, in two hours thru high Transition and Canadian.

This afternoon, Mrs. G and I re-determined the corner "monuments" of our 6½ acres that we censused two years ago — 200 paces square, a "pace" = 32 inches. We were struck by the fewness of birds, and the silence of what there were; not a fox sparrow, tanager, wood pewee, or olive-sided flycatcher — as yet.

Watched a consortium of small insectivorous birds in the group of smallish firs in which the Ruby-crowned Kinglet's nest was found two years ago. These birds were insect-gathering on the southwestern face of the foliage mass, the side away from the cold north wind



MUSEUM OF VERTEBRATE ZOOLOGY — CENSUS SHEET

Locality: To Lassen Peak
Date: July 26, 1929
Observer: J. Grinnell
Time in field: 7:20 to 12:10
Approximate no. miles: 6 (by trail)

Nature of route (zone, fauna, associations): 7300 to 8200 feet; 8200 to 8750 feet; 8750 to 9500 feet; 9500 to 10,000; 10,000 to 10

Weather

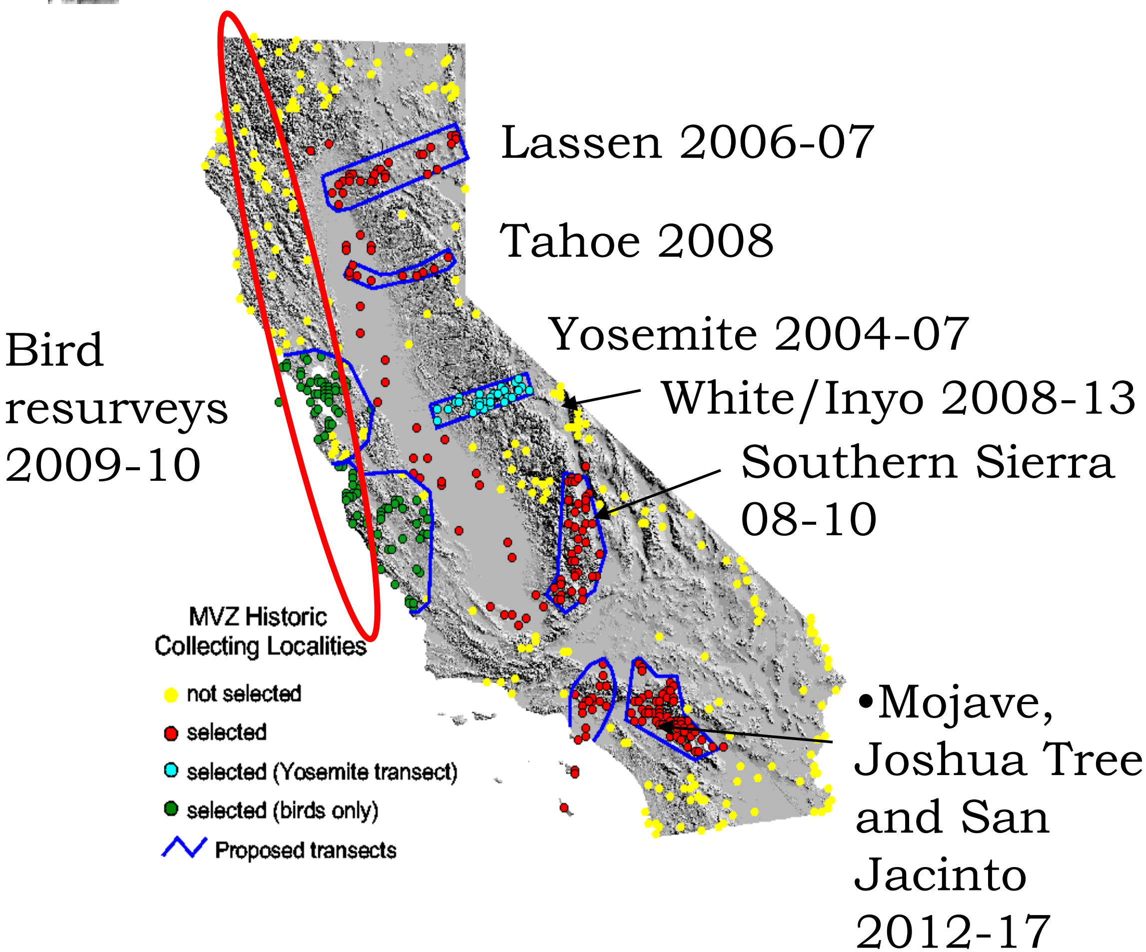
Species (Hours)	7:20–	8:20–	9:20–	10:20–	11:20–12:10
Spotted Sandpiper	2				
Western Wood Pewee	4	3			
White-crowned Sparrow	3				
Western Robin	3	2			
Lincoln Sparrow	2				
Cassin Purple Finch	16	1			
Canada Nuthatch	3	1			
Audubon Warbler	3	6			
Sierra Junco	17	13			
Mountain Chickadee	7				
Pacific Chipping Sparrow	5				
Ruby-crowned Kinglet	2				
Pine Siskin	2				
Golden-crowned Kinglet	7+				
Townsend Solitaire	1				
Clark Nutcracker	2	11			
Arctic Three-toed Woodpecker	1				
Hairy Woodpecker	1				
Western Tanager		1			
Swainson Hawk			1	1	
Rock Wren					2

TOTALS (hourly and grand)

Field Notes

~ 3 times more species per site **observed** than **collected**

Grinnell Resurvey Project: Status and Future



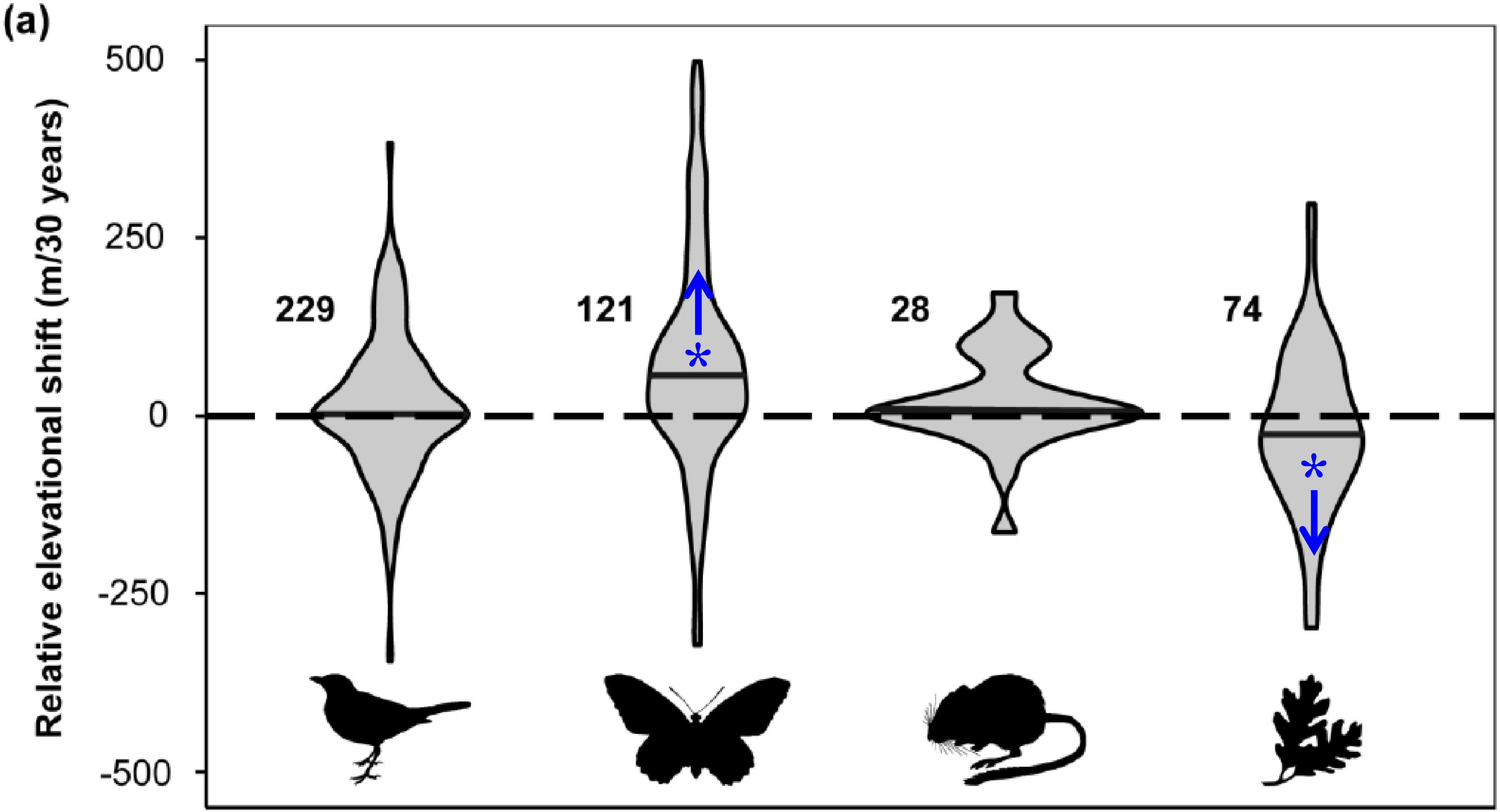
- **Sierra and Coastal range resurveys** (2004-10)
- **Modeling past & future change** (2008-12)
- **Current resurveys in the CA desert and Central Valley** (2015-18)

Global Biodiversity Monitoring:
Sampling for Trends, Searching for Causality

Trend Metrics:

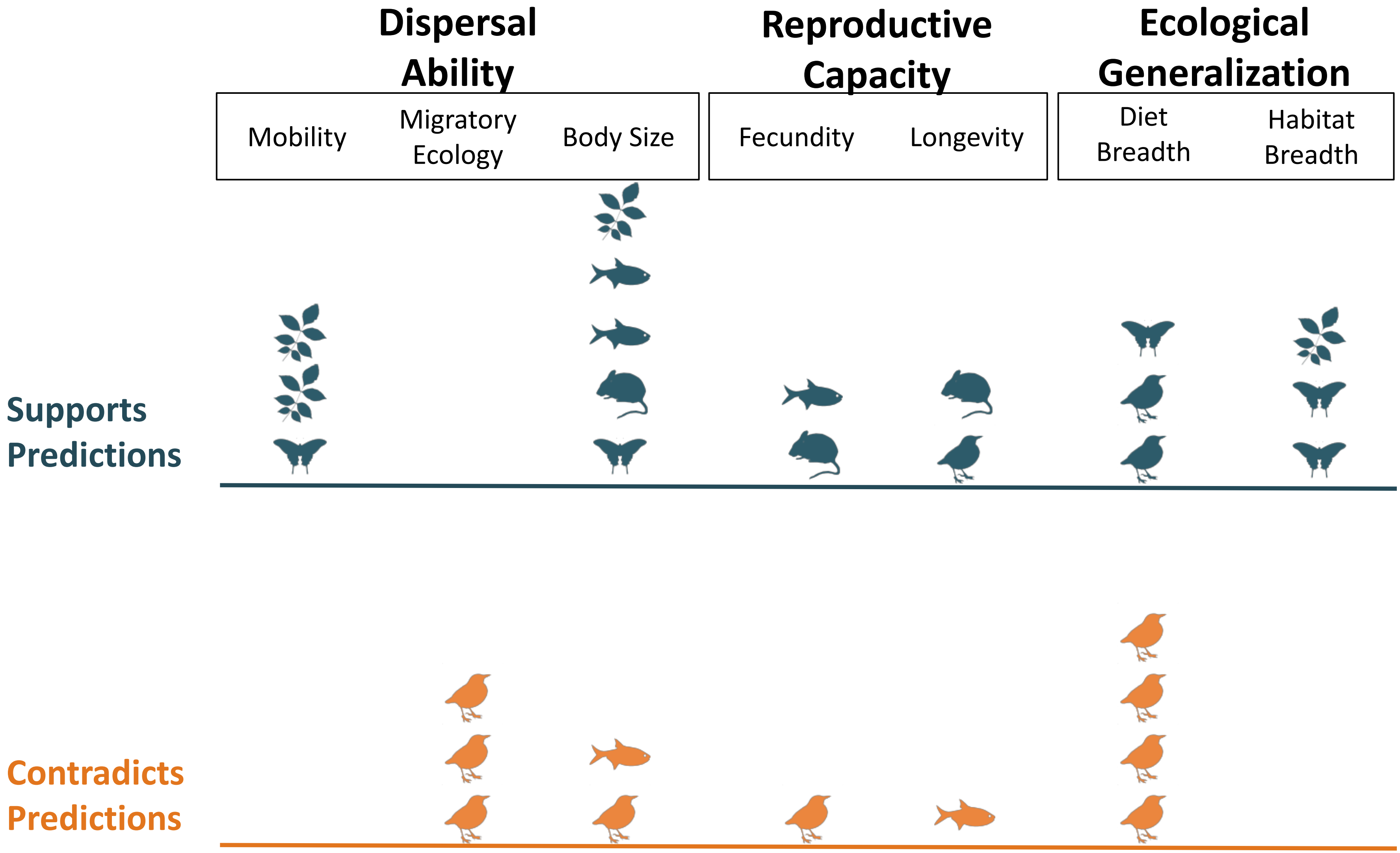
- Species level:
  - Occurrence (Presence or "Absence") of organisms
  - Abundance of organisms
- Community level:
  - Occurrence (Presence or "Absence") of organisms
  - Abundance of organisms
- Ecosystem and higher levels
  - Occurrence (Presence or "Absence") of pixels/process

Are Range Shifts Congruent Across Sierra Nevada Taxa?



(Rapacciuolo, Maher,..., & Beissinger. 2014. Global Change Biology 20:2841-2855)

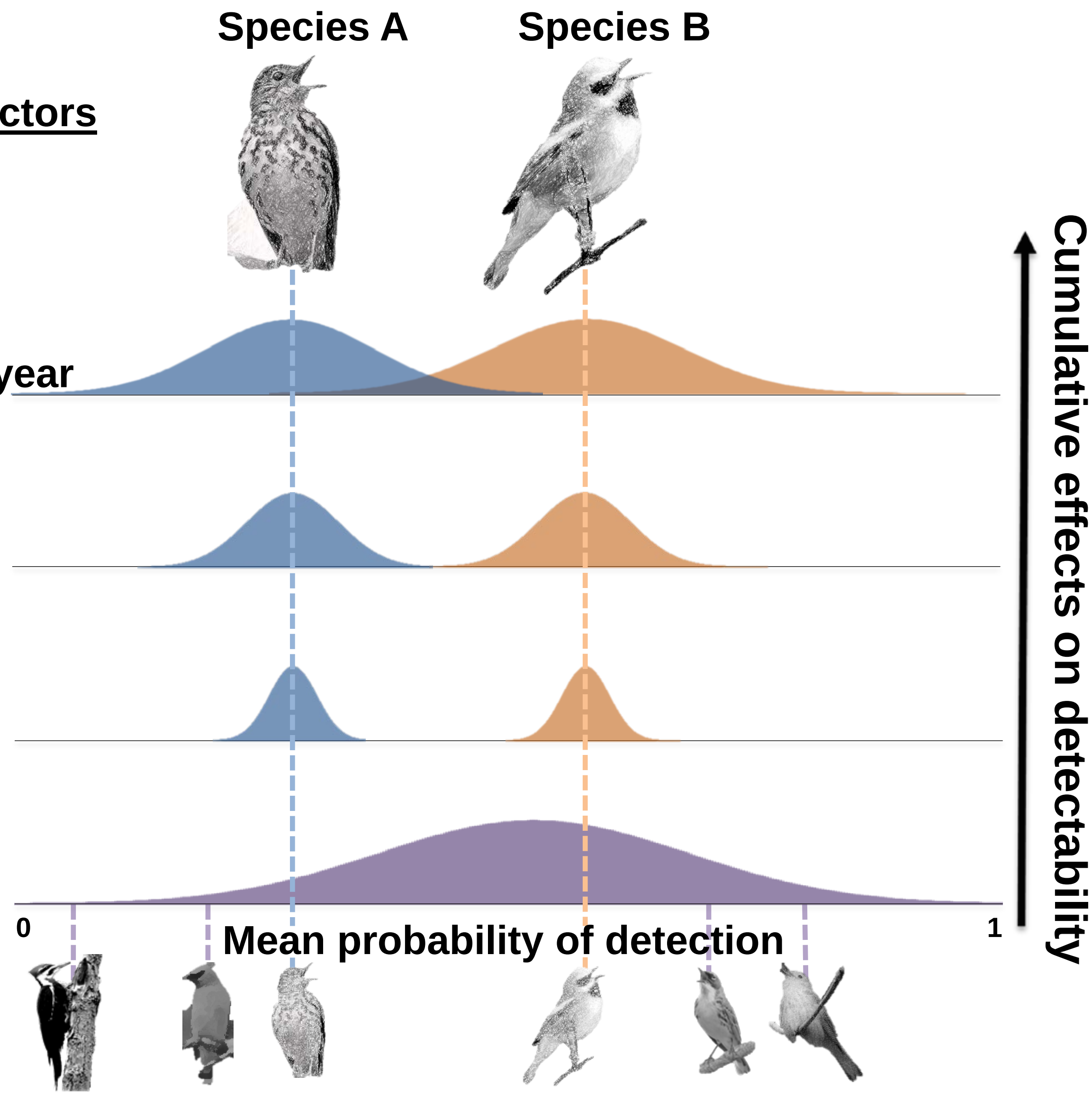
Do Species Traits Predict Range Shifts?



MacLean and Beissinger unpubl. ms

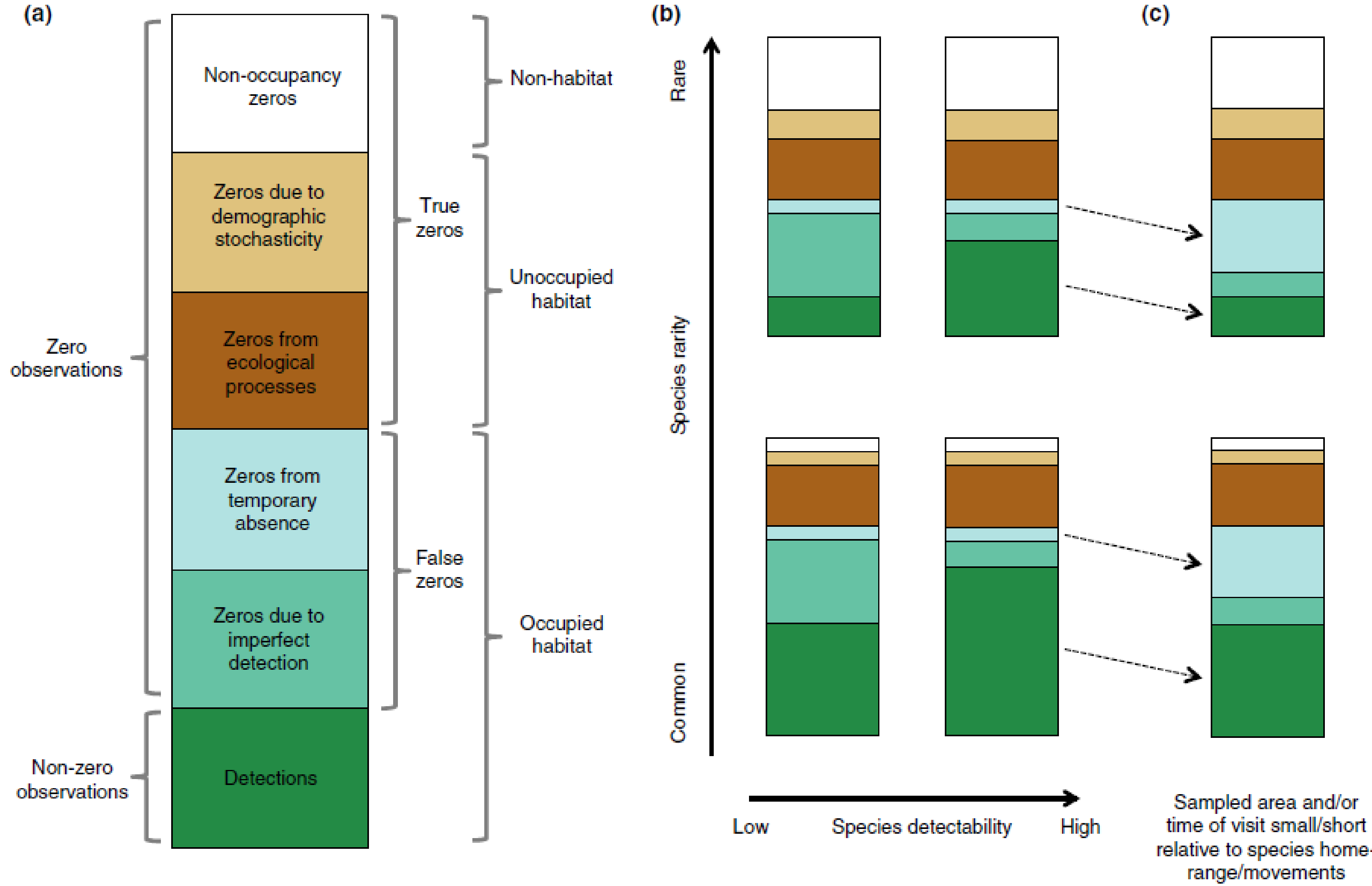
Factors Affecting the Probability of Detecting a Species

