Greater sage-grouse population ecology studies to inform land management actions in sagebrush ecosystems

Peter S. Coates, Ph.D.

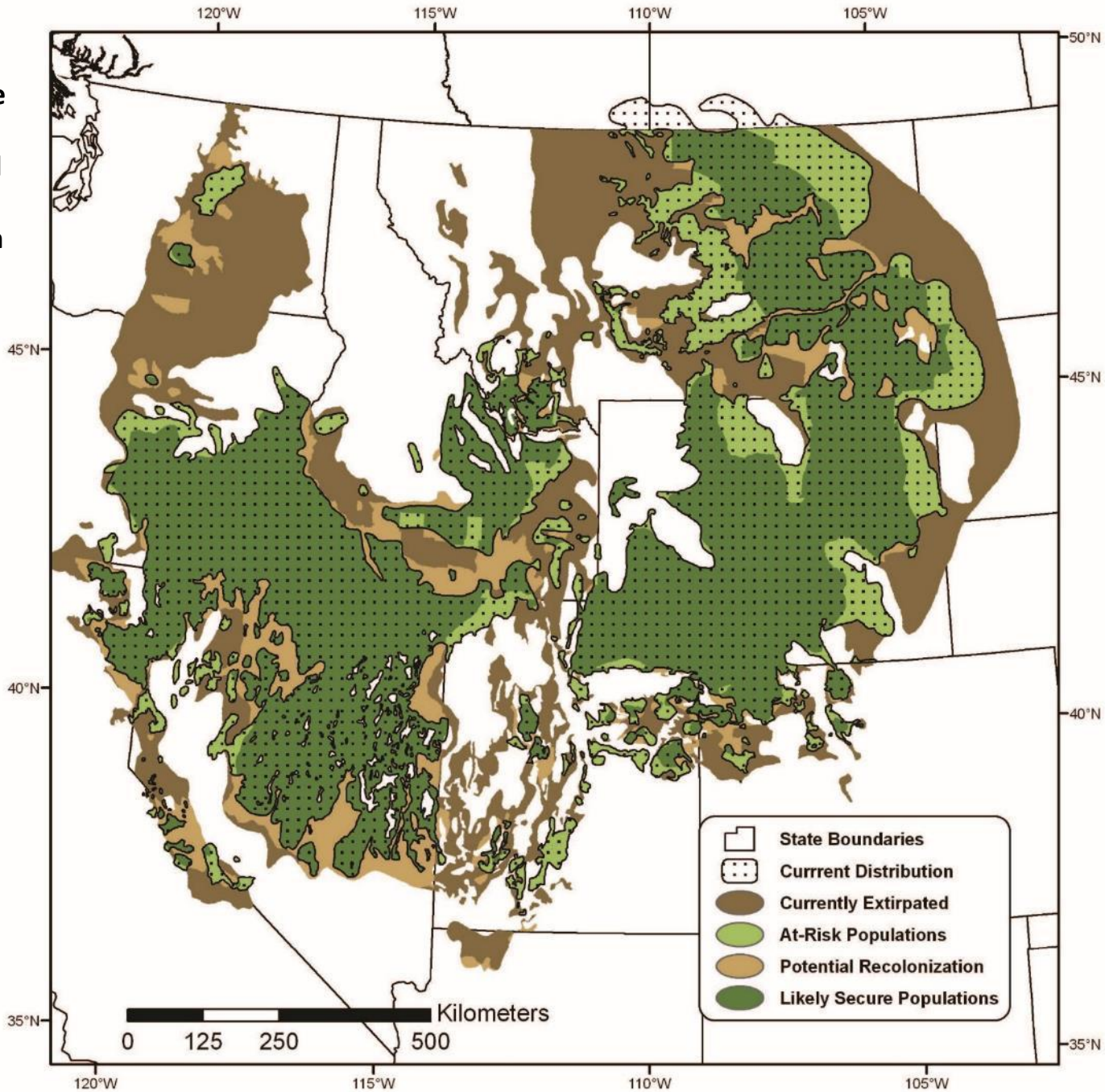
Mark A. Ricca, Ph.D.

U.S. Geological Survey

Western Ecological Research Center

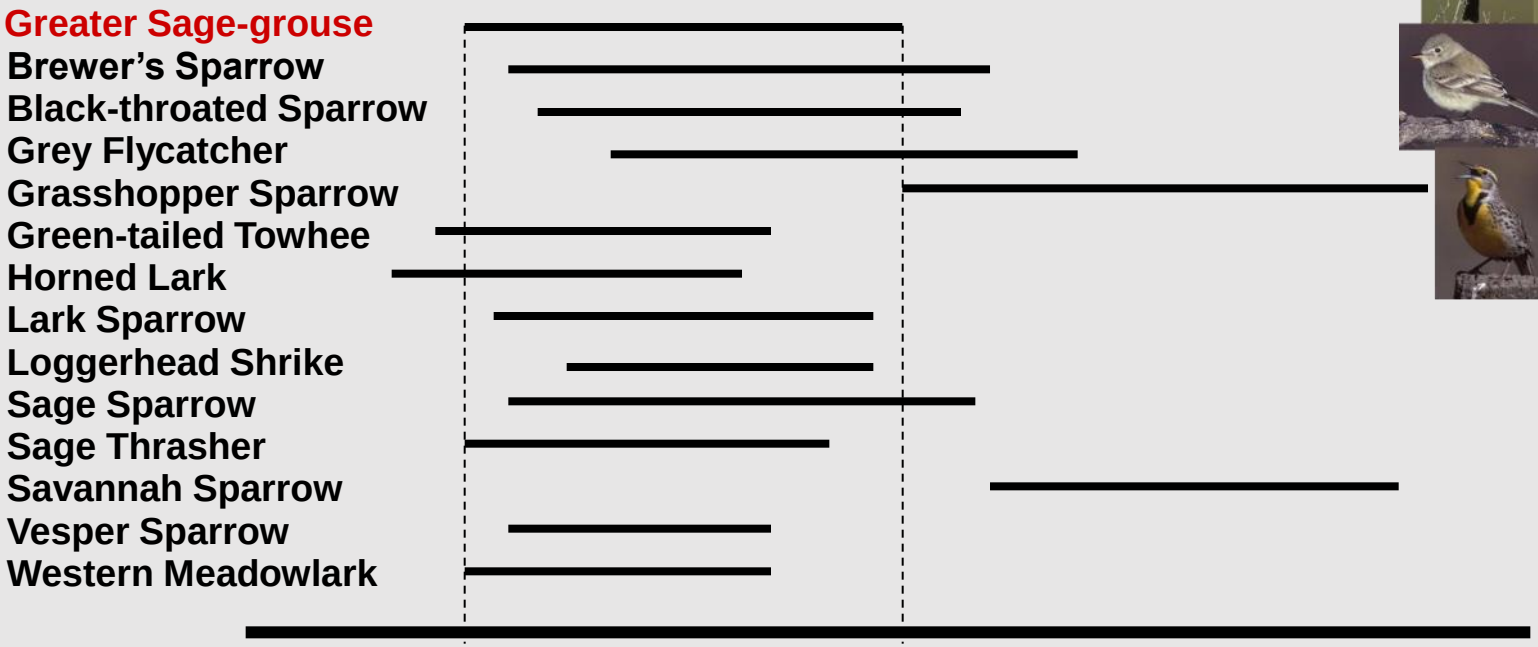
Greater Sage-grouse

Current and Historic Distribution

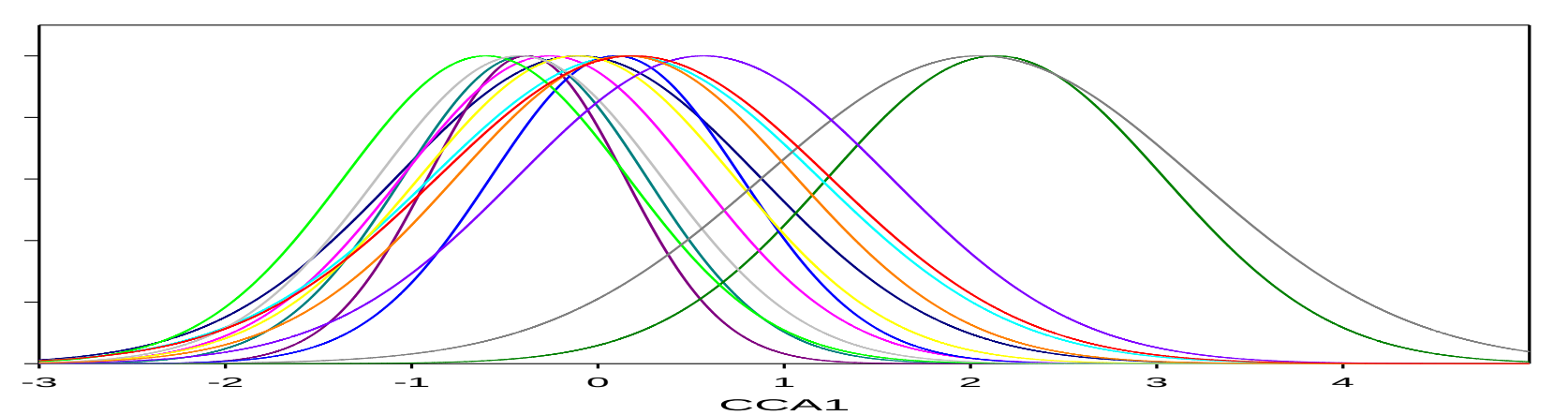


Greater Sage-Grouse as an Avian Indicator Species

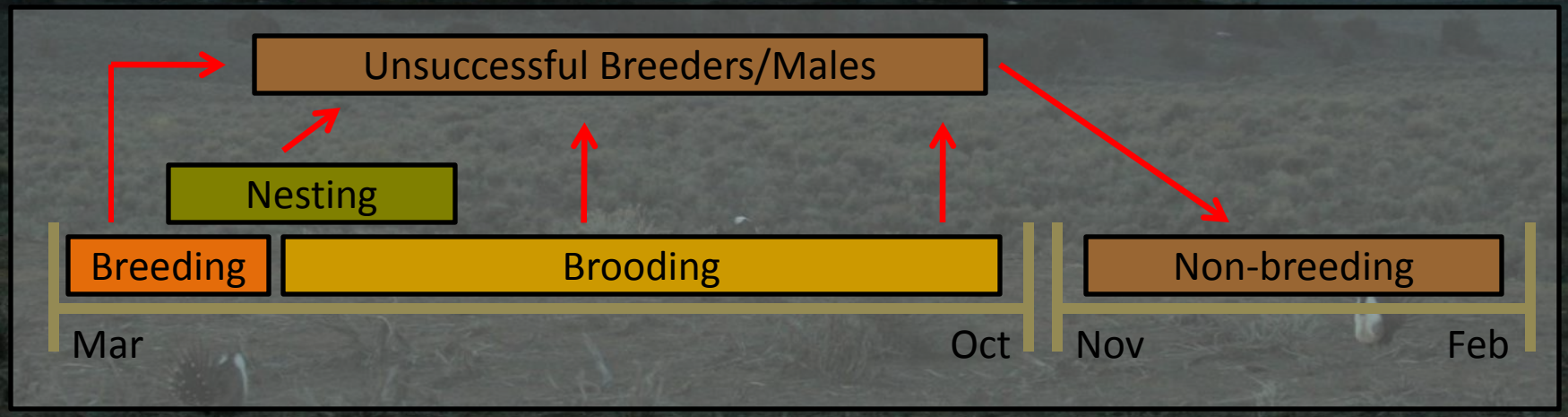
Hanser et al. (2011)

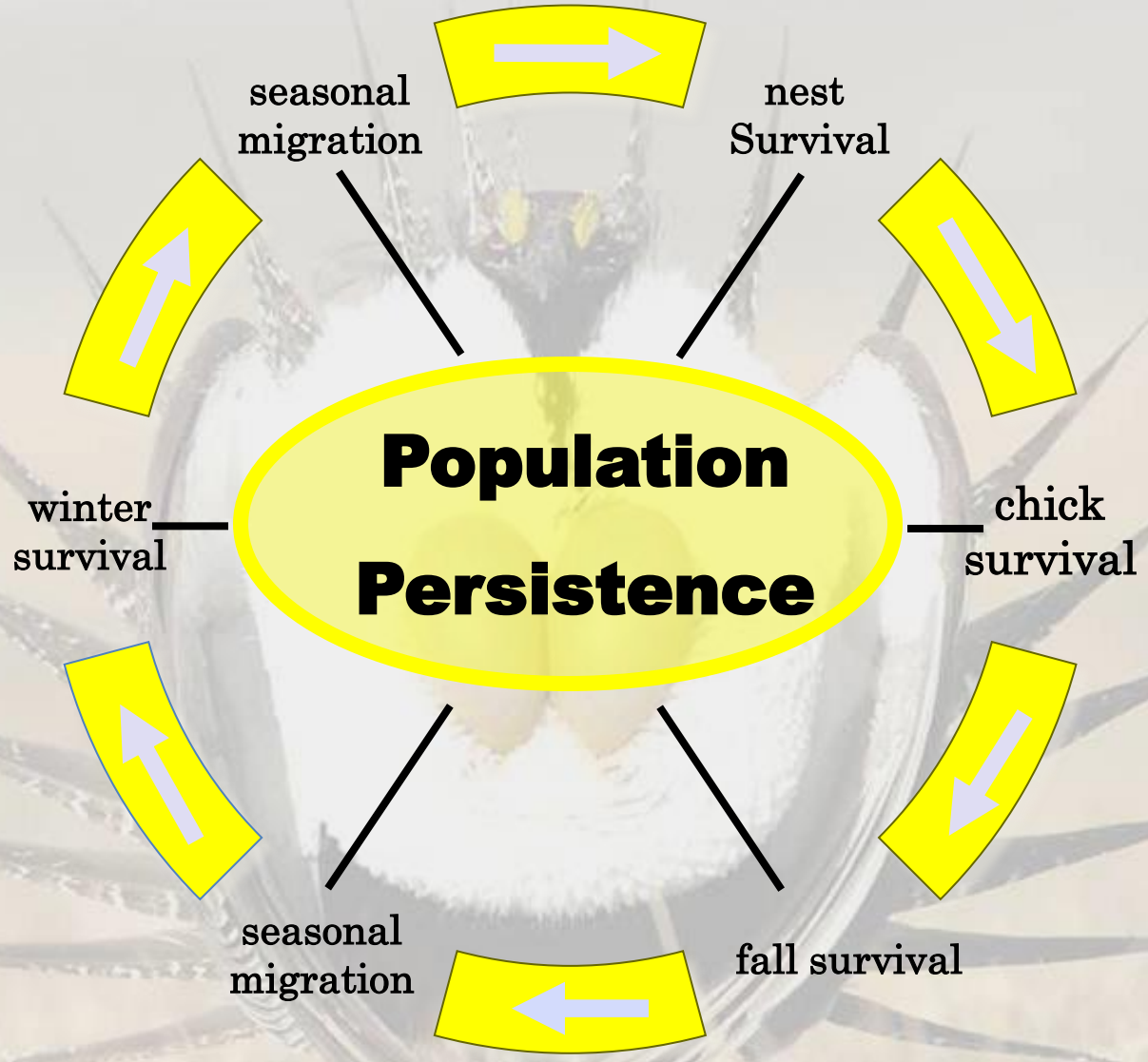


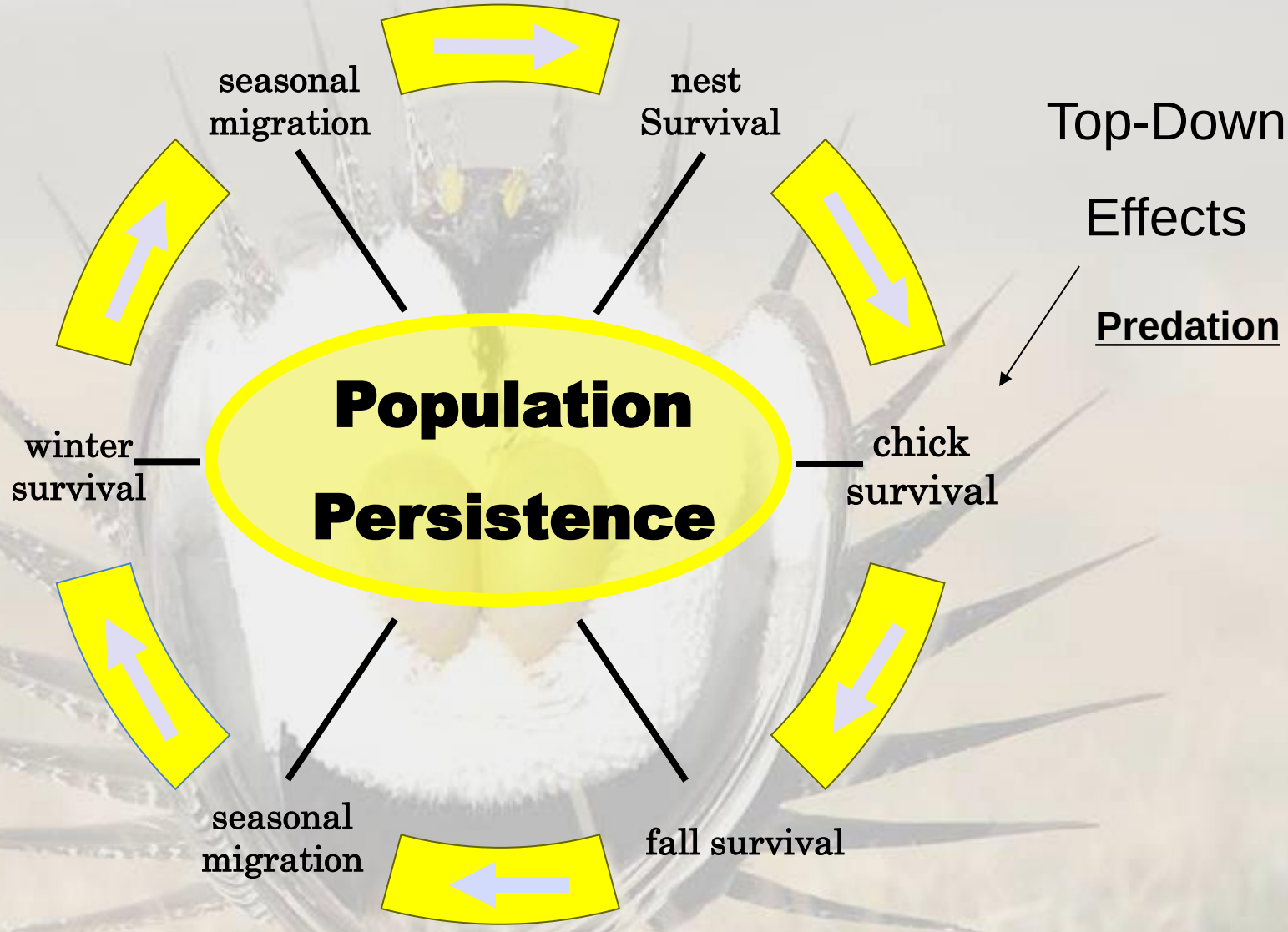
Sagebrush ← **Environmental Gradient** → Grassland