Group	Detection Factors
Survey	Effort Observer Method Time of day/year
Site	Habitat Noise Elevation
Individual	Sex Age Distance
Species	Behavior Life history Rarity



Iknayan , Tingley, Furnas, & Beissinger. 2014. TREE 29:97-106

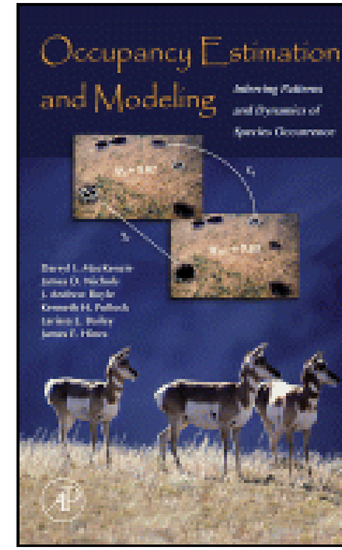
Mechanisms that Cause Different Types Of Zero Observations in Count Surveys and their Effects



Denes, Silveira & Beissinger. 2015. Methods in Ecology and Evolution. DOI: 10.1111/2041-210X.12333

Occupancy Models

(MacKenzie et al. Ecology 2002, 2004; book in 2006)



- Investigate patterns in occupancy Ψ using **detection-nondetection data [*h* = 0,0,1 1,0,1].**
- Recognize that an observed 'absence' may be the result of a **true absence or a nondetection**.
- Depend on **repeated surveys at a site over a short (closed) time period** to determine presence or absence.

Single Season Occupancy

$$L(\psi, \mathbf{p} \mid h_1, h_2, .. h_s) = \left[\psi^{n.} \prod_{t=1}^{T} p_t^{n_t} (1 - p_t)^{n. - n_t}\right] \times \left[\psi \prod_{t=1}^{T} (1 - p_t) + (1 - \psi)\right]^{N - n.}$$

Multi-Season Dynamics

$$\Psi_t = \Psi_{t-1} (1 - \varepsilon_{t-1}) + (1 - \Psi_{t-1}) \delta_{t-1}$$

Factors Affecting Detectability of 43 Bird Species

8 Candidate Detection Models

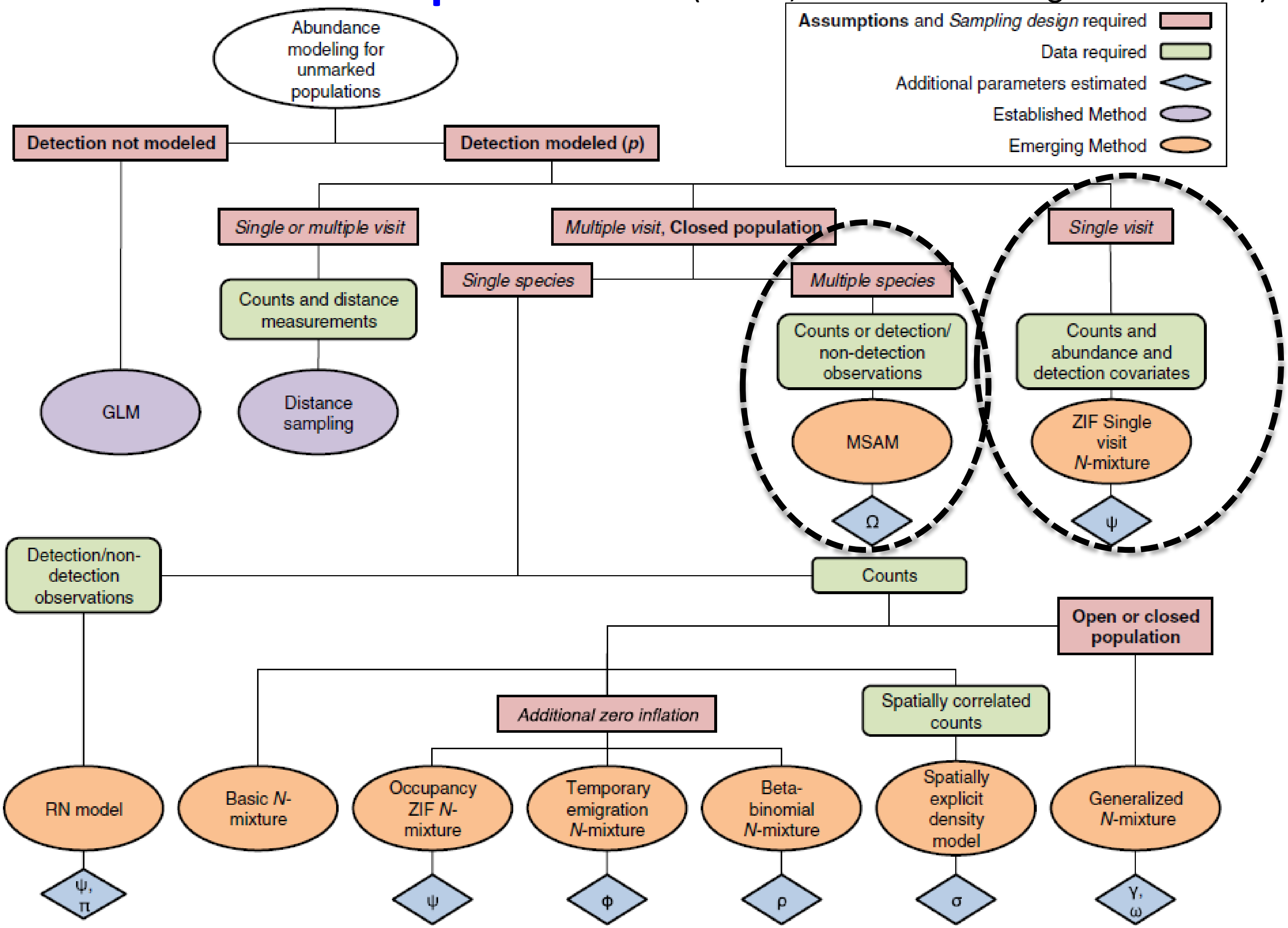
1. (.)
2. Era (Grinnell vs. Us)
3. Julian day
4. Observer
5. Era + Julian Day
6. Era * Julian Day
7. Observer + Julian Day
8. Observer + Julian Day + Julian Day * Era

Detection models with	Cumulative AIC weight
Era	**0.89**
Julian Day	0.71
Observer	0.34

Tingley & Beissinger. Unpublished data.

Modeling Approaches for Estimating Abundance of Unmarked Animal Populations

(Denes, Silveira & Beissinger. 2015. MEE)



Multi-Species Occupancy and Abundance Models (MSOM and MSAM)

MSOM:

$w_i \sim \text{Bernoulli}\,(\Omega)$ – superpopulation process (data augmentation); [I]

$z_{i,j} | w_i \sim \text{Bernoulli}\,(w_i * \Psi_{i,j})$ – ecological process; [II]

$y_{i,j,k} | z_{i,j} \sim \text{Bernoulli}\,(z_{i,j} * p_{i,j,k})$ – observation process. [III]

MSAM:

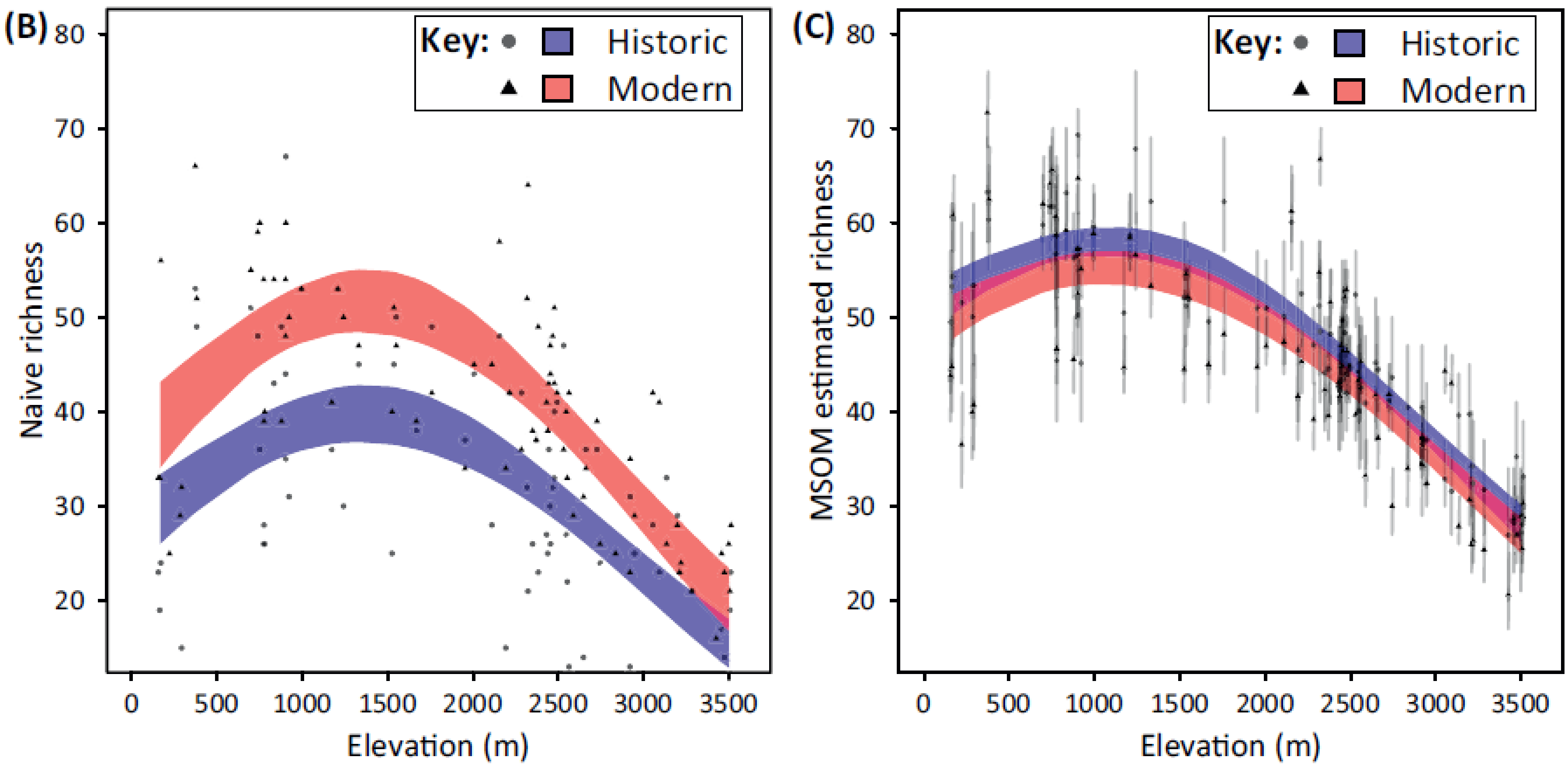
$w_i \sim \text{Bernoulli}\,(\Omega)$ – superpopulation process (data augmentation); [IV]