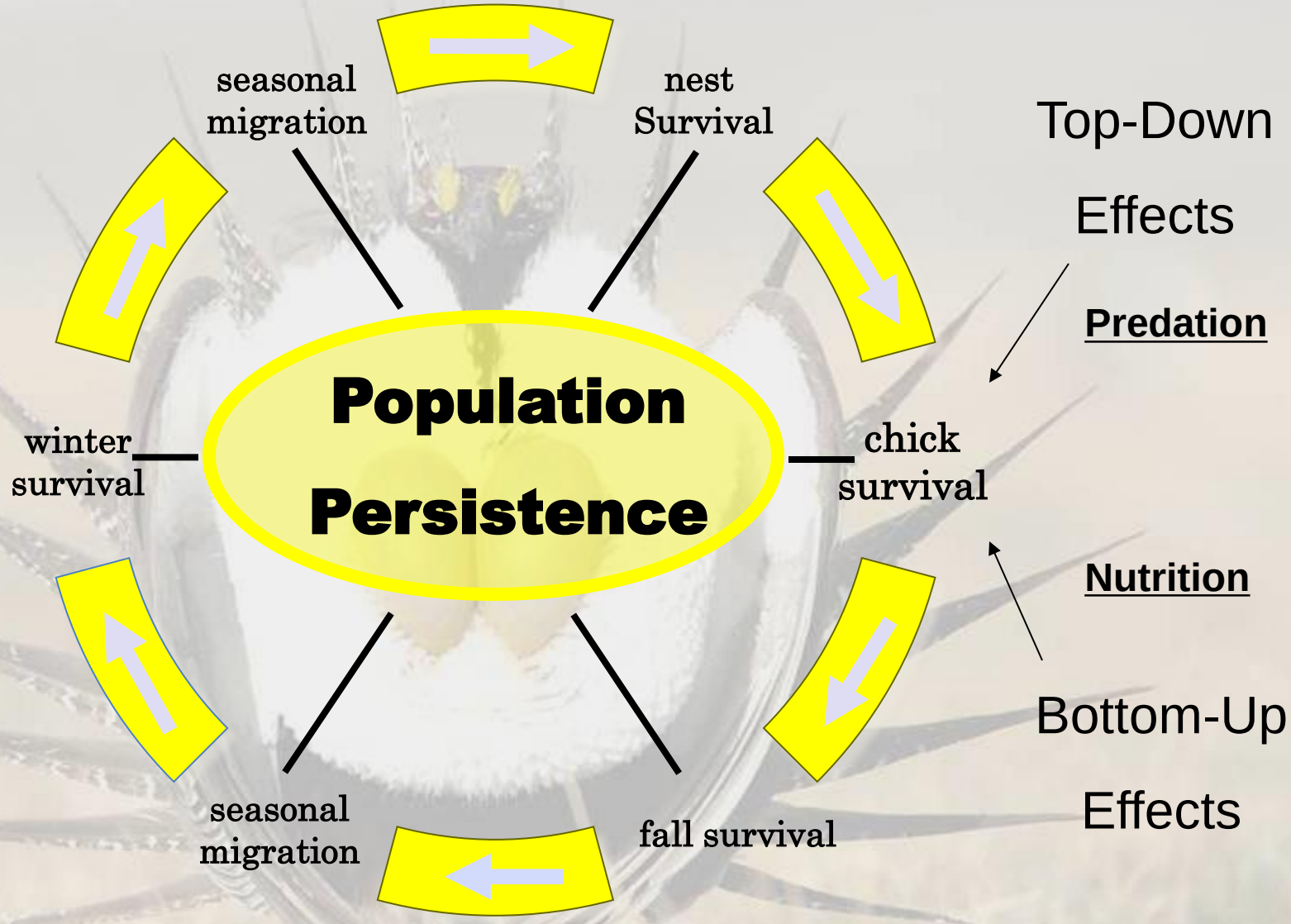


Life Cycle


Unsuccessful Breeders/Males
Nesting
Breeding
Brooding
Non-breeding
Mar
Oct
Nov
Feb


Population
Persistence
seasonal
migration
nest
Survival
chick
survival
fall survival
seasonal
migration
winter
survival


seasonal migration
nest Survival
Top-Down Effects
Predation
Population Persistence
winter survival
chick survival
seasonal migration
fall survival


seasonal migration
nest Survival
Top-Down Effects
Predation
Population Persistence
winter survival
chick survival
Nutrition
Bottom-Up Effects
seasonal migration
fall survival

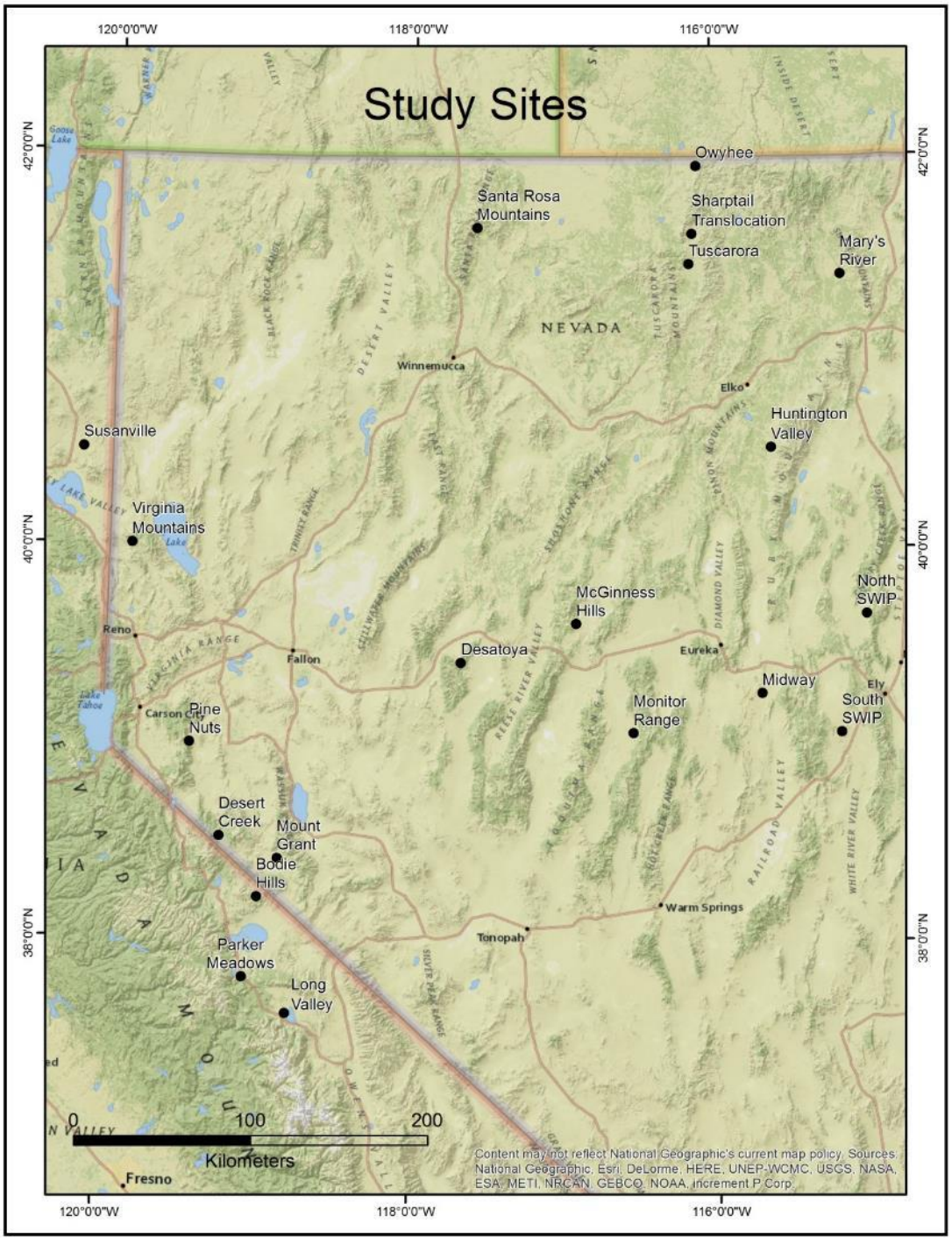
H. Copeland

R. Arkle

USGS

G. Vyn

M. Schoeder



USGS-WERC Sage-grouse Research Program Overview

- **Conduct applied science to inform management decisions by federal, state, and private stakeholders**
- **Field research in > 15 study sites since 2009**
- **Study scales:**
  Field - local (field)
  GIS - landscape, regional, range-wide

Presentation Overview:
Research & Science Solutions for Management

1) Wildfire

2) Predators (Ravens)

3) Conifer Encroachment

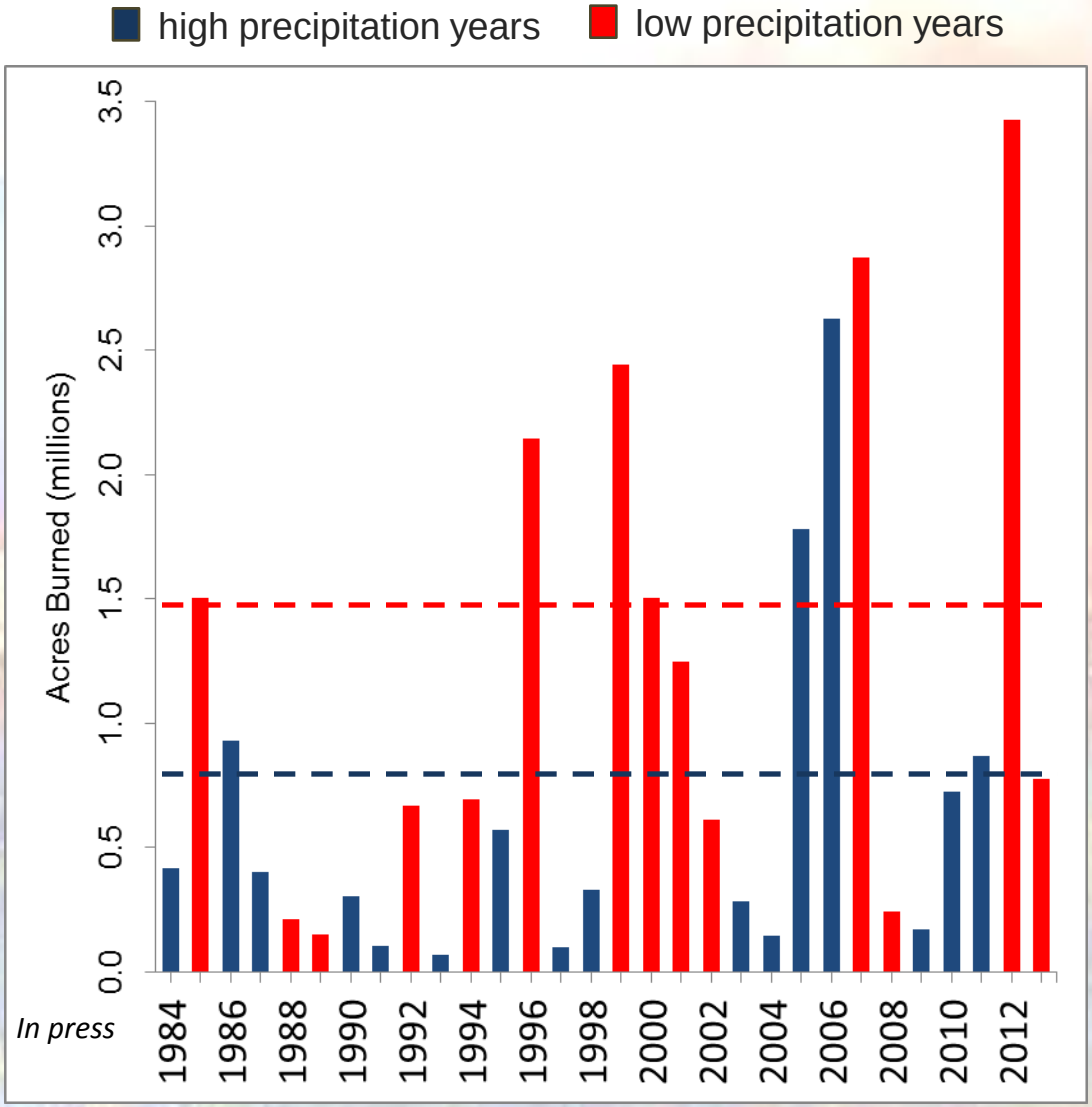
4) Macro- and Micro-Habitat

5) Multi-scale Population Assessment Tools

I. WILDFIRE AND INVASIVE GRASS

Shaff, USGS

Total Area Burned has Increased



In press

Wildfire/Grass Cycle

Wildfire Occurrence
(dominated by sagebrush)

Burned Area
(loss of sagebrush)

State Transition
(conversion to annual grass)

Wildfire Recurrence
(dominated by cheatgrass)

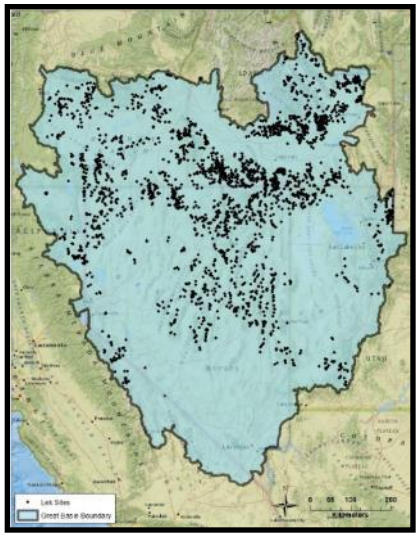
Positive Feedback Loop

Mike Pellant (BLM)

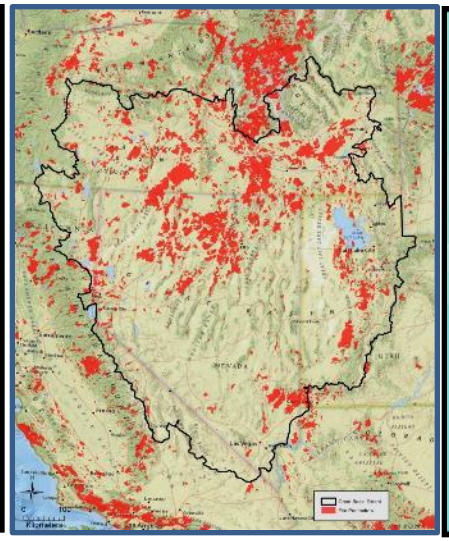
Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems

Peter S. Coates[a,1], Mark A. Ricca[a], Brian G. Prochazka[a], Matthew L. Brooks[b], Kevin E. Doherty[c], Travis Kroger[a], Erik J. Blomberg[d], Christian A. Hagen[e], and Michael L. Casazza[a]

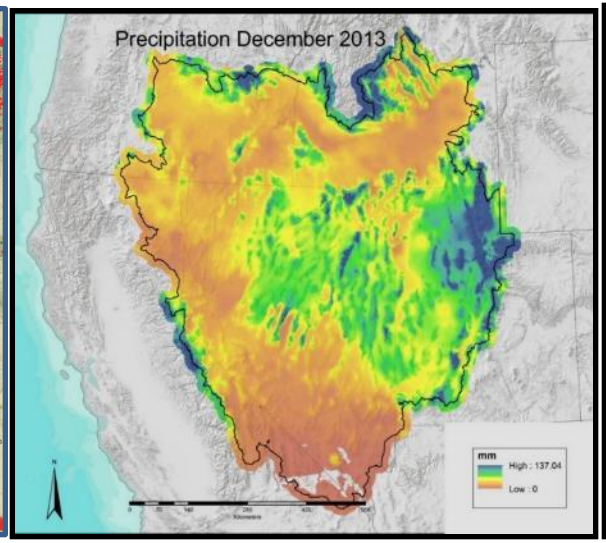
Lek Data Base
WAFWA
>2,700 sites



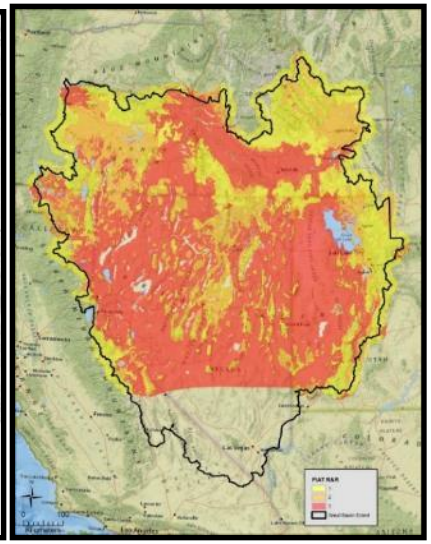
Monitoring Trends in Burn Severity (MTBS) database, 1984 – 2013 (USGS and USFS)



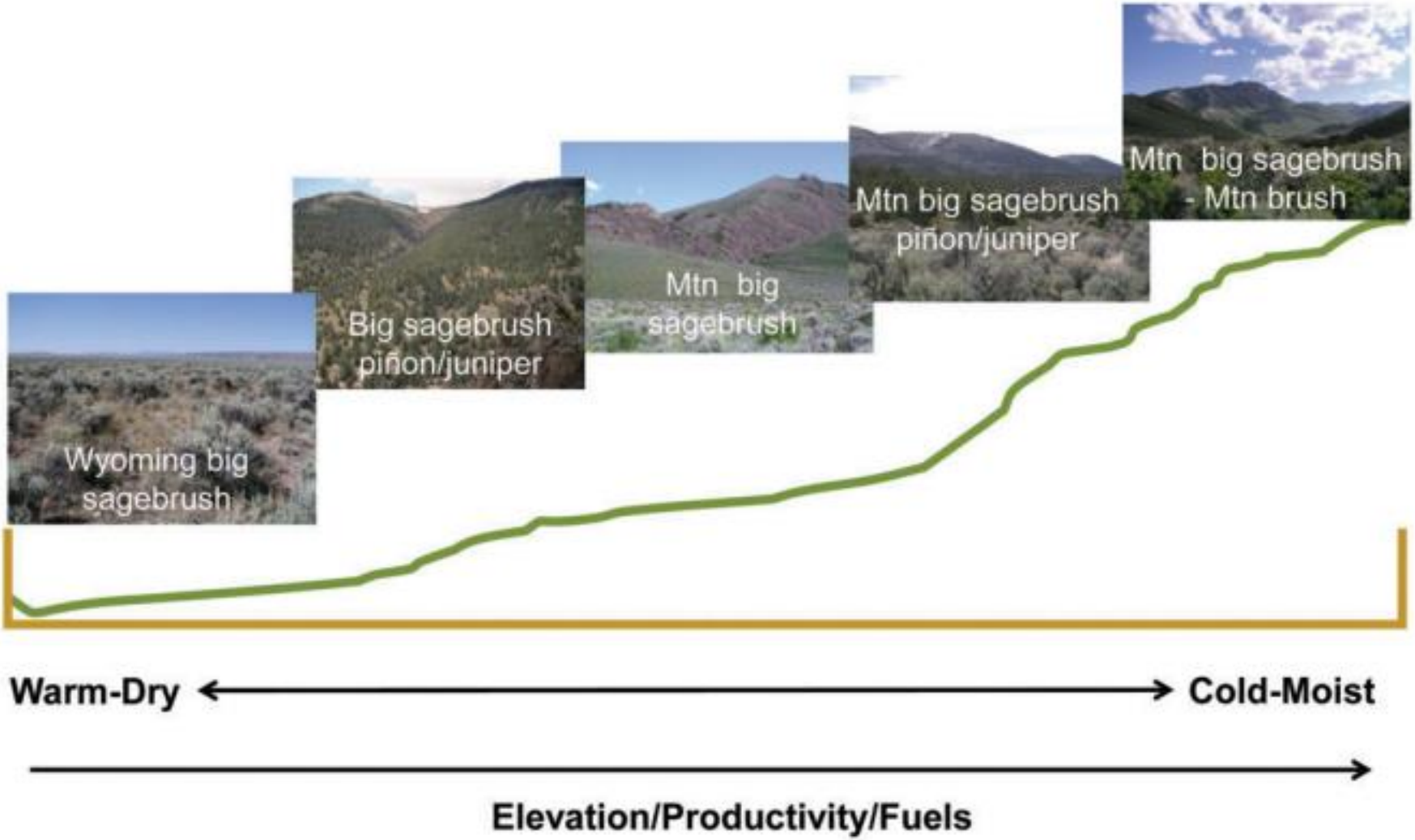
PRISM Climate Group (Oregon State University)



Ecosystem Resilience and Resistance

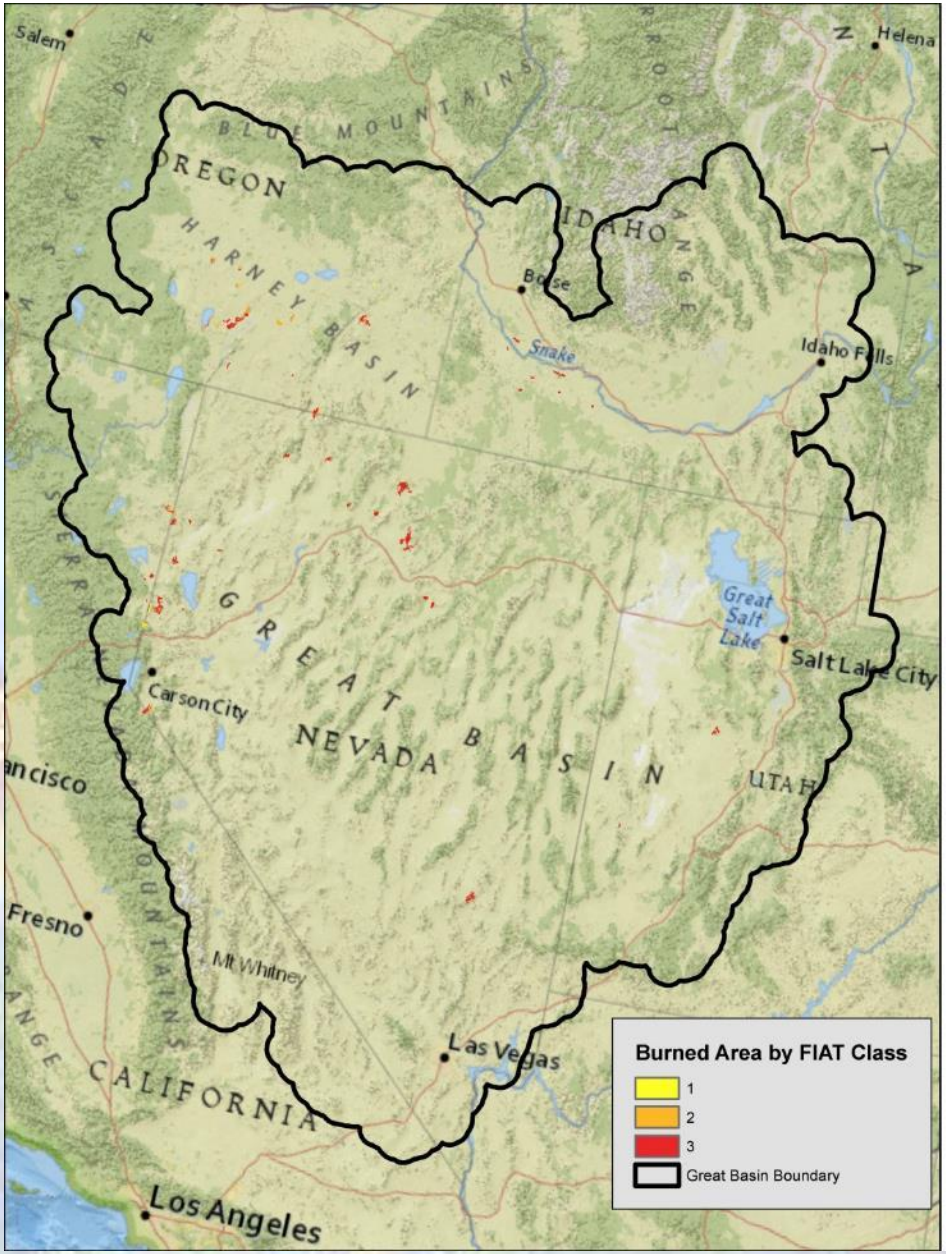


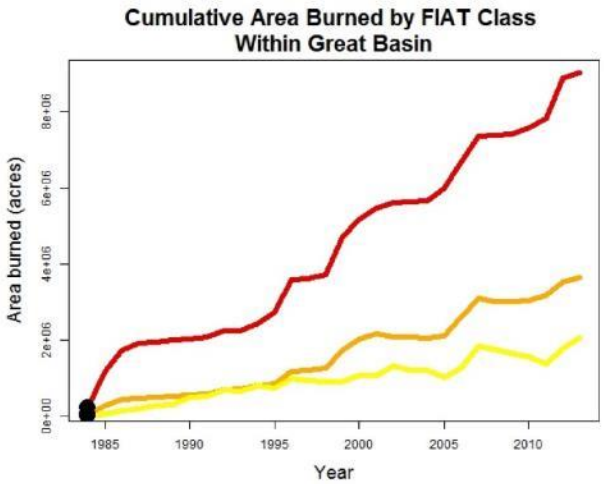
Incorporating Sagebrush Recovery into Model

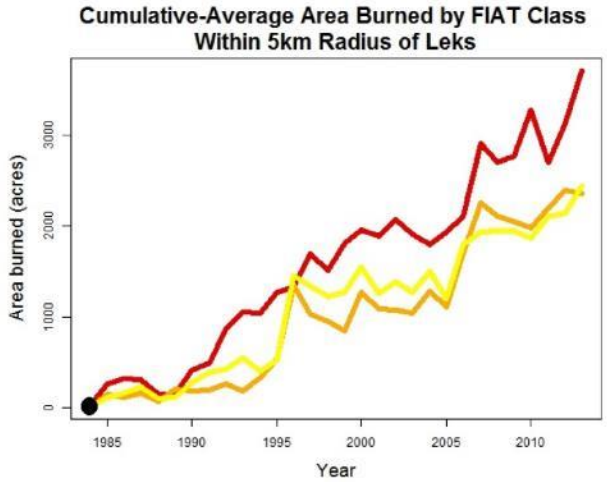


Sources: Chambers et al. 2014

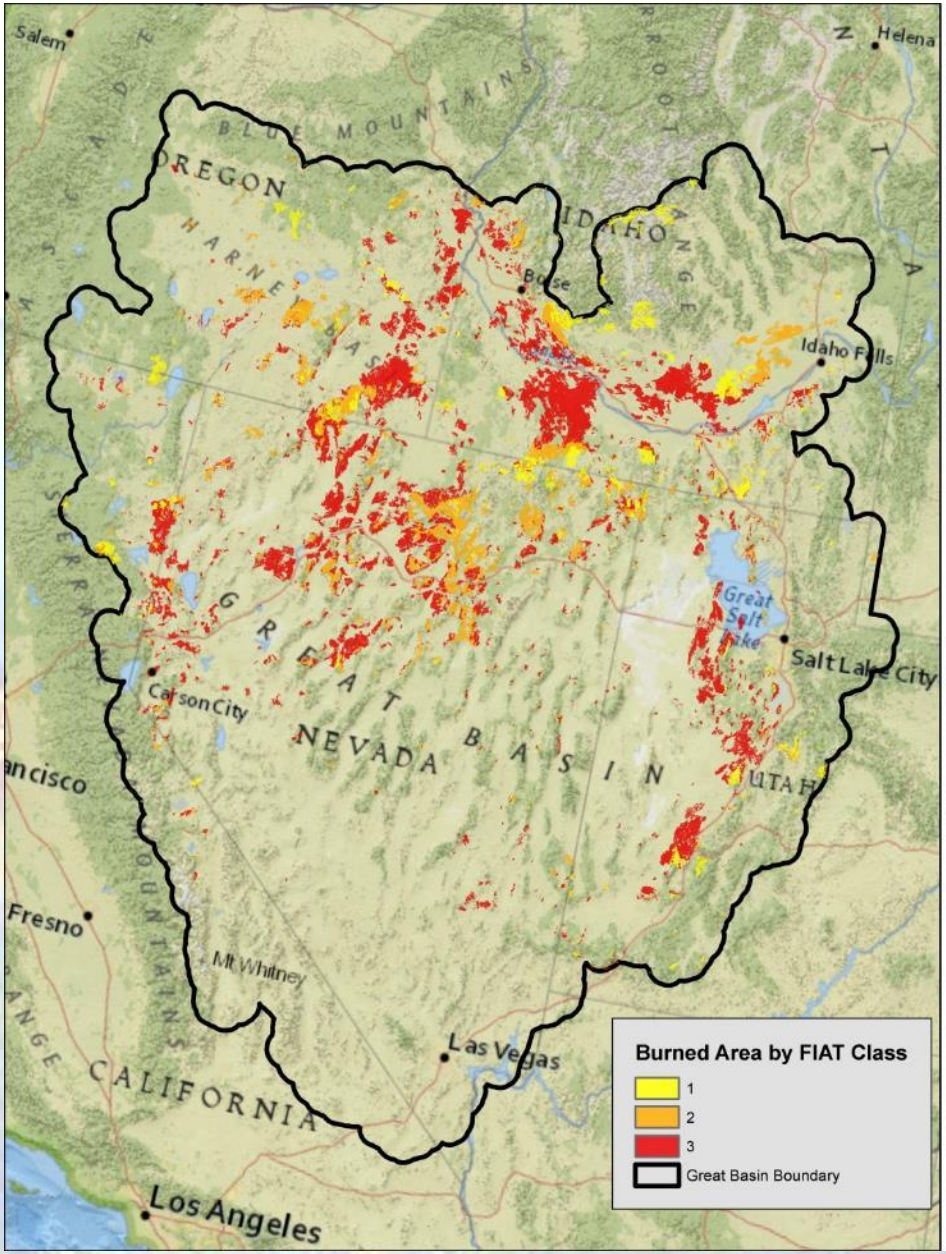
1984


Salem
Helena
BLUE MOUNTAINS
OREGON
HARNEY BASIN
IDAHO
Boise
Snake
Idaho Falls
GREAT BASIN
Great Salt Lake
Salt Lake City
Carson City
NEVADA
UTAH
Fresno
Mt Whitney
Las Vegas
CALIFORNIA
Los Angeles
Burned Area by FIAT Class
1
2
3
Great Basin Boundary


Cumulative Area Burned by FIAT Class
Within Great Basin
Area burned (acres)
0e+00
2e+06
4e+06
6e+06
8e+06
1985
1990
1995
2000
2005
2010
Year


Cumulative-Average Area Burned by FIAT Class
Within 5km Radius of Leks
Area burned (acres)
0
1000
2000
3000
1985
1990
1995
2000
2005
2010
Year