$N_{i,j} | w_i \sim \text{Poisson}\,(w_i * \lambda_{i,j})$ – ecological process; [V]

$y_{i,j,k} | N_{i,j} \sim \text{binomial}\,(N_{i,j},\ p_{i,j,k})$ – observation process. [VI]

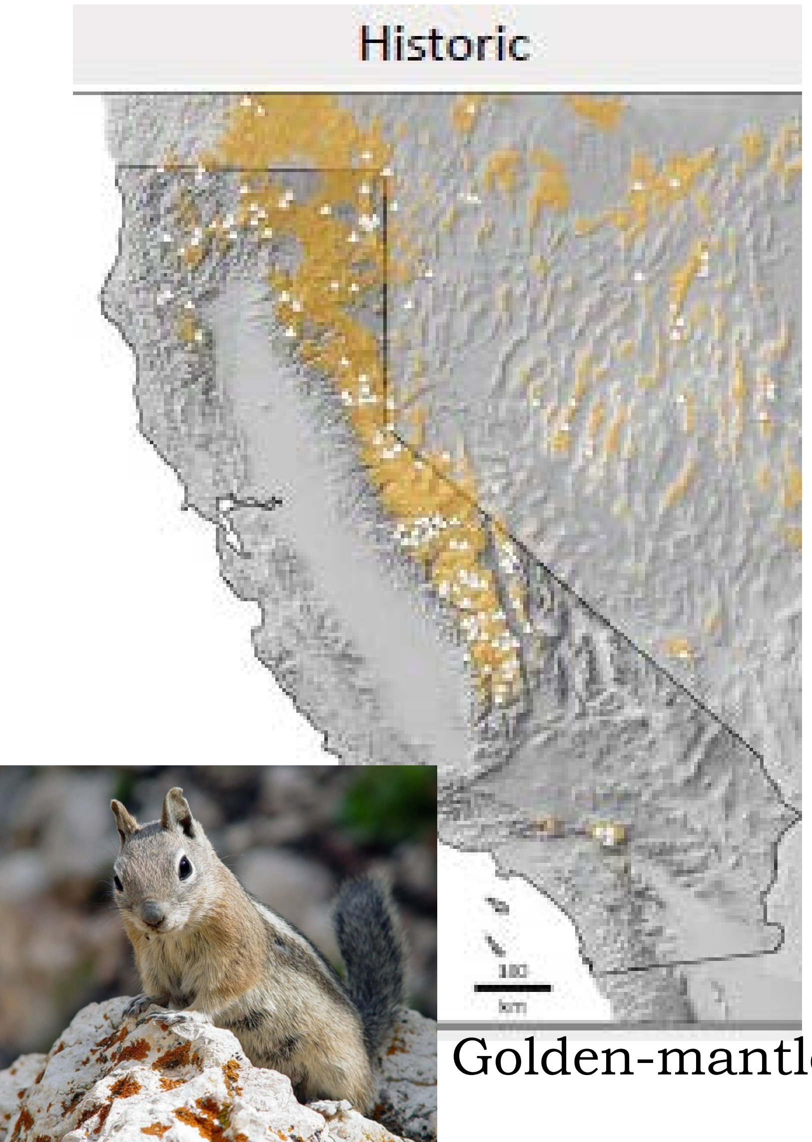
Iknayan , Tingley, Furnas, & Beissinger. 2014. TREE 29:97-106

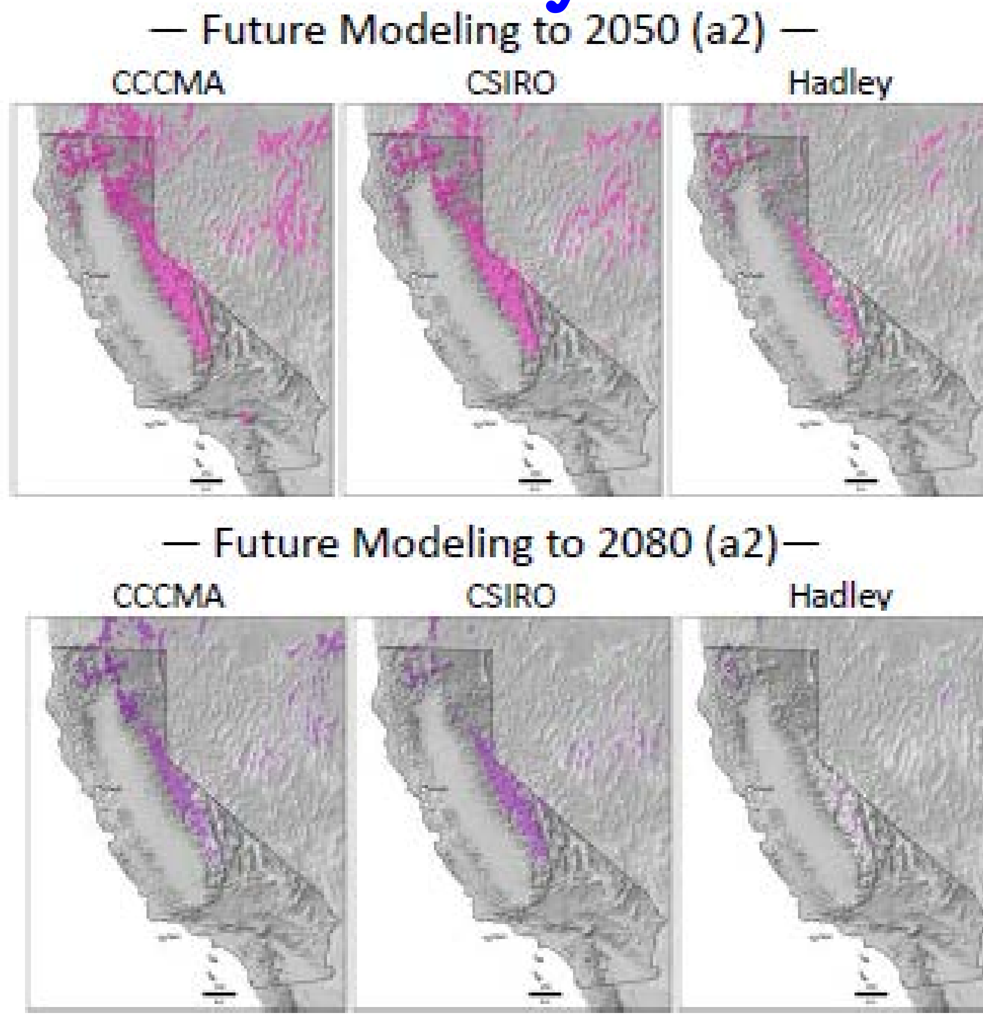
Modeling Community Change in Faces the Same Detection Problem



Tingley & Beissinger. 2013. *Ecology 94: 598-609*

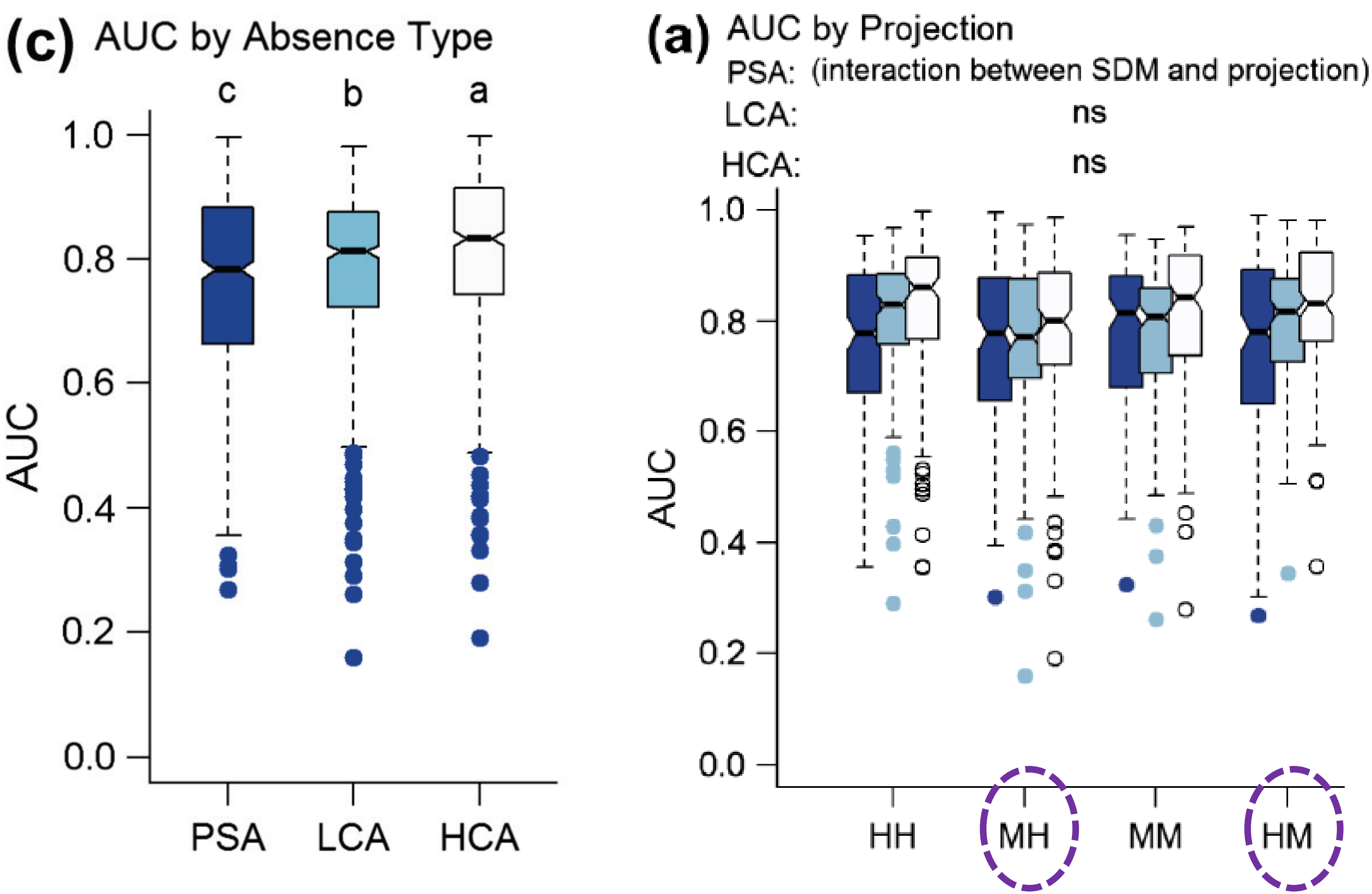
Species Distribution Models use climate to project occupancy. How well do they perform for 18 mammal species we resurveyed?





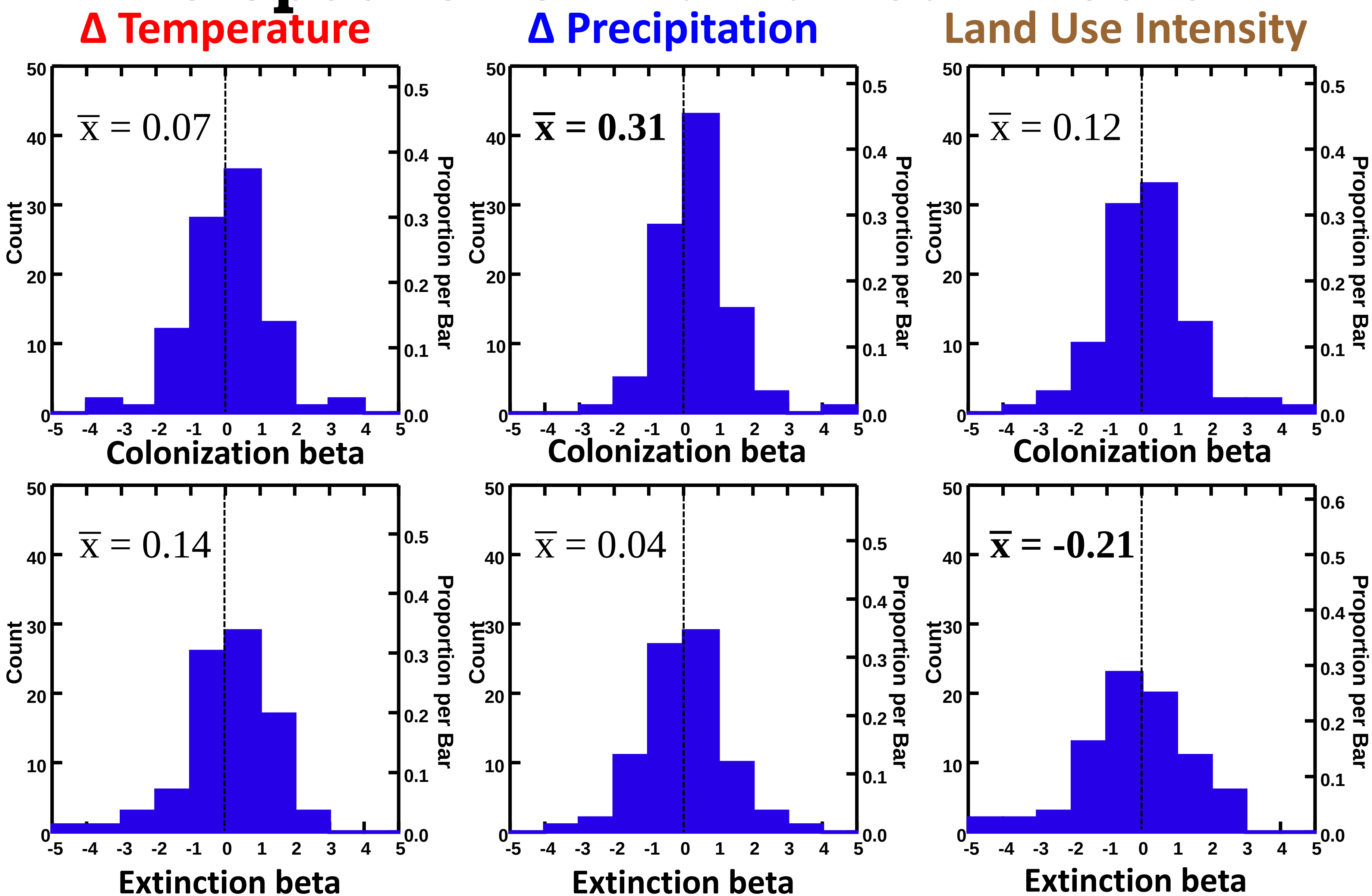
Golden-mantled ground squirrel

SDM Model Performance Increased with High Quality Data that was Corrected for Detectability



(Smith et al. 2013. Ecography 36:1017-1031)

Metacommunity (100 Bird Species)
Slopes for Standardized Effects



Some Concluding Thoughts

- We are at the start of a statistical shift to the "Detecting Diversity" Paradigm
- "Big Data" and Citizen Science will make huge contributions to future monitoring of global of biodiversity
- This necessitates developing SDMs that account for both false negatives and false positives
- More than ever, we will need boots on the ground to do systematic surveys ("Little Data")
- We are rapidly losing decades of "Little Data" that has already been collected

Someday your data will be "historic". How will you preserve it?

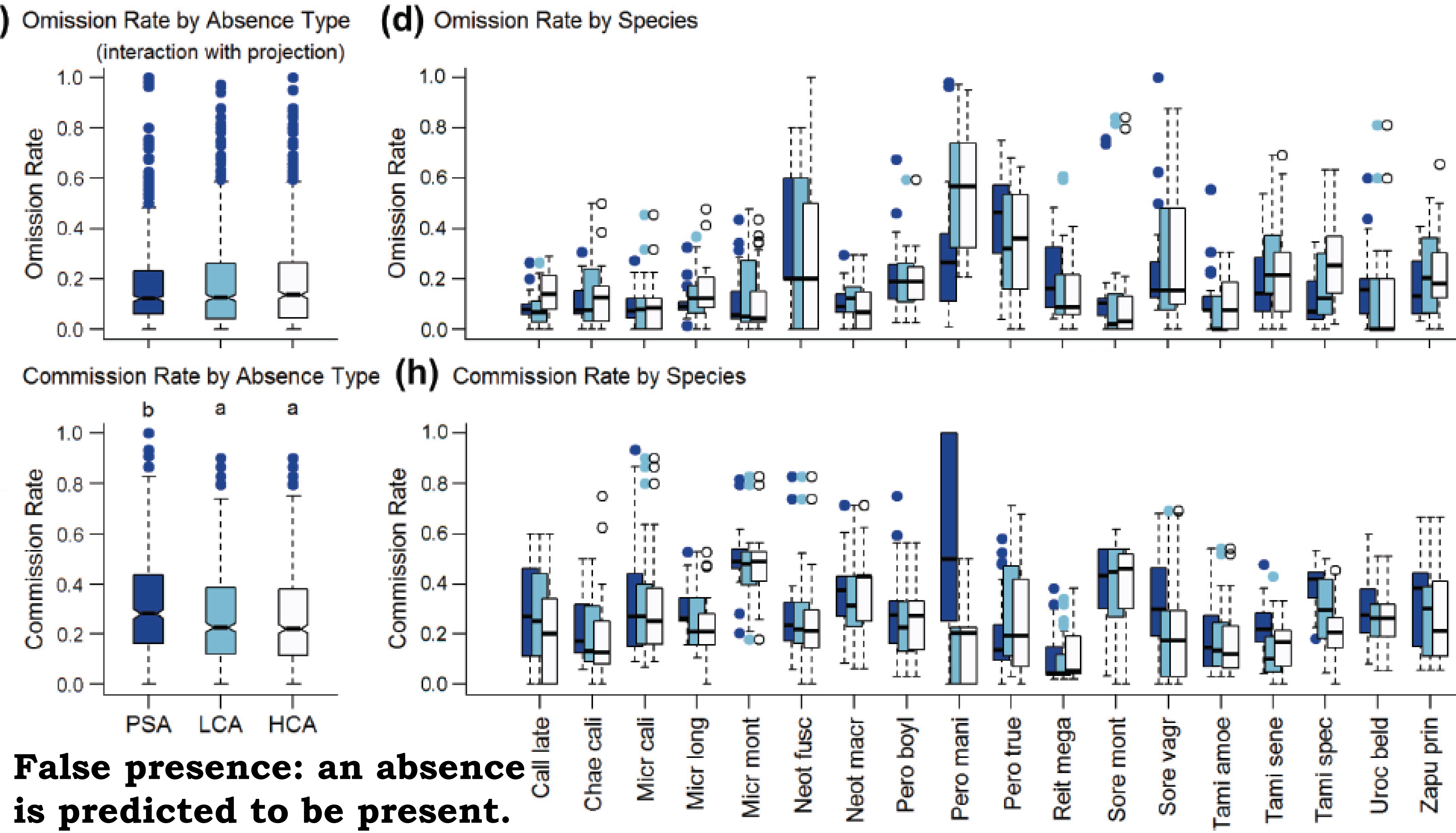
Thanks!

And to NSF, National Geographic Society, CA Energy Commission, MVZ, and NPS for funding.

SDMs over-predicted presence more than absence

(Smith et al. 2013. Ecography 36:1017-1031)

False absence: known occurrence predicted to be absence by model



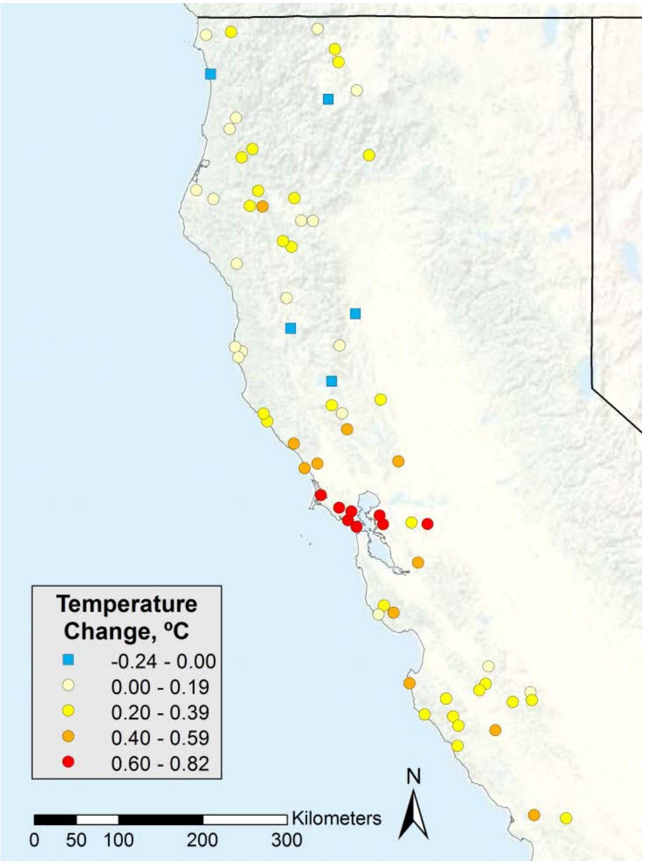
False presence: an absence is predicted to be present.