2013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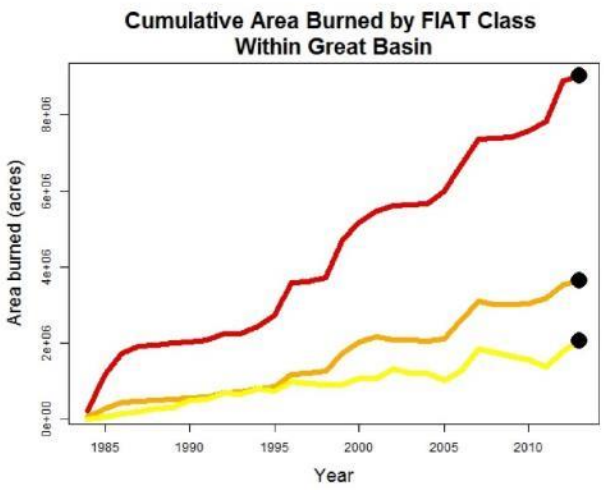
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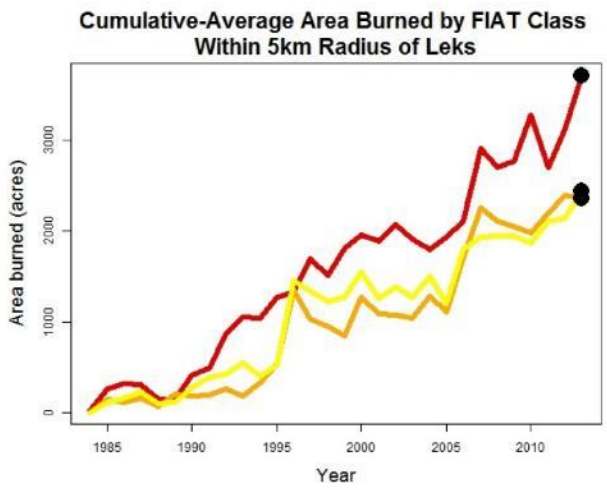
Cumulative-Average Area Burned by FIAT Class
Within 5km Radius of Leks
Area burned (acres)
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1985
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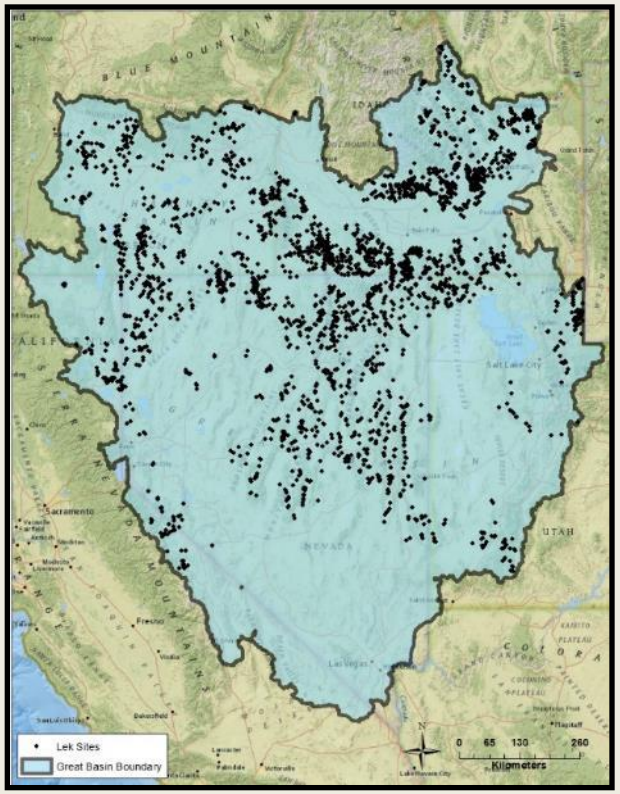
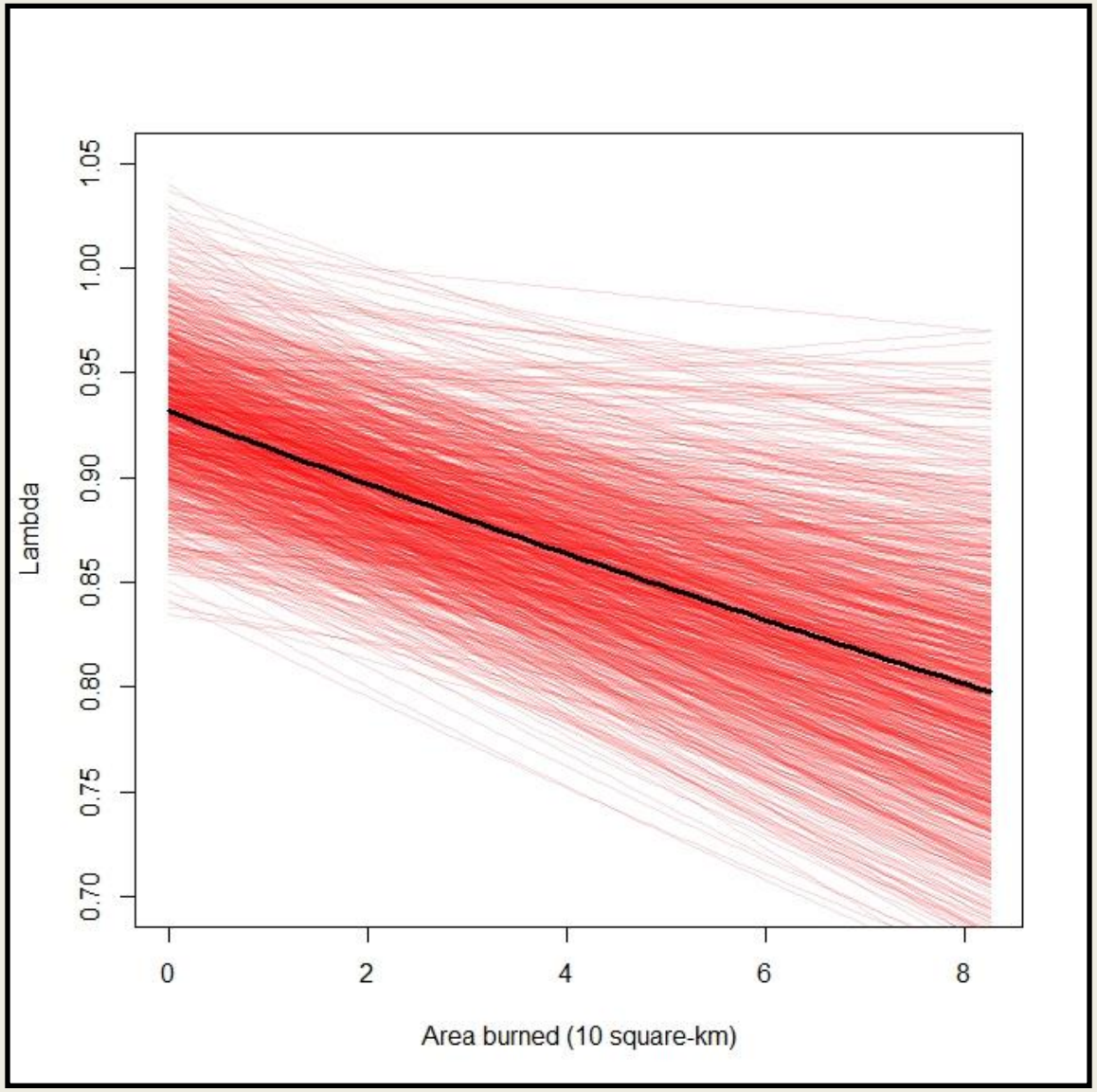
2005
2010
Year

Credit: A. Stillman, Bureau of Land Management



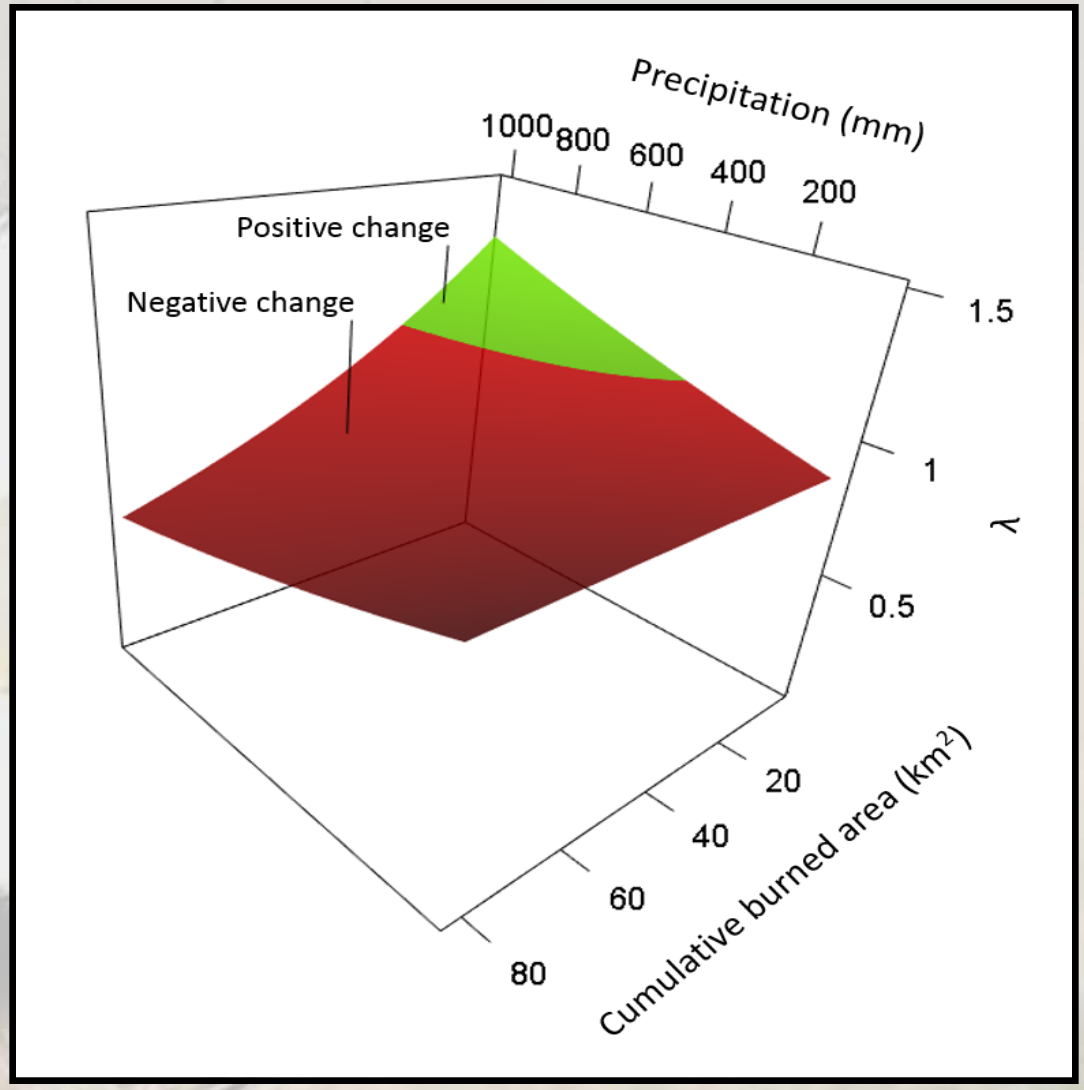


Lek Data Base
WAFWA
>2,700 sites

A 10-km^2 increase in burned area decreased lambda by approximately **2.1% (95% CL = 1.2 – 3.1)**

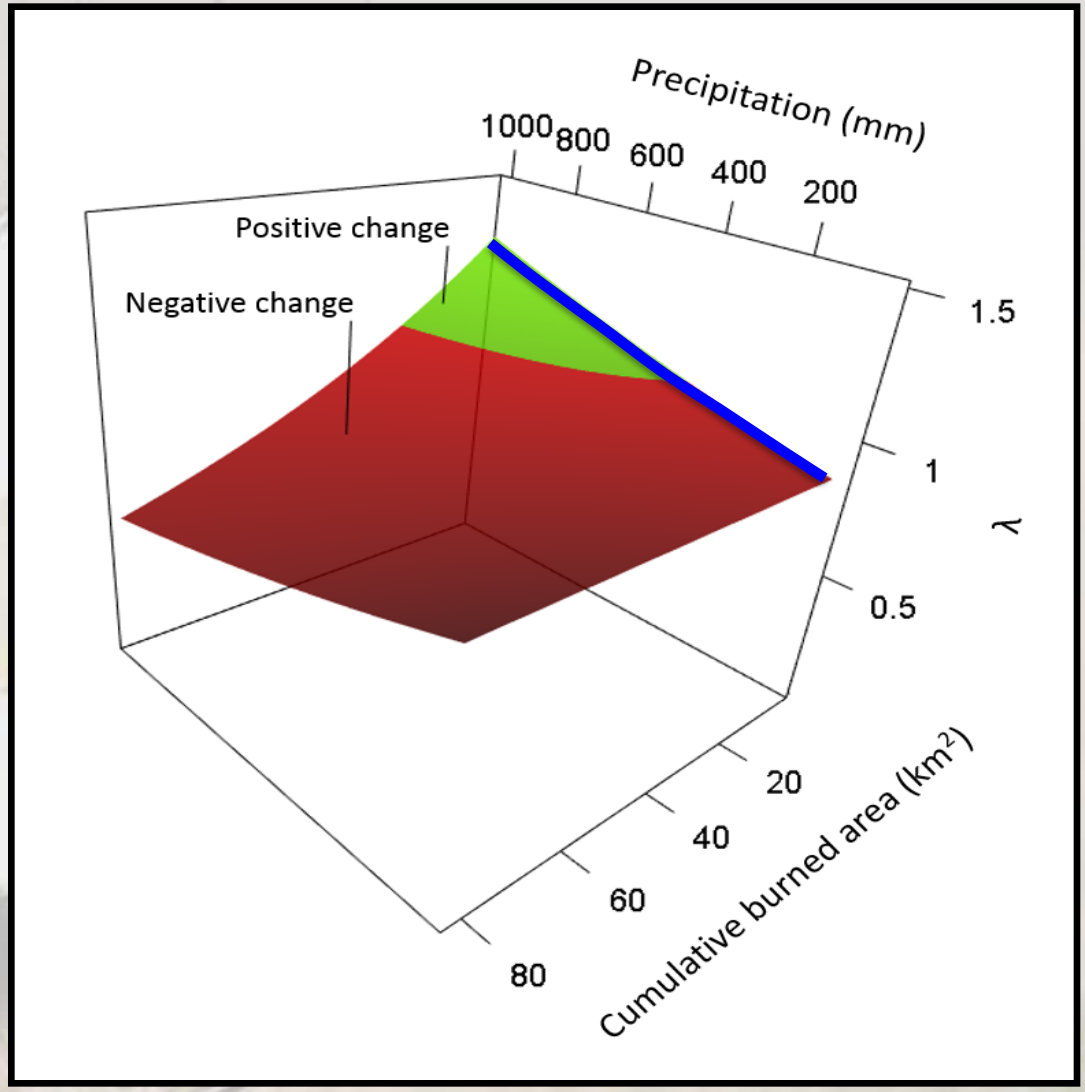
Cumulative Burned Area and Precipitation Relationship

- **Mostly negative change**
- **Positive change: Above average precipitation and little to no burned area**



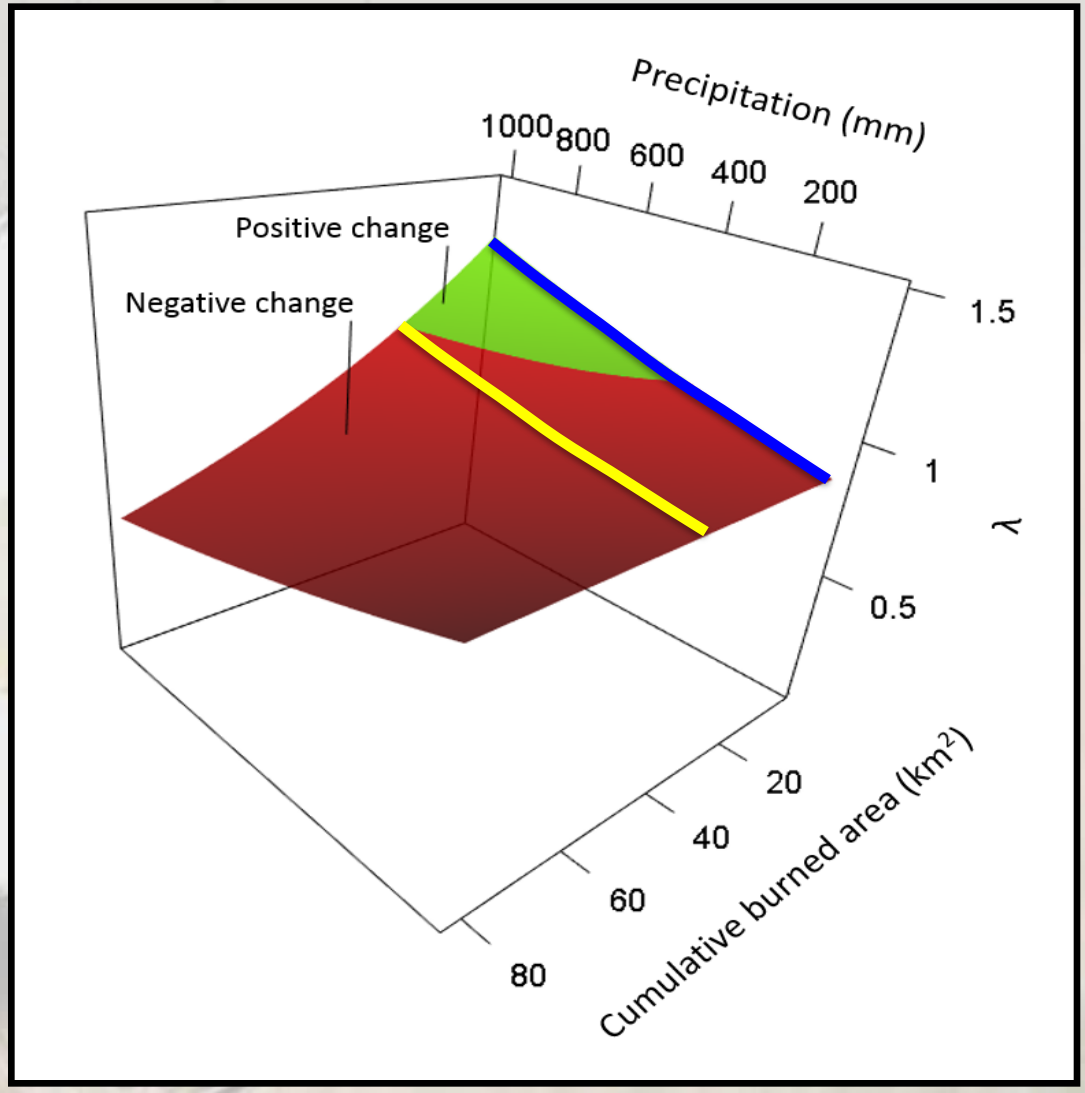
Cumulative Burned Area and Precipitation Relationship