Land Use, Climate Change and Bird Resurveys

Resurveys (1911-40 vs 2009-10): 2 km transect, 10 pt. counts,70 sites
Climate Change (1900-1939 vs. 1970-2009): PRISM 1 km buffer
Land Use Intensity (Sanderson et al. 2002): 1 km buffer

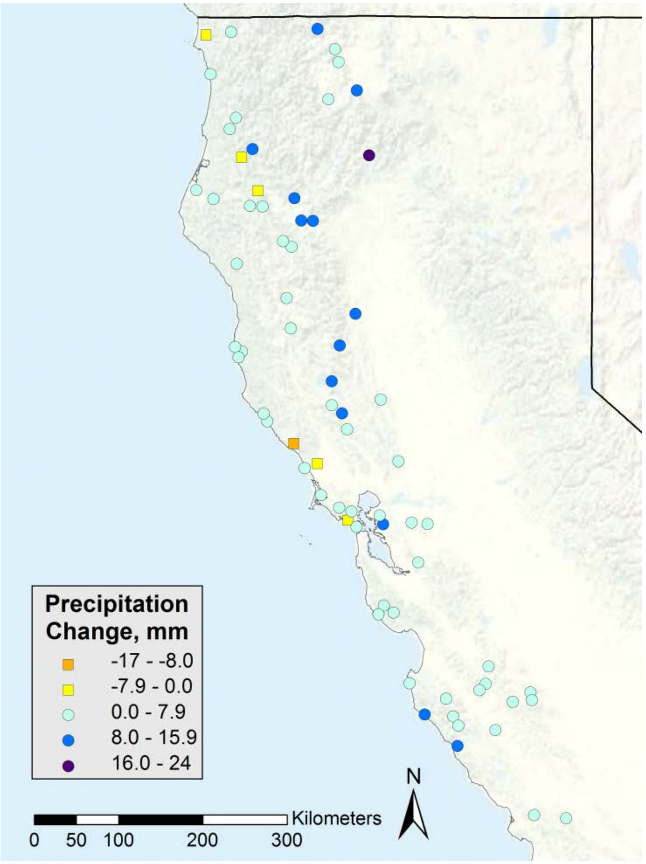
Δ Temperature

($\bar{x}$ = 0.29°C, -0.24-0.82)



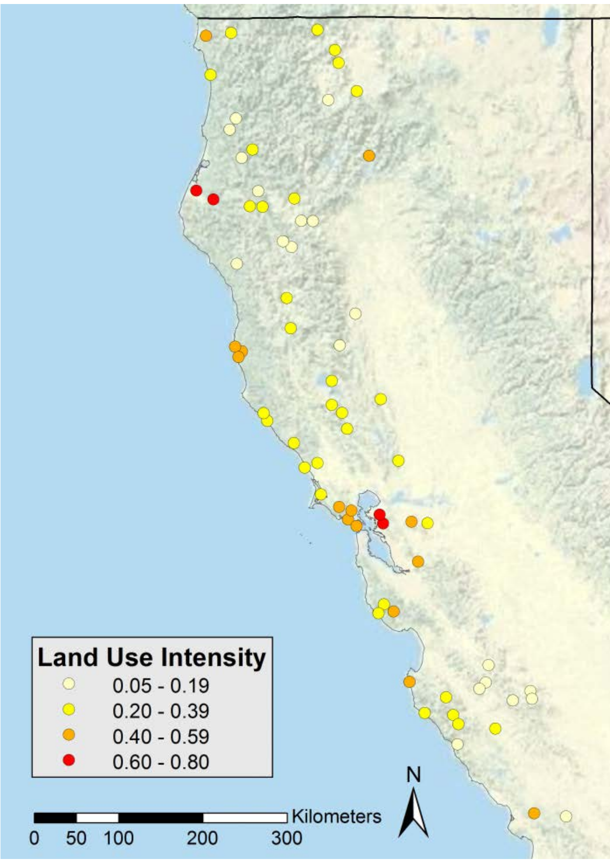
Δ Precipitation

($\bar{x}$ = 4.6mm, -16.8-23.8)

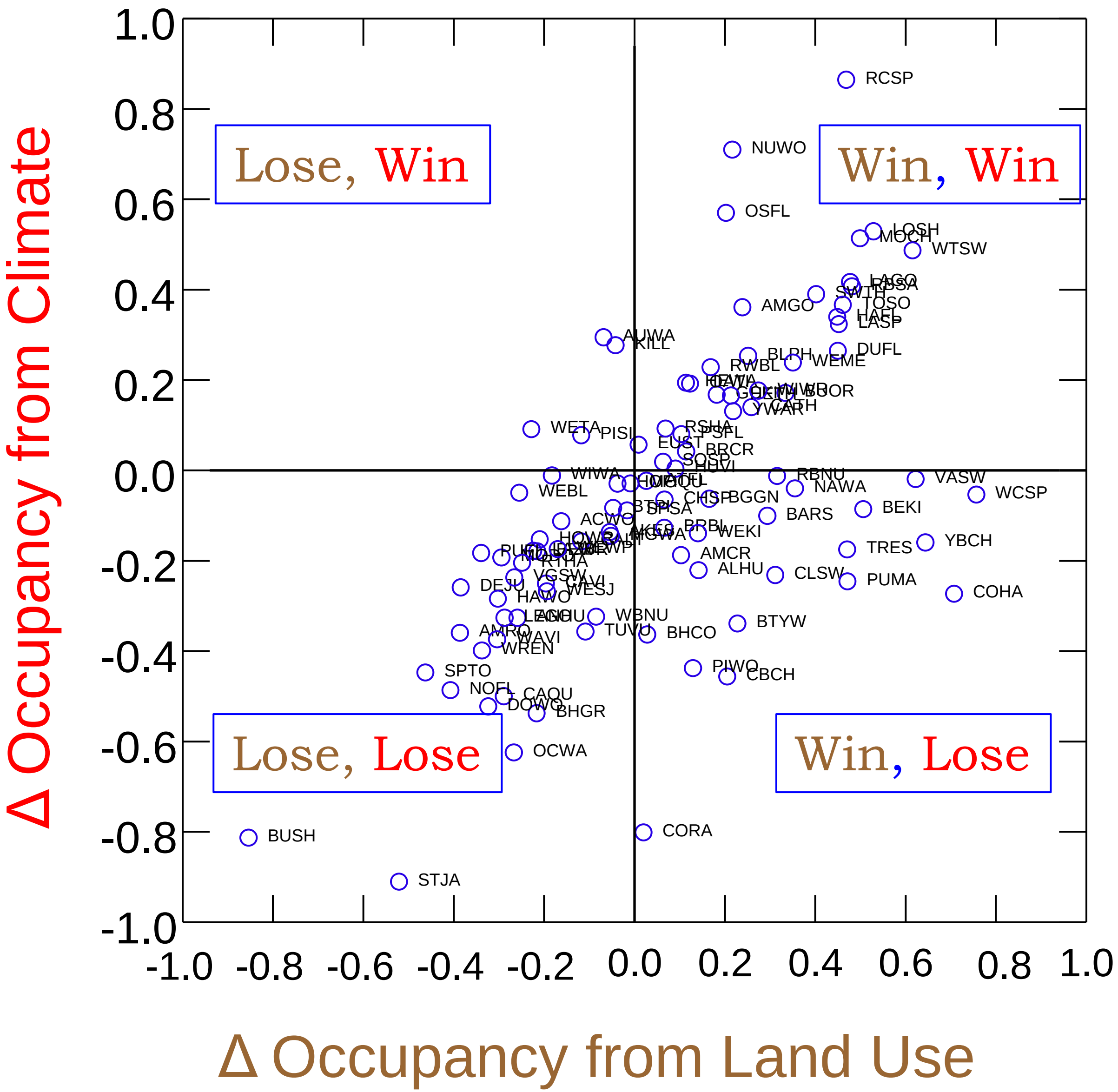


Land Use Intensity

($\bar{x}$ = 0.29, 0.06-0.76)



Winners and Losers from Climate (1°C warming & 100 mm drying) and Land Use Change



Double Whammy:
***r* = 0.63,**
***P* < 0.001**

Multiple-Season Occupancy Models to Estimate Colonization and Extinction

(MacKenzie et al. 2002, 2006)

$$\Psi_t = \Psi_{t-1}(1-\varepsilon_{t-1}) + (1-\Psi_{t-1})\,\delta_{t-1}$$

Occupied Undetected Not extinct

Unoccupied Colonized

$$Pr(\boldsymbol{h}_2 = 000\,010)$$

$$= \left\{\varphi_1 \prod_{1}^{3} (1 - p_{1,j})(1-\varepsilon) + (1-\varphi_1)\delta_1\right\} x\ (1 - p_{2,1})\, p_{2,2}\, (1 - p_{2,3})$$

Detection history

Inference About Turnover based on Naïve Site "Occupancy" History

(1 = present and 0 = absent) for two eras (historic = h and modern = m) derived from its probability of detection (D).

Occupancy history	Persistence (1,1)	Colonization (0,1)	Extinction (1,0)	Unoccupied (0,0)
1,1	1	0	0	0
0,1	$1\text{-}D_h$	D_h	0	0
1,0	$1\text{-}D_m$	0	D_m	0
0,0	$(1\text{-}D_h)*(1\text{-}D_m)$	$D_h*(1\text{-}D_m)$	$(1\text{-}D_h)*D_m$	$D_h\, D_m$

Inference About Occupancy based on Naïve Site "Occupancy", False Absence and False Detections

(z = 1 = present and z = 0 = absent) for two eras (historic = h and modern = m) derived from its probability of detection (D).