- **Blue line: Precipitation is positively related to population growth**
- **Population growth occurs when precipitation is approximately above the 30-year averaged value**



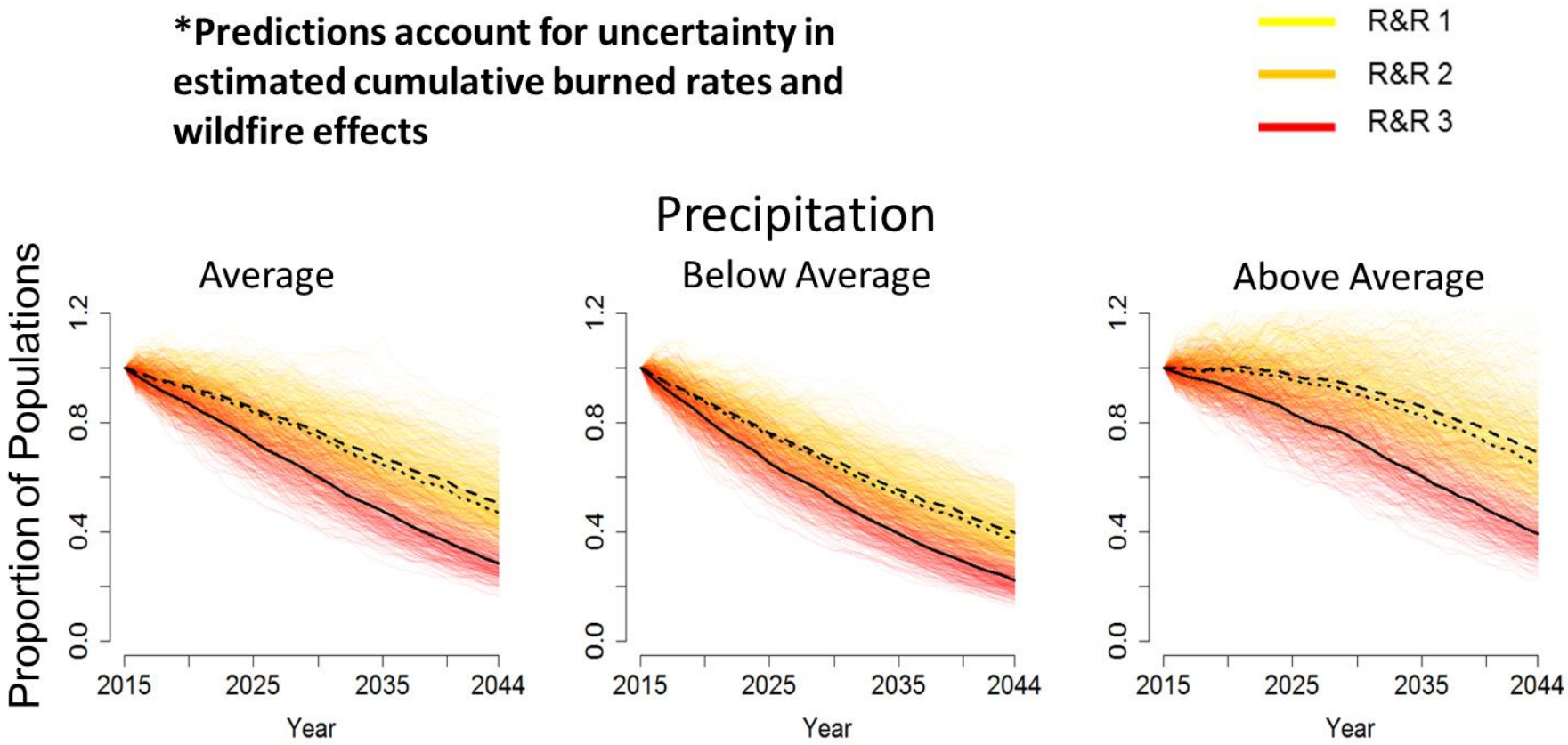
Cumulative Burned Area and Precipitation Relationship

- Yellow line: ~35% of burned area around a lek nullifies positive impacts of all precipitation levels
- Sage-grouse exhibit cyclical abundance patterns (boom and bust cycles)
- Wildfire appears to diminish "boom" effects resulting in steady declines

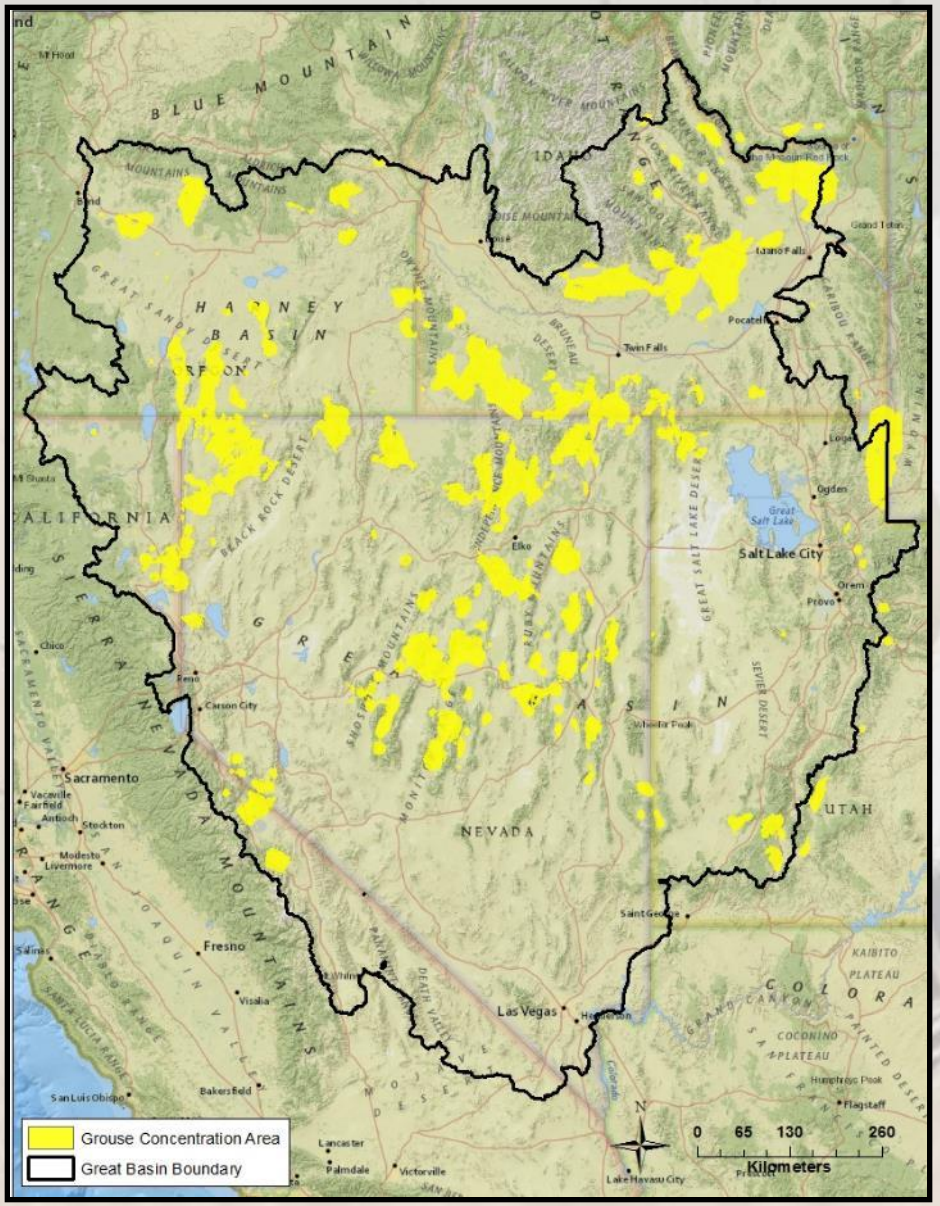


Predicted Population Declines

***Predictions account for uncertainty in estimated cumulative burned rates and wildfire effects**



Informing Wildfire Management



Sage-Grouse Concentration Area (SGCA)

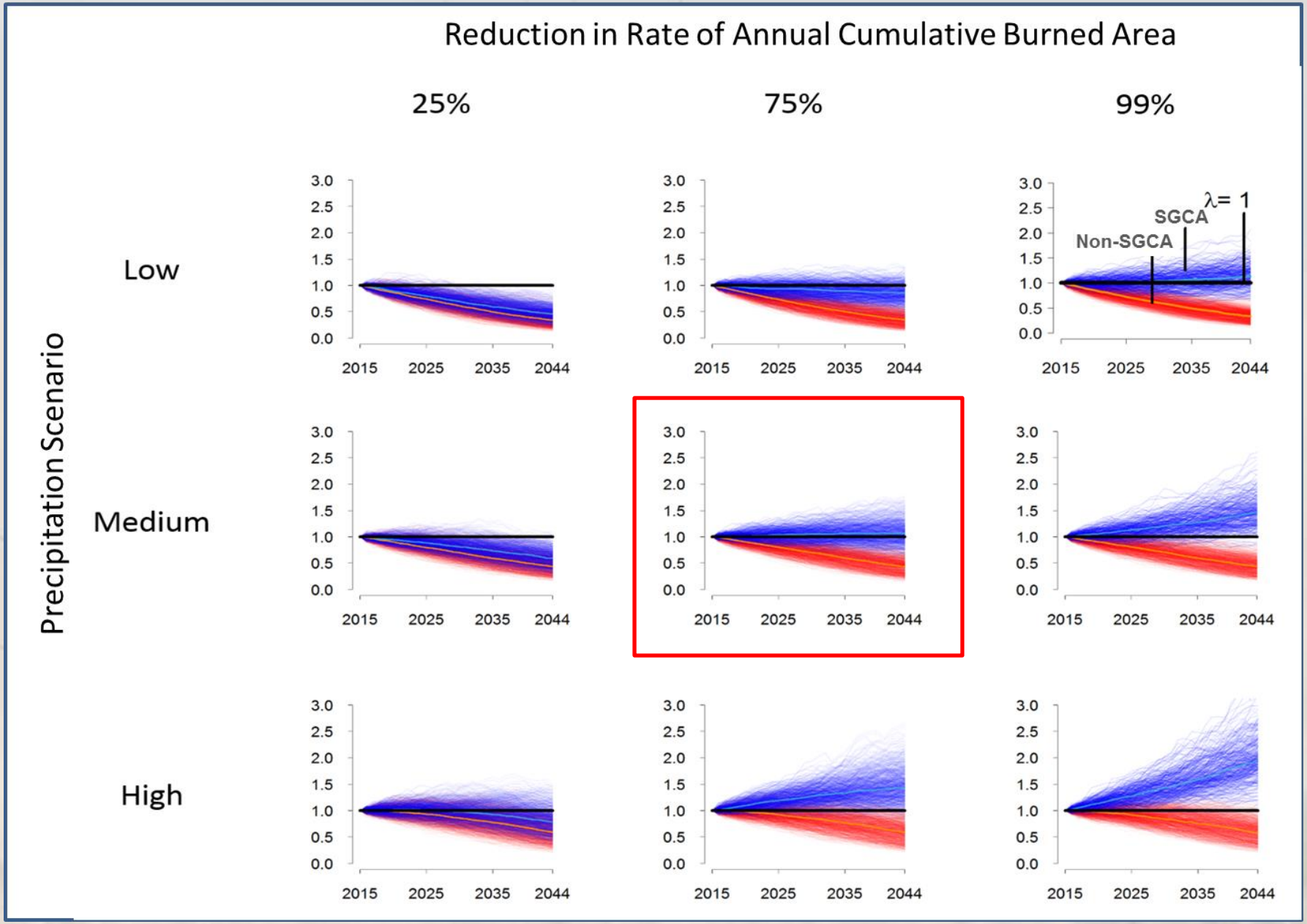
Calculated based on:

1) Modeled sage-grouse habitat using Resource Selection Functions (Random Forest Models)

2) Abundance and Space Use

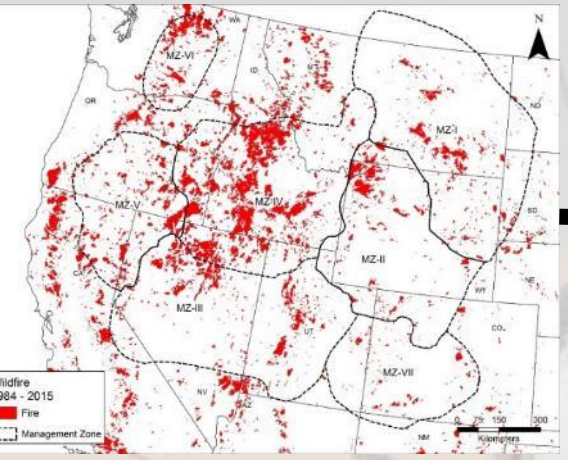
- SGCAs comprise of ~19% of sage-grouse habitat
- SGCAs captured 78.5% of the number of leks and 89% of males

Target Reduction in Cumulative Area Burned

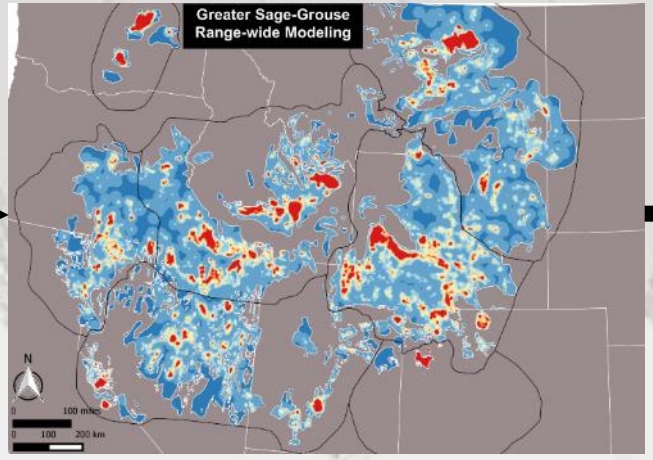


Rangewide Framework

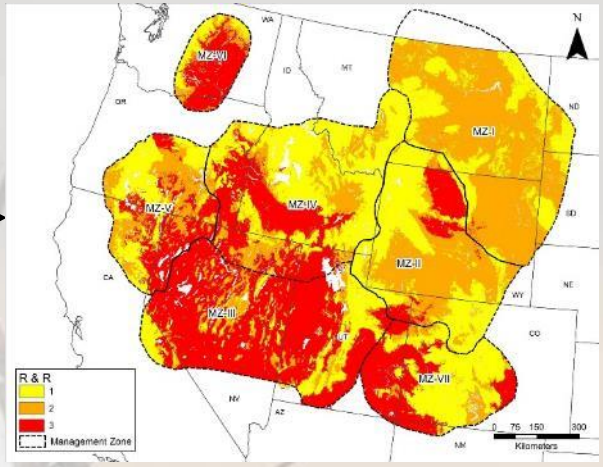
Wildfire Threat



GRSG Population Index



R&R Classes

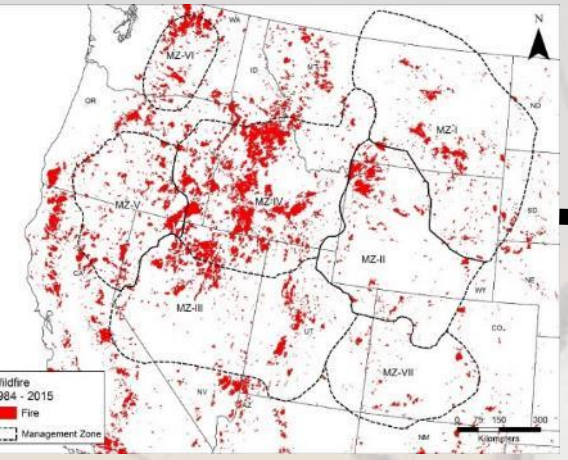


R&R	Habitat Probability: Low	Habitat Probability: Moderate	Habitat Probability: High
High	High potential for perennial recovery without seeding Low risk of invasive grass Seeding/transplant success is high		
Moderate	Moderately high potential for perennial recovery without seeding Moderate risk of invasive grass Seeding/transplant success dependent on site characteristics		
Low	Low potential for perennial recovery without seeding High risk of invasive grass Seeding/transplant success dependent on site but often low		

MTBS; Doherty et al. 2016; Chambers et al. 2014, 2016; Maestas et al. 2016

Rangewide Framework

Wildfire Threat



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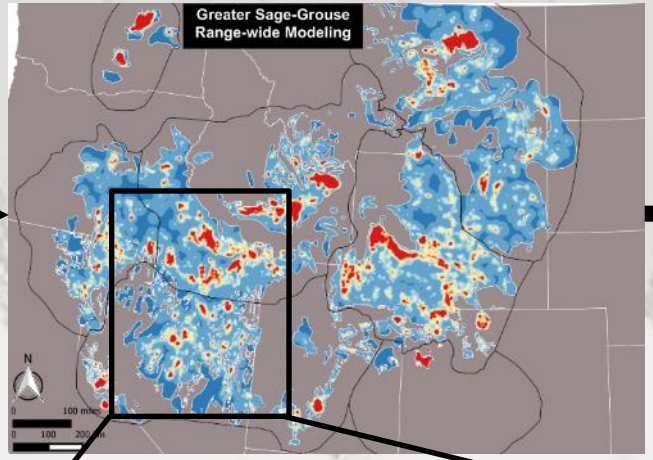
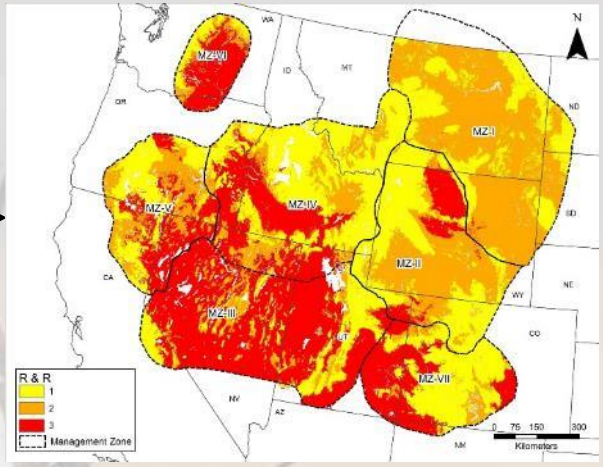
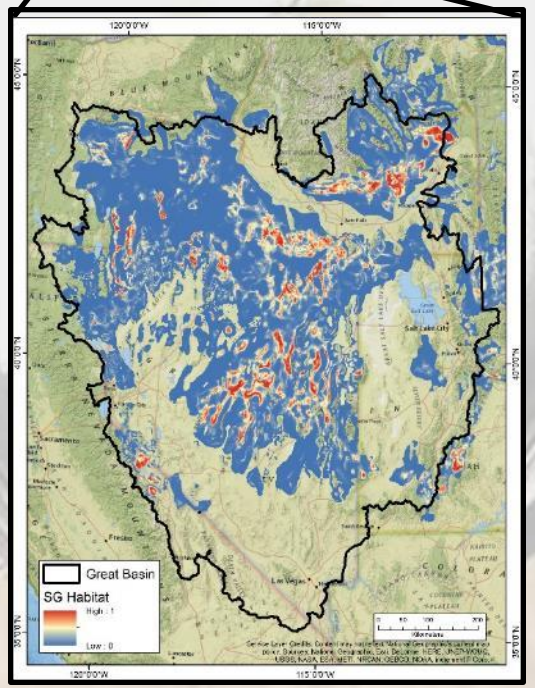


R&R Classes





Apply to Great Basin to Prioritize Fire Mgmt:

-Protection/Prevention

-Suppression

-Restoration

MTBS; Doherty et al. 2016; Chambers et al. 2014, 2016; Maestas et al. 2016

Prioritizing Areas for Suppression Activities

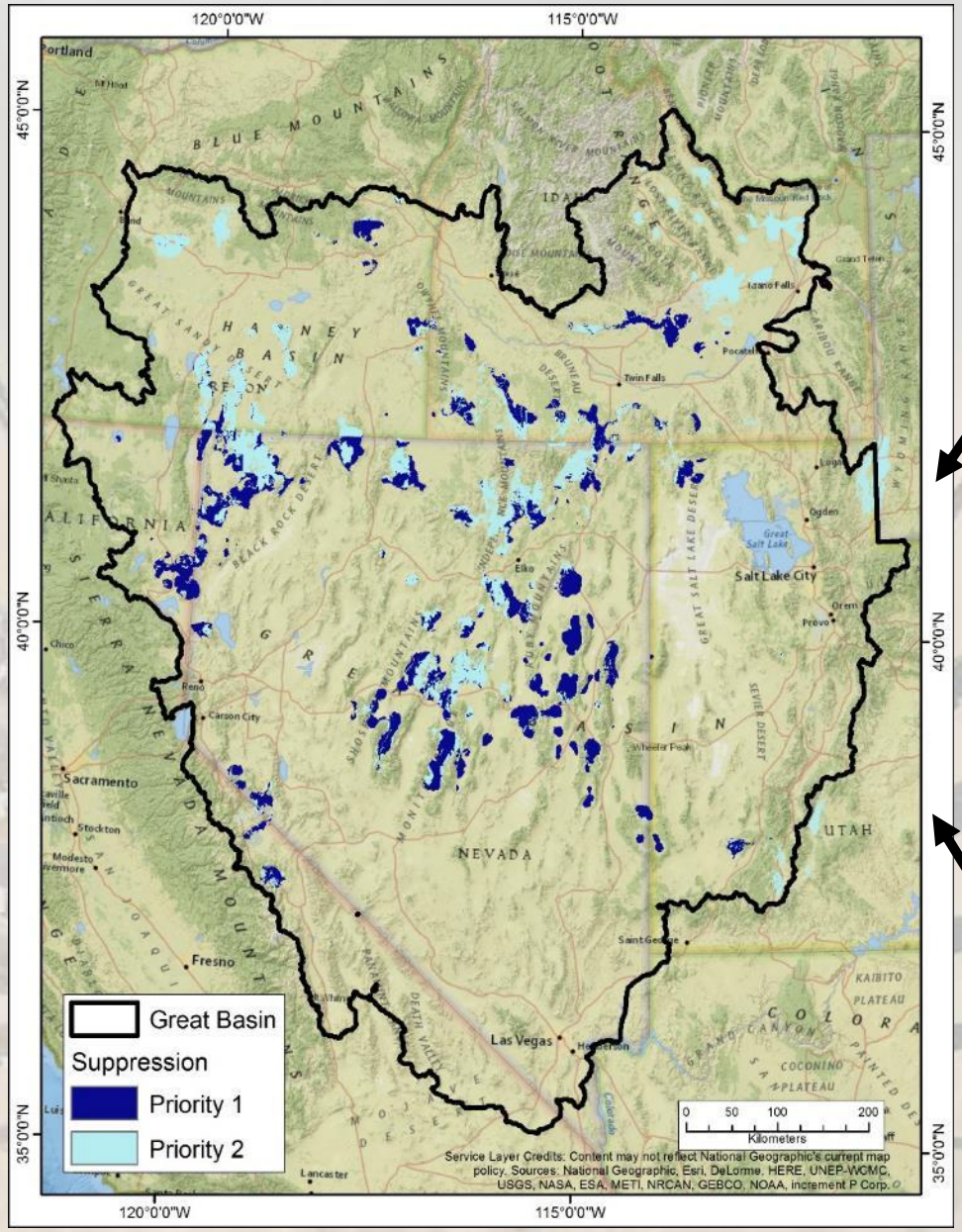
Spatial Overlay:

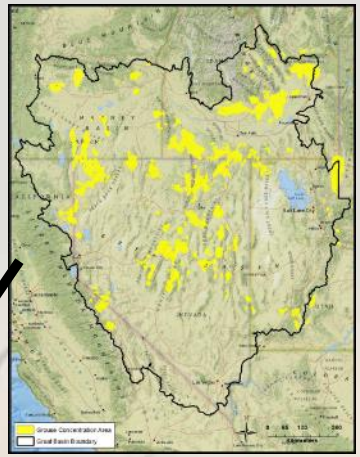
(1) GRSG concentration areas
(2) R&R categories

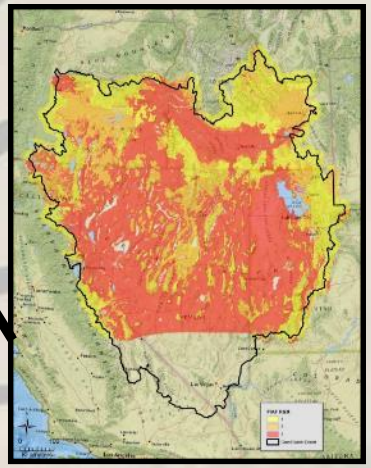
Suppression prioritization:

S1: Low R&R, GRSG area

S2: Moderate R&R, GRSG area







Prioritizing Areas for Protection/Prevention Activities

Burn Probability Data

Identify areas for wildfire prevention actions

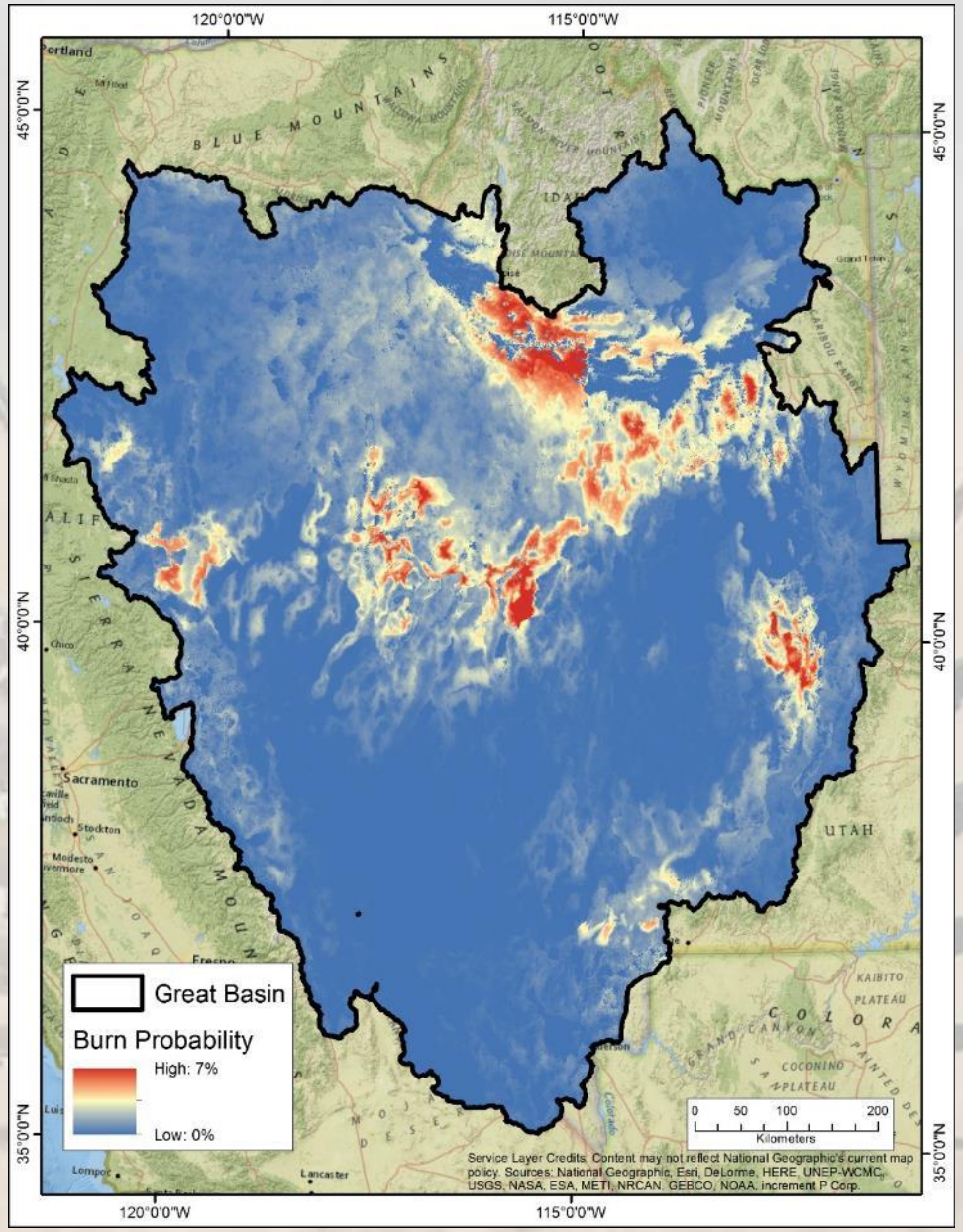
-fuels management
resiliency

-PJ removal

-grazing practices (e.g., targeted)

-fuel breaks

-staging and resources for initial attack actions



Short et al.2016

Assessment at Ecoregion Scale

Spatial Overlay:

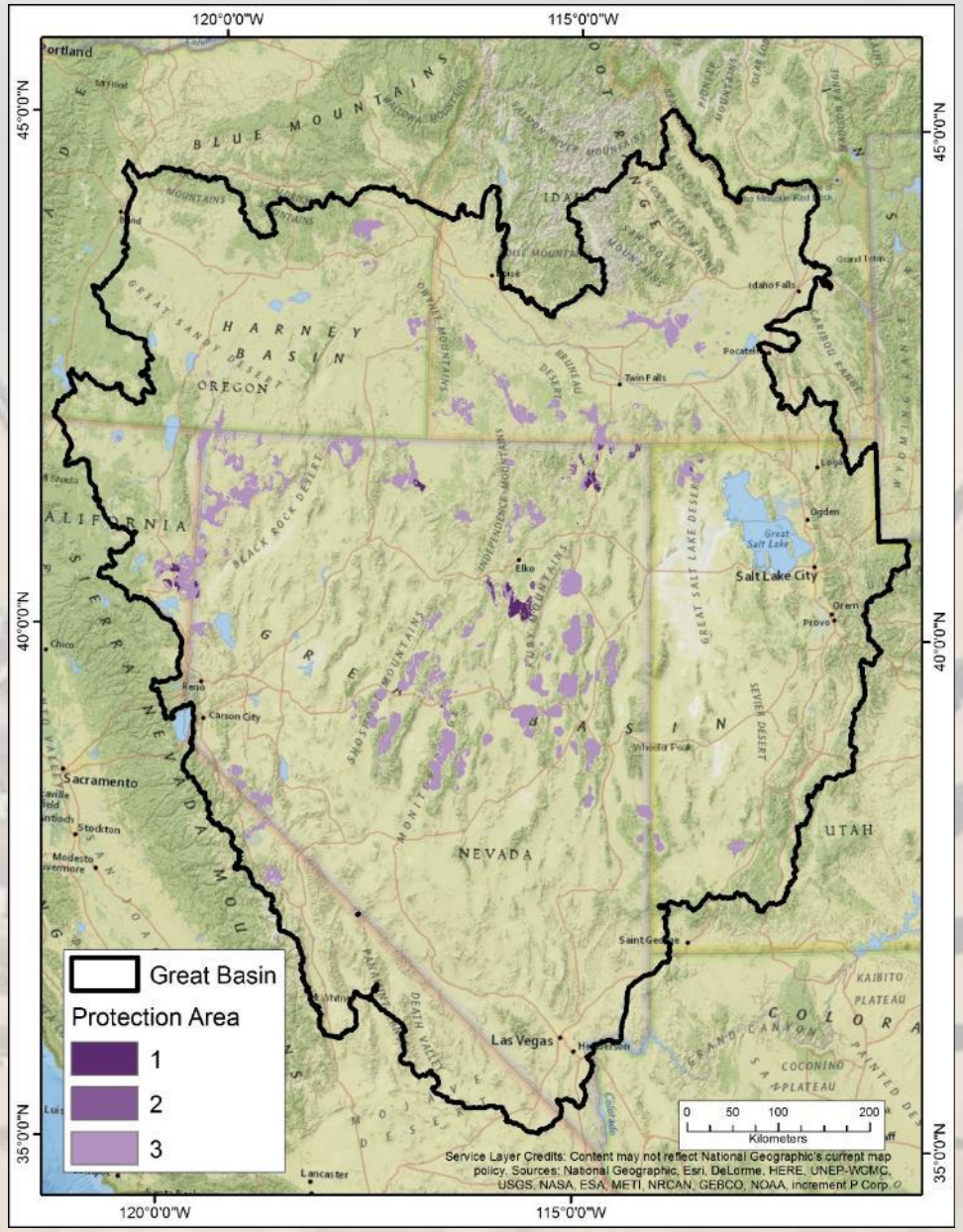
(1) Areas likely to burn
(2) GRSG population areas
(3) R&R categories

Protection prioritization:

P1: Low R&R, burn likely, GRSG area

P2: Moderate R&R, burn likely, GRSG area

P3: Low R&R, burn unlikely, GRSG area



Prioritizing Areas for Rehabilitation

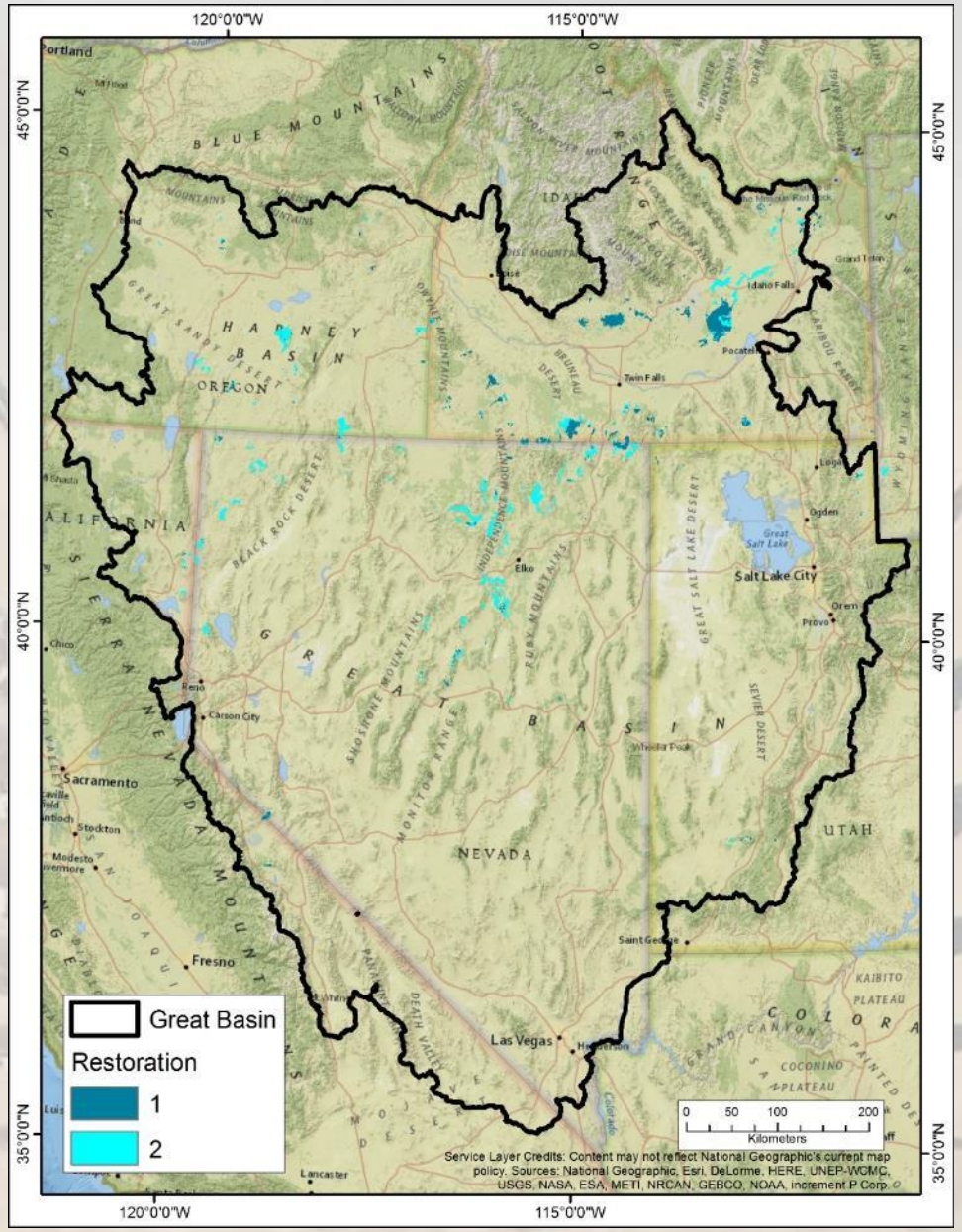
Spatial Overlay:

(1) MTBS Burn Perimeter
(2) GRSG population areas
(3) R&R categories

Restoration prioritization:

R1: High R&R, GRSG area

R2: Moderate R&R, GRSG area



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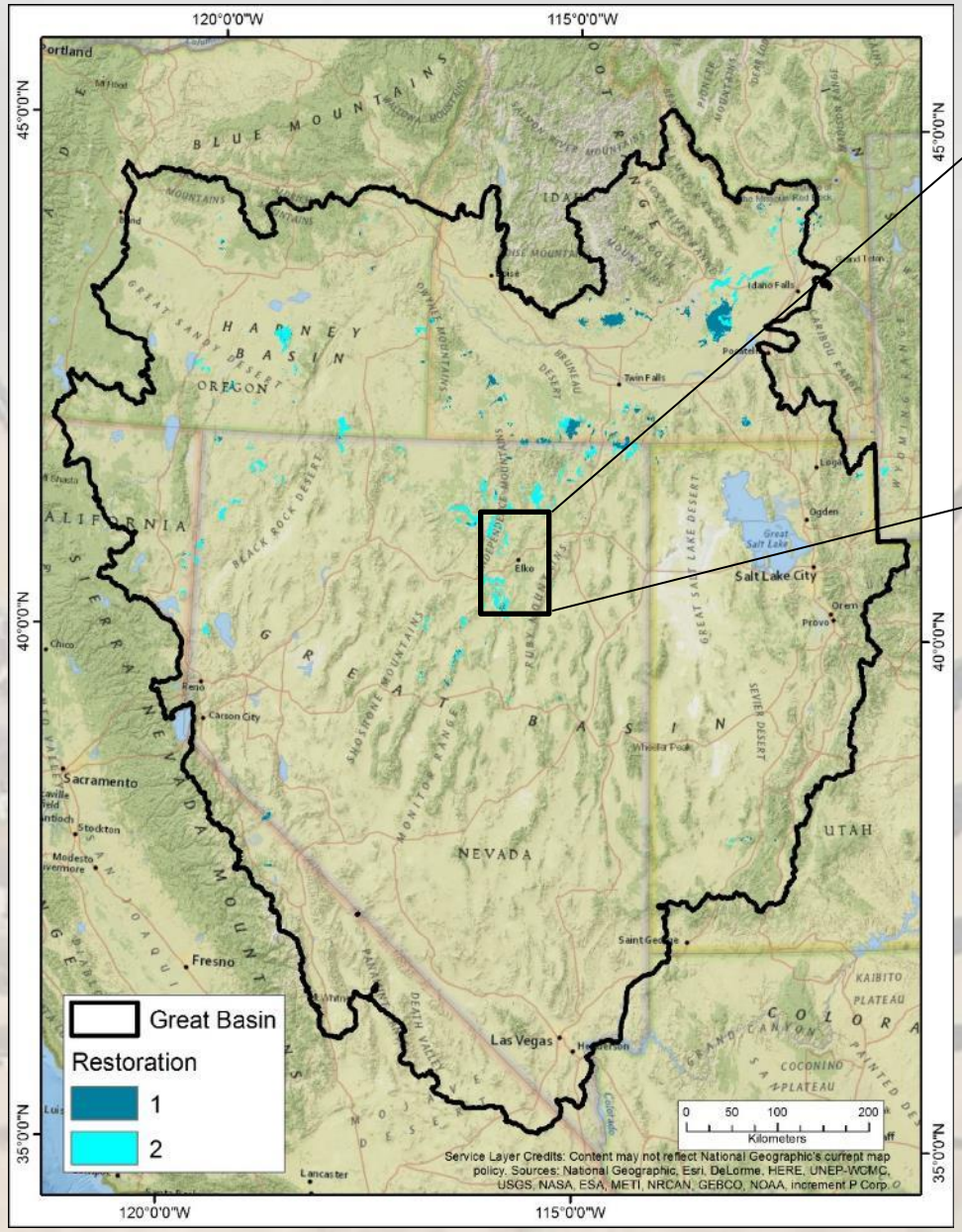
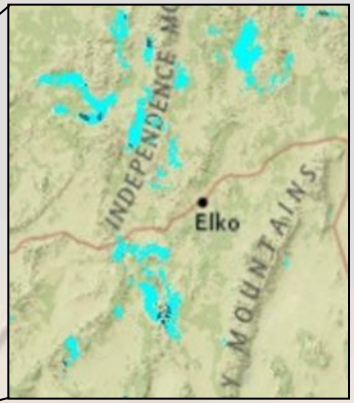
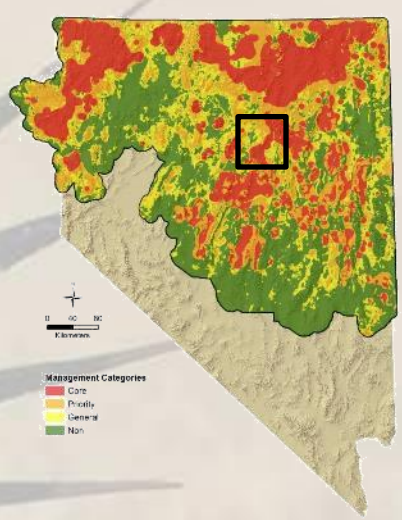
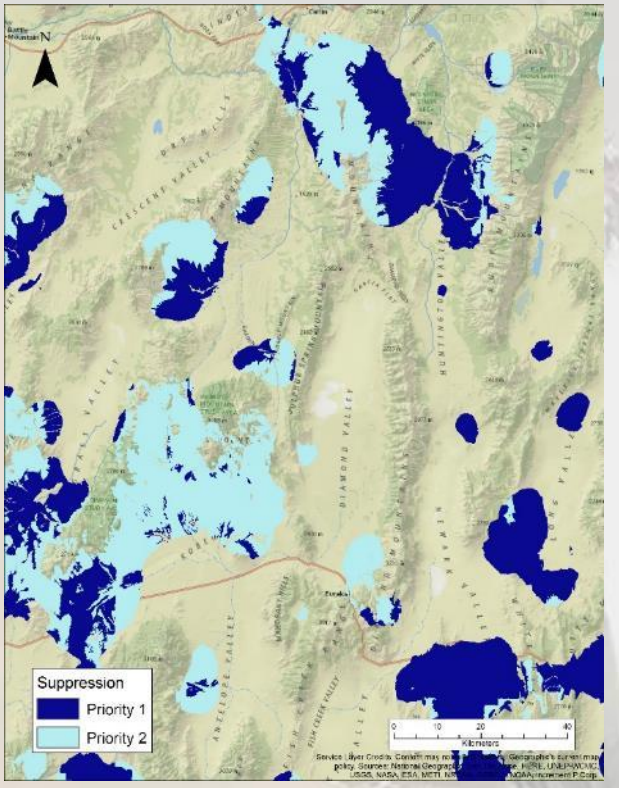




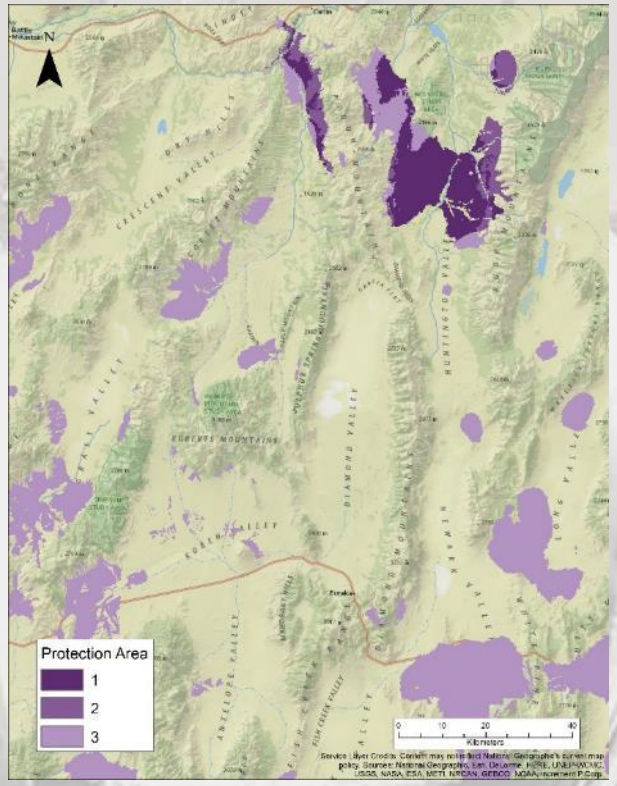


Regional Model (Finer Resolution Data)

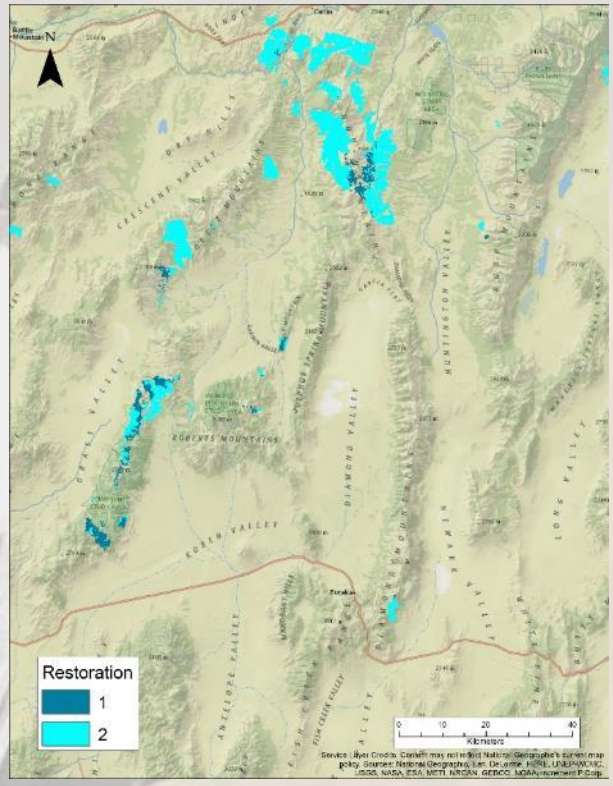
Suppression



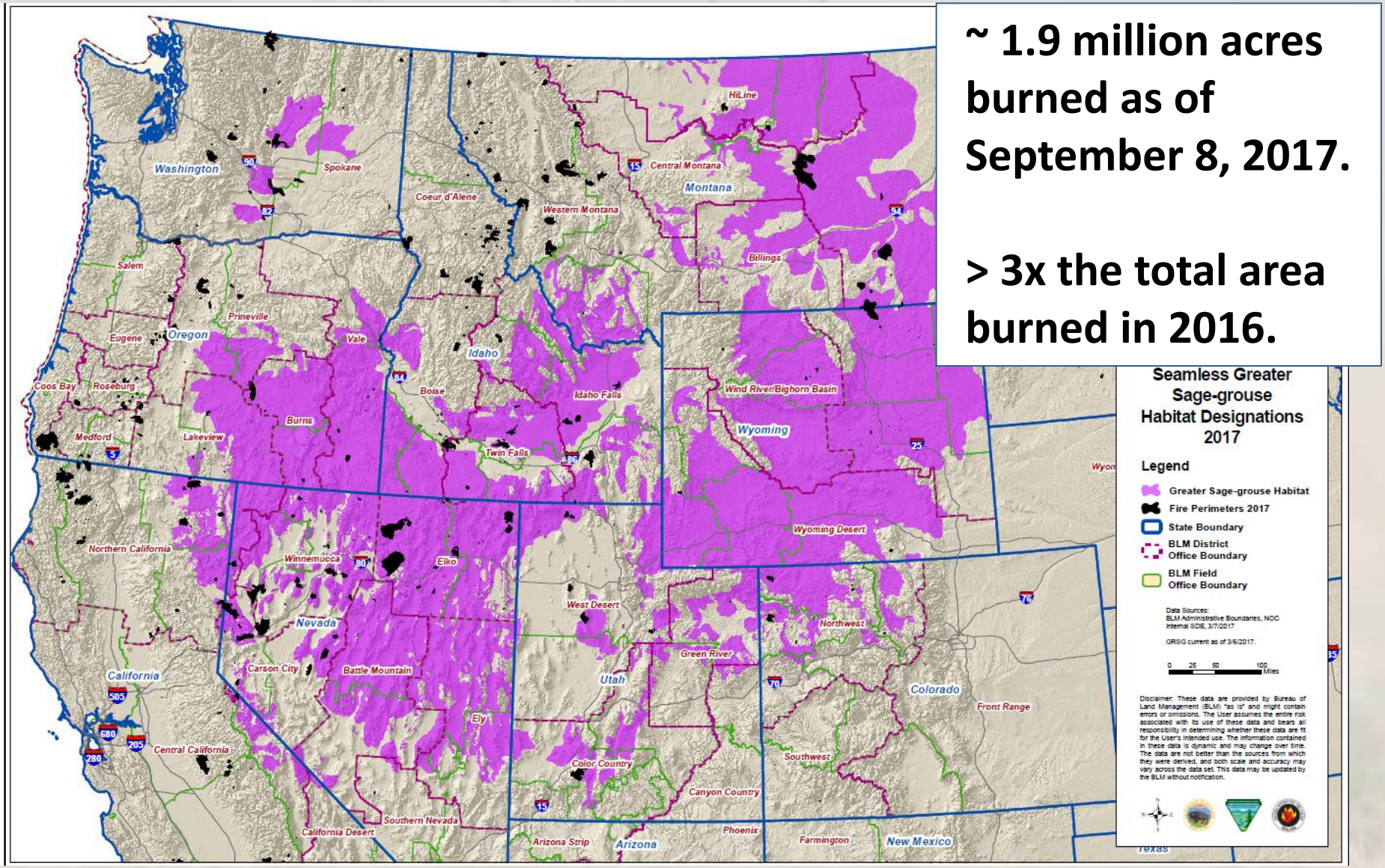
Prevention/Protection



Restoration



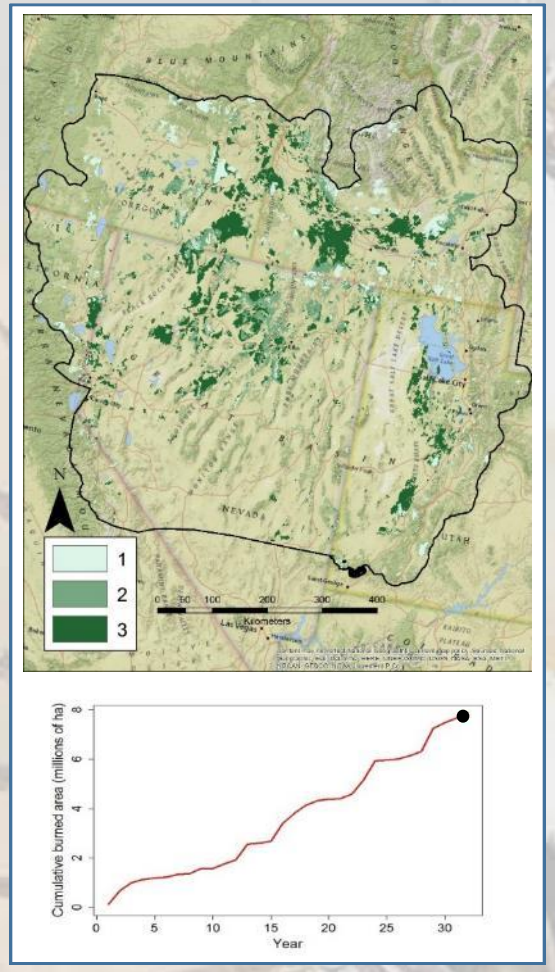
Current Status of Wildfires in Sage-Grouse Habitat