True state	fersistence (1,1)	Colonization (0,1)	Extinction (1,0)	Unoccupied (0,0)
Unoccupied (z=0)	1	0	0	0
0,1	$1\text{-}D_h$	D_h	0	0
1,0	$1\text{-}D_m$	0	D_m	0
0,0	$(1\text{-}D_h)*(1\text{-}D_m)$	$D_h*(1\text{-}D_m)$	$(1\text{-}D_h)*D_m$	$D_h\,D_m$

Multiple-Season Occupancy Models to Estimate Colonization and Extinction

(MacKenzie et al. 2002, 2006)

$$\Psi_t = \Psi_{t-1}(1 - \varepsilon_{t-1}) + (1 - \Psi_{t-1})\,\delta_{t-1}$$

Occupied Undetected Not extinct

Unoccupied Colonized

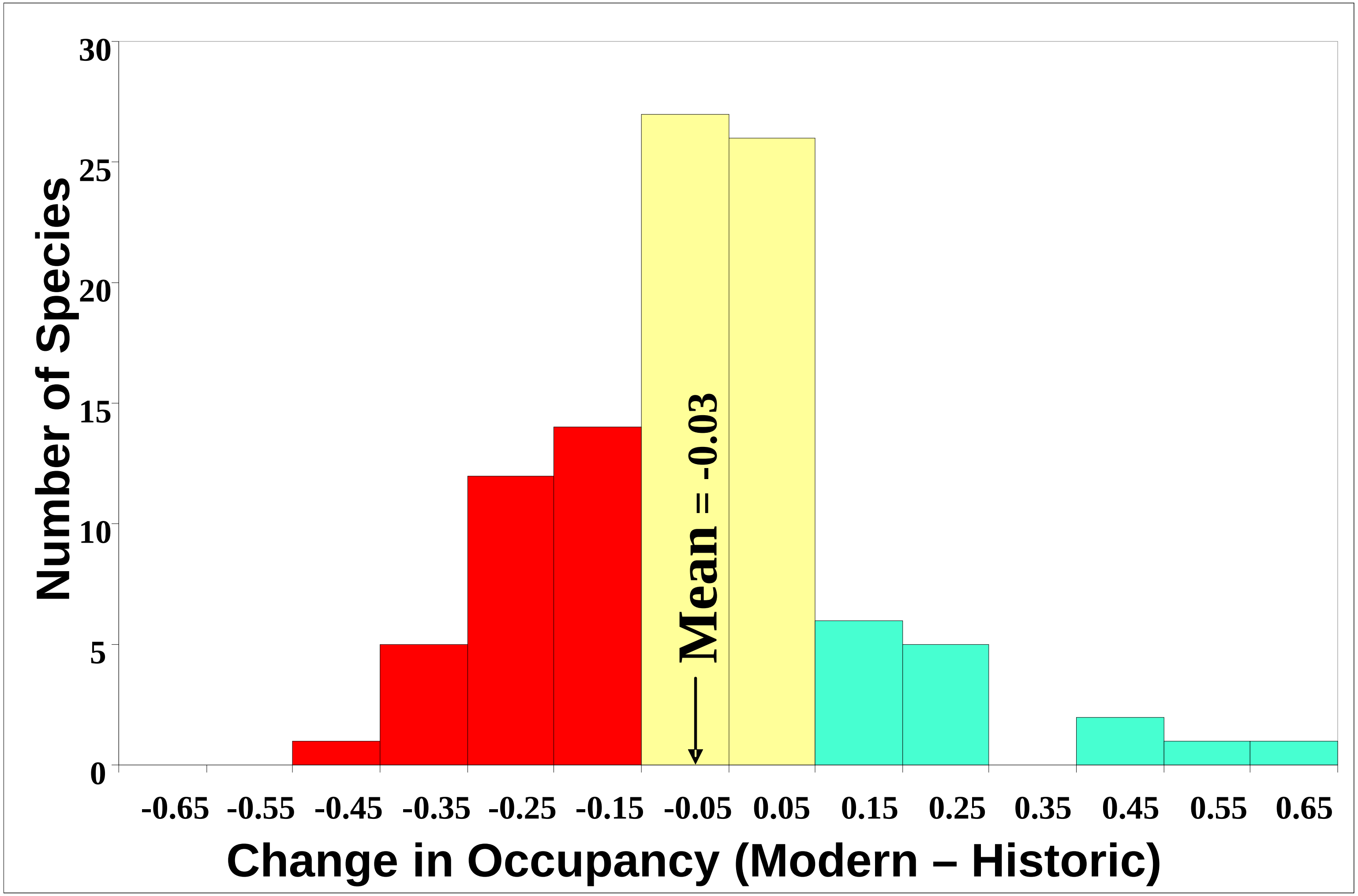
$$Pr(\boldsymbol{h}_2 = 000\,010)$$

$$= \left\{\varphi_1 \prod_{1}^{3} (1 - p_{1,j})(1 - \varepsilon) + (1 - \varphi_1)\delta_1\right\} x \; (1 - p_{2,1})\, p_{2,2}\, (1 - p_{2,3})$$

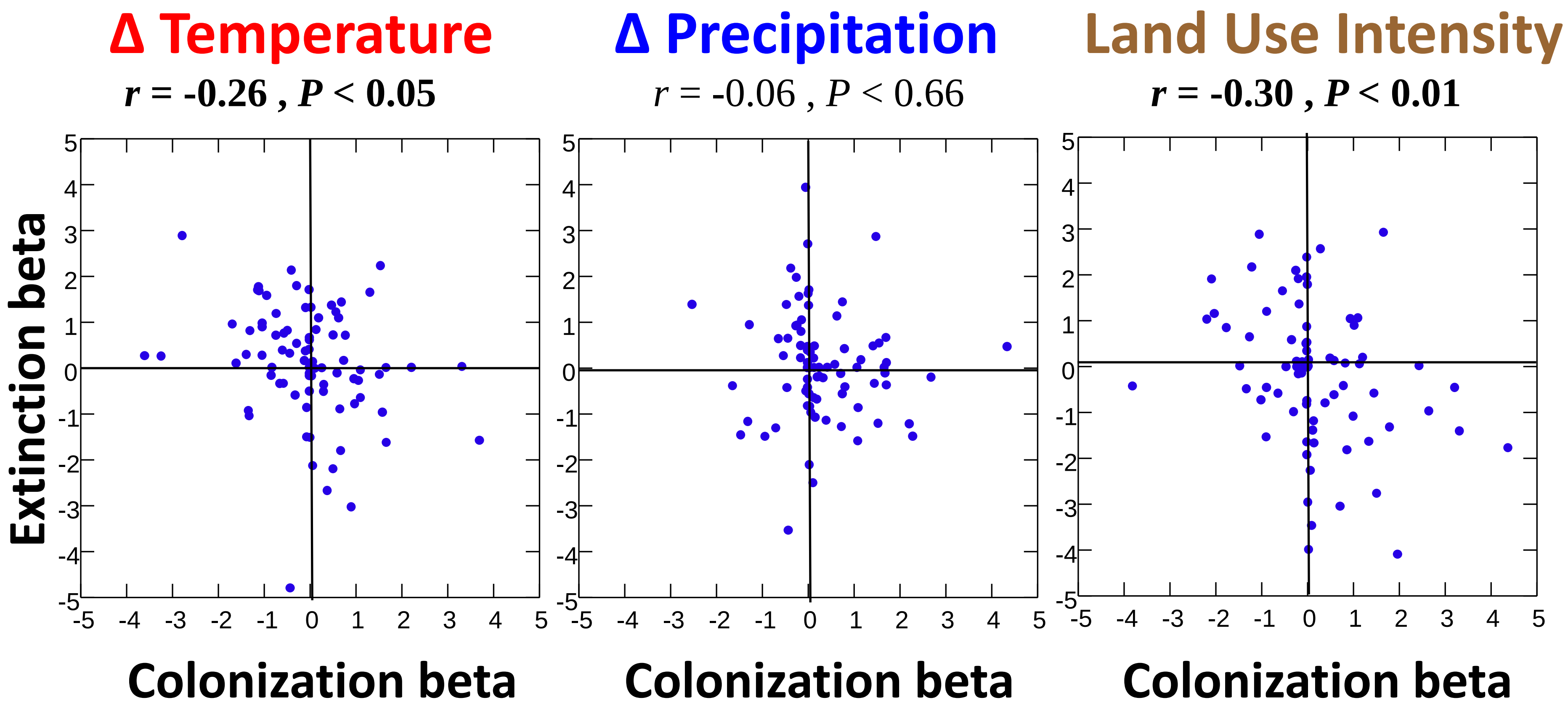
Detection history

Change in Occupancy (Modern – Historic) for 100 Coast Range Bird Species

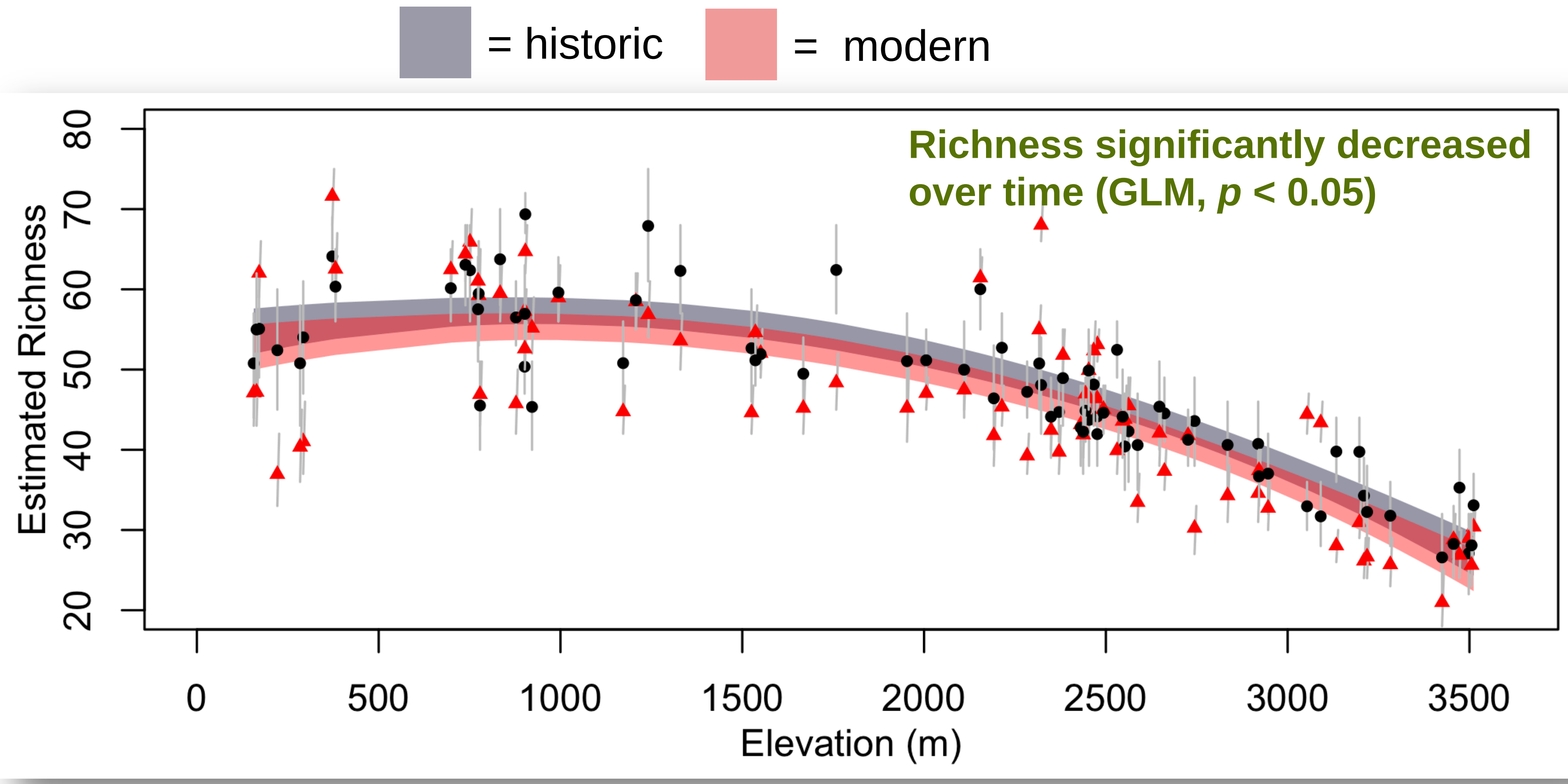
Over **twice as many species decreased** (n = 32) **in occupancy** by >0.1 as those that increased (n = 15) in occupancy by >0.1



Consistency of Metacommunity Responses: Slopes of Colonization vs. Extinction

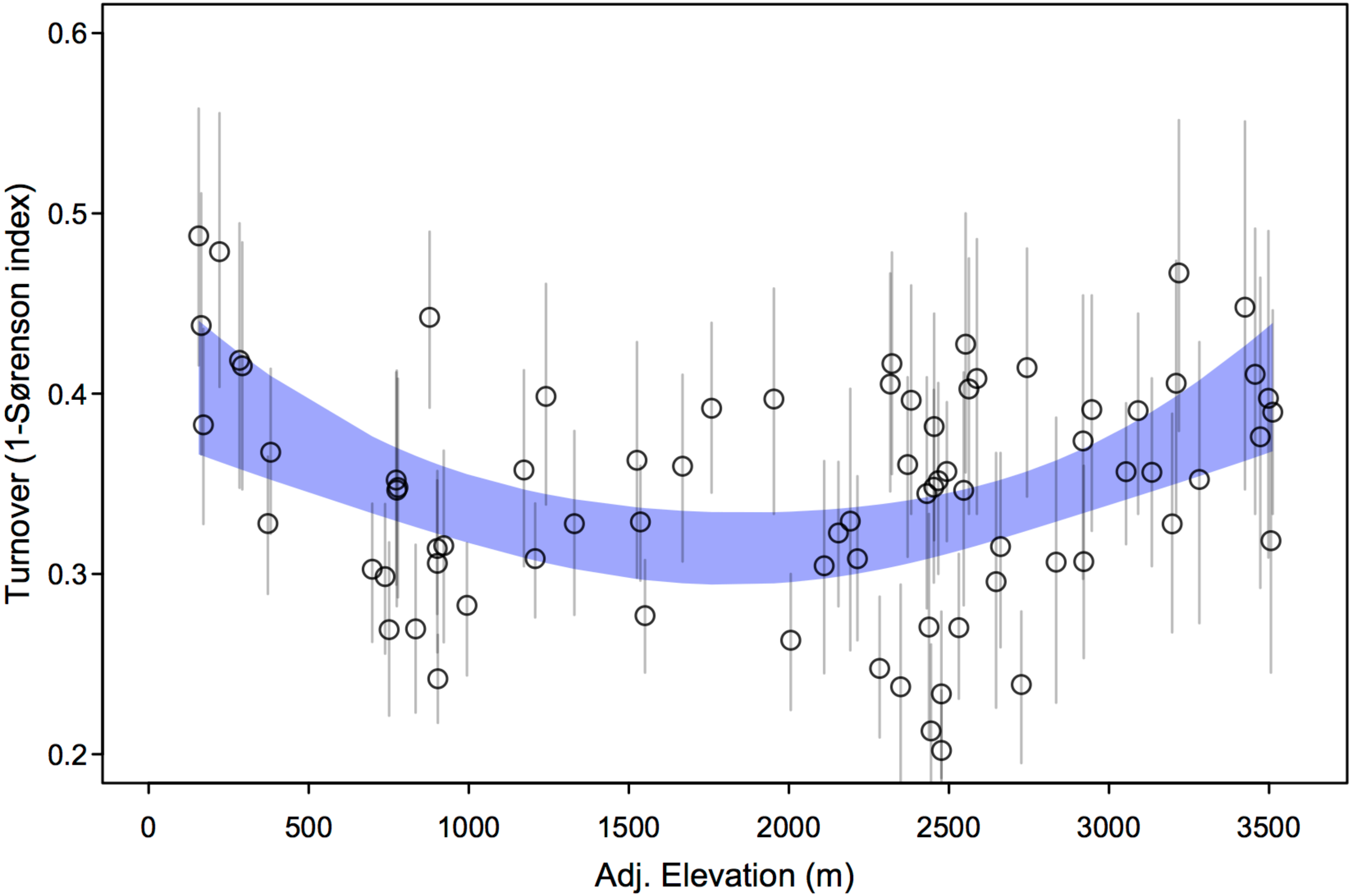


How Does This Affect Avian Communities?
Changes in Avian Species Richness



Tingley & Beissinger. 2013. *Ecology 94: 598-609*

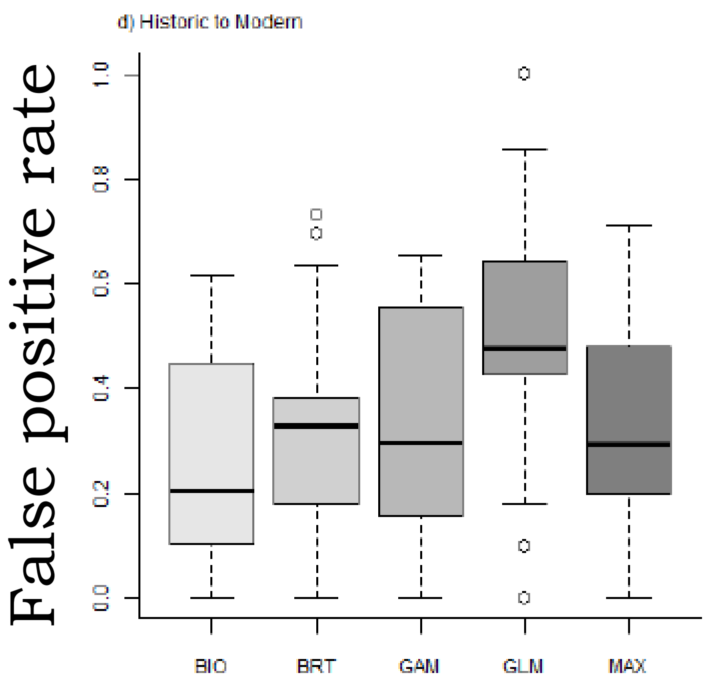
How Does This Affect Communities? Turnover in Avian Species Composition



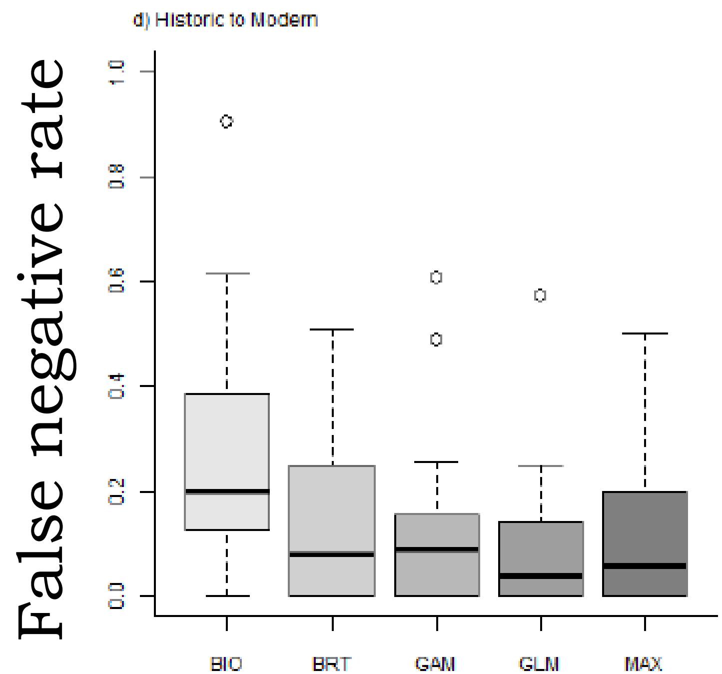
Tingley & Beissinger. 2013. *Ecology 94: 598-609*

Species distribution models (SDMs) over-predict presence more often than absence.

Mean = 0.35

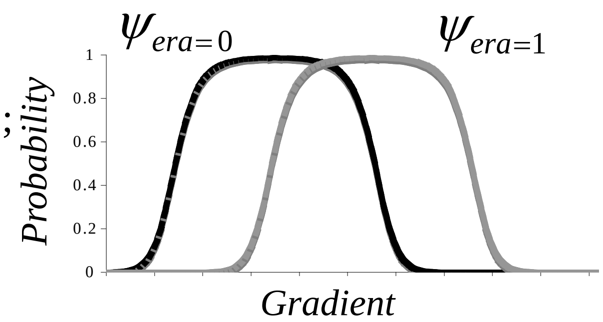
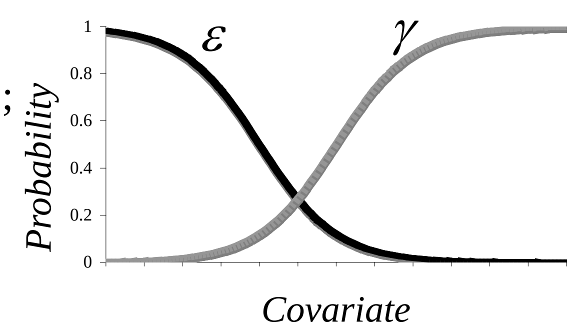


Mean = 0.14



SDMs that had good predictive performance for historic data did not perform as well in projecting contemporary occupancy.

Parameterizations of Occupancy Models for Inferring Range Shifts

Model	Sites	Modeled Parameters	Example Equations	Range Change Inference
Single Season	**Unpaired**	$\psi,\ p$	$\text{logit}(\psi)=\beta_0+\beta_1\cdot era+\beta_2\cdot gradient+\beta_3\cdot gradient^2;$ $\text{logit}(p)=\beta_4$	
Multi-Season	**Paired**	$\psi_0,\ \varepsilon,\ \gamma,\ p$	$\text{logit}(\psi_0)=\beta_0+\beta_1\cdot\text{covariate}+\beta_2\cdot gradient^2;$ $\text{logit}(\varepsilon)=\beta_3+\beta_4\cdot\text{covariate};$ $\text{logit}(\gamma)=\beta_5+\beta_6\cdot\text{covariate};$ $\text{logit}(p)=\beta_7$	

Tingley and Beissinger. 2009. TREE 24:625-633.