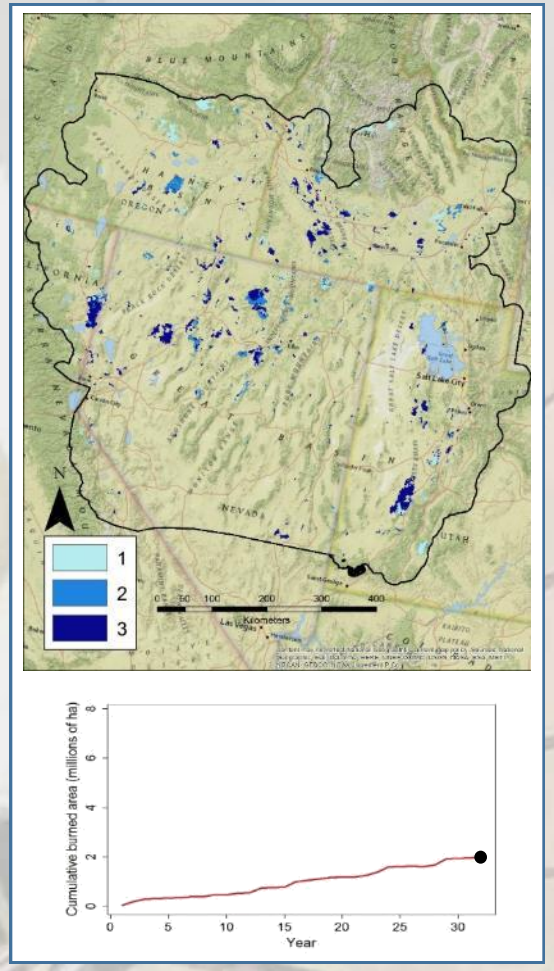
~ 1.9 million acres burned as of September 8, 2017.

> 3x the total area burned in 2016.

Can restoration keep pace with the rate of fire?

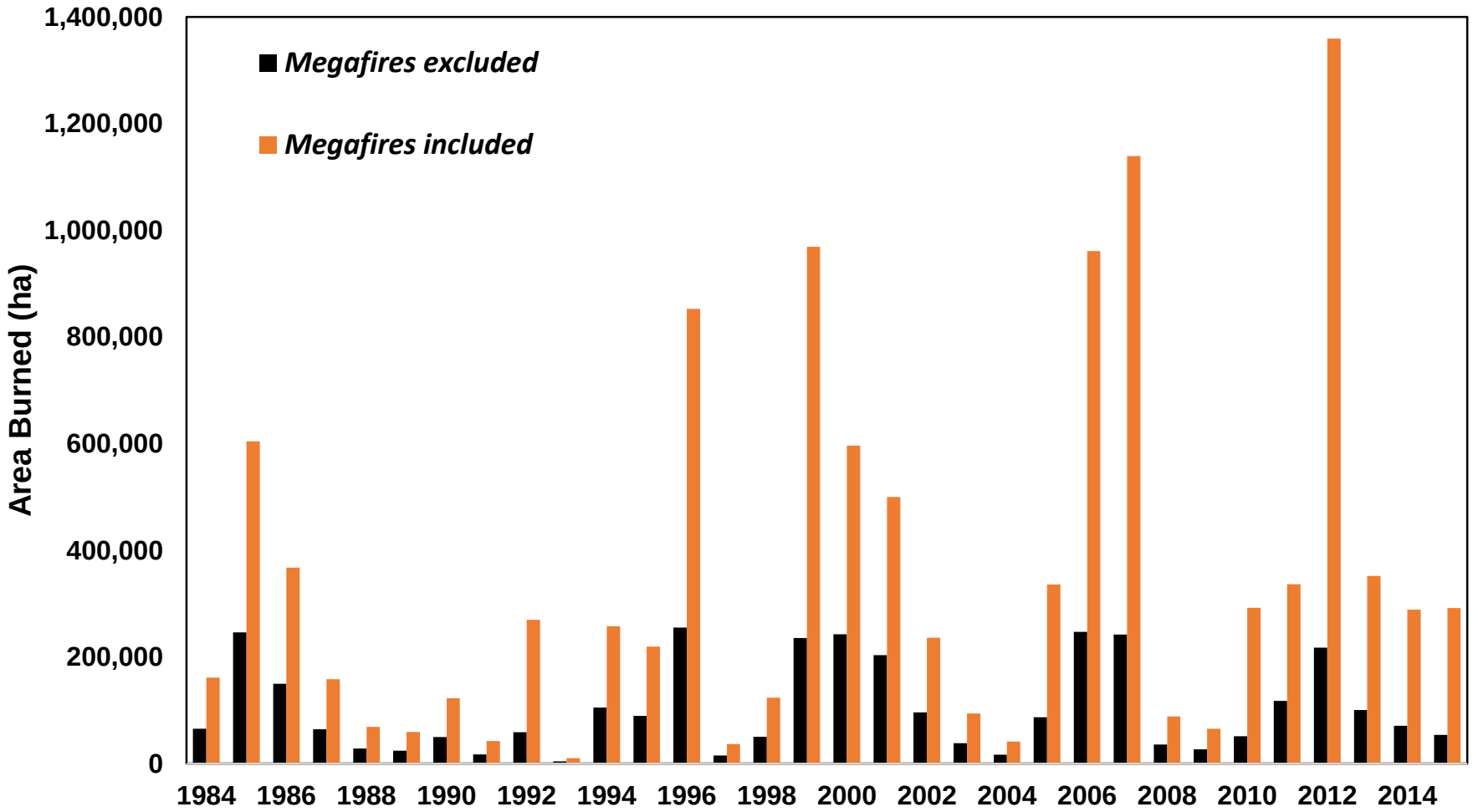


Restoration with 75% effort

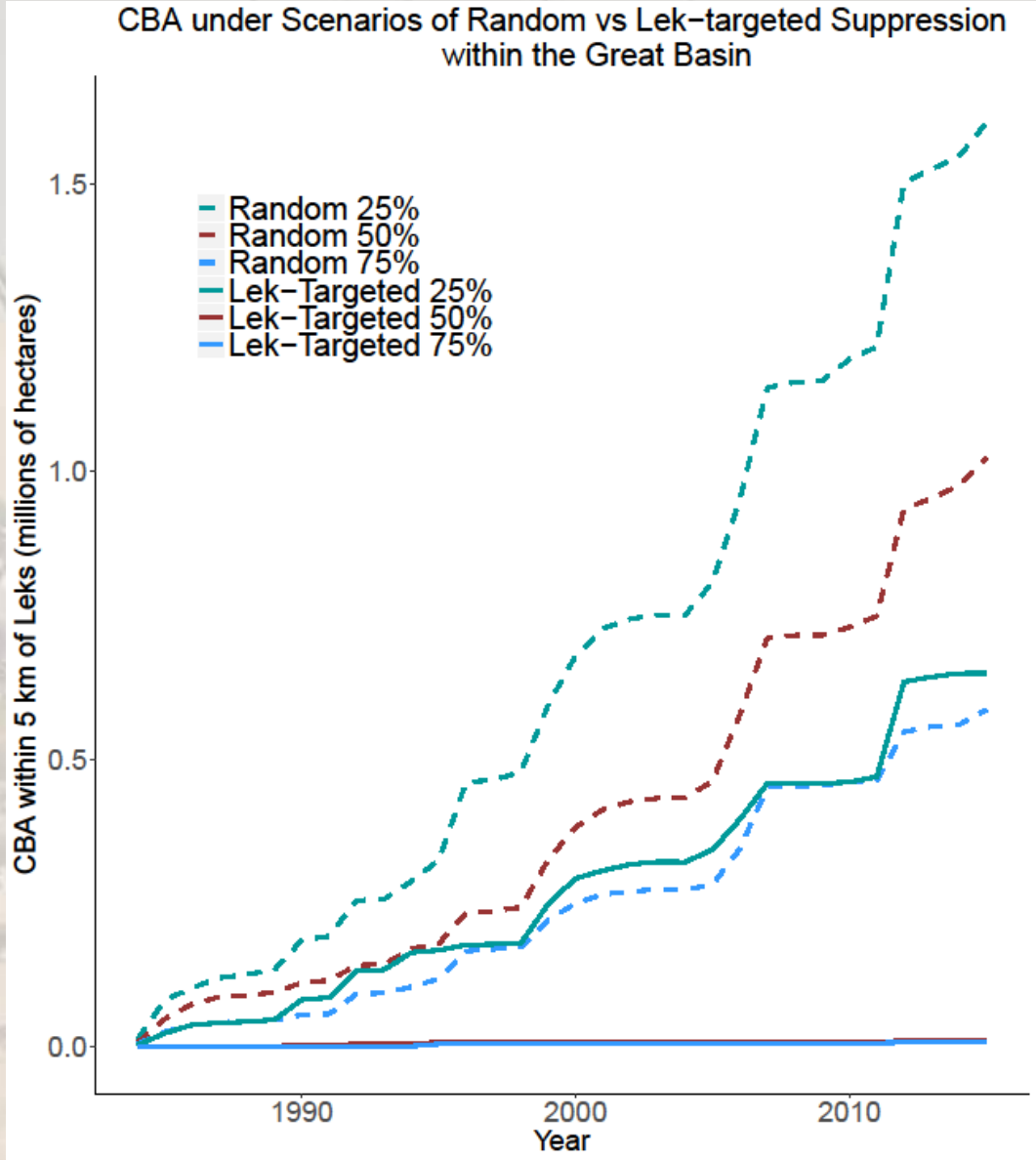


Fire prevention & suppression at 75%

Contribution of Megafires

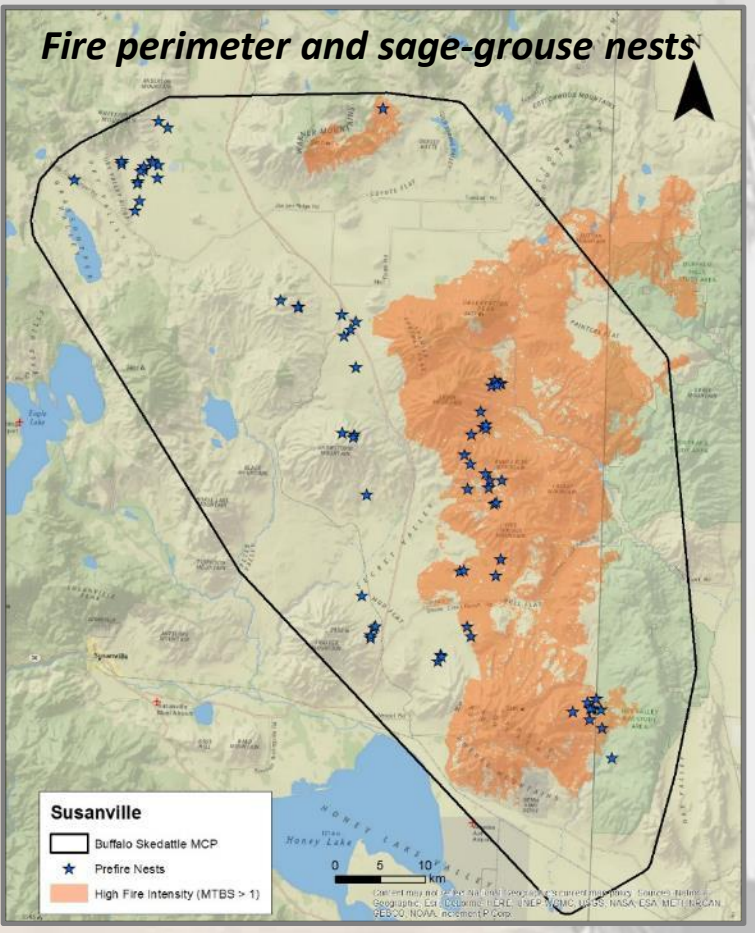


Efficiency of Sage-Grouse Centric Targeted Prevention and Suppression

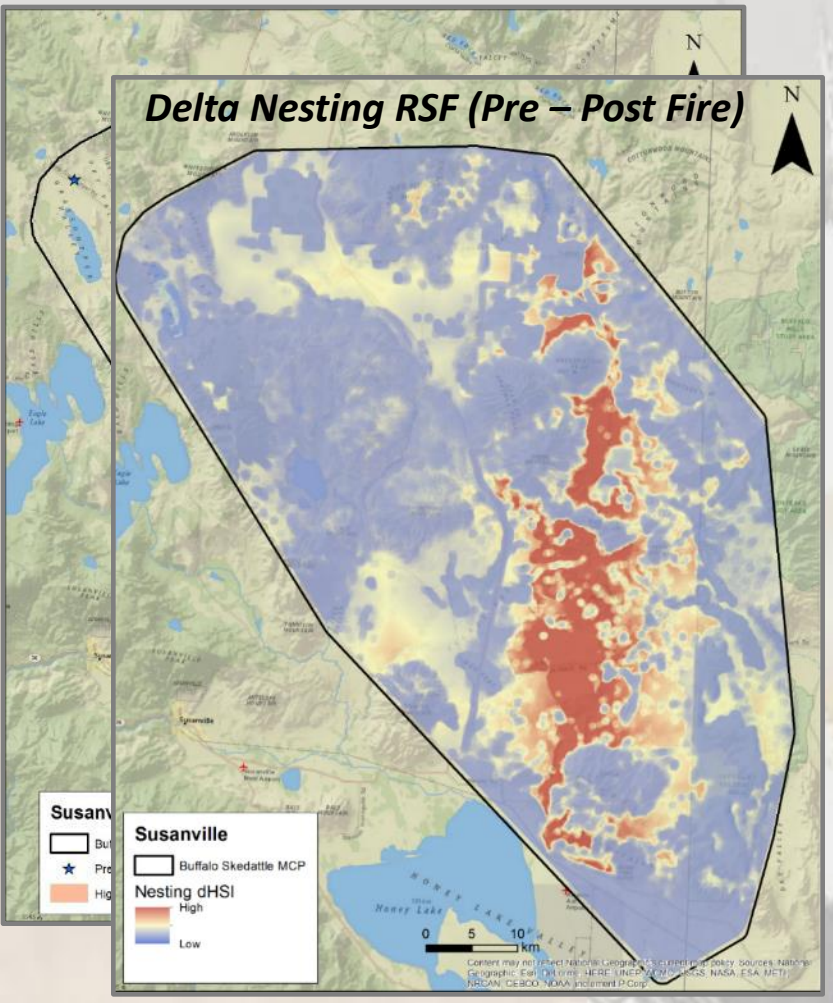


Preliminary Information—Subject to Revision. Not for Citation or Distribution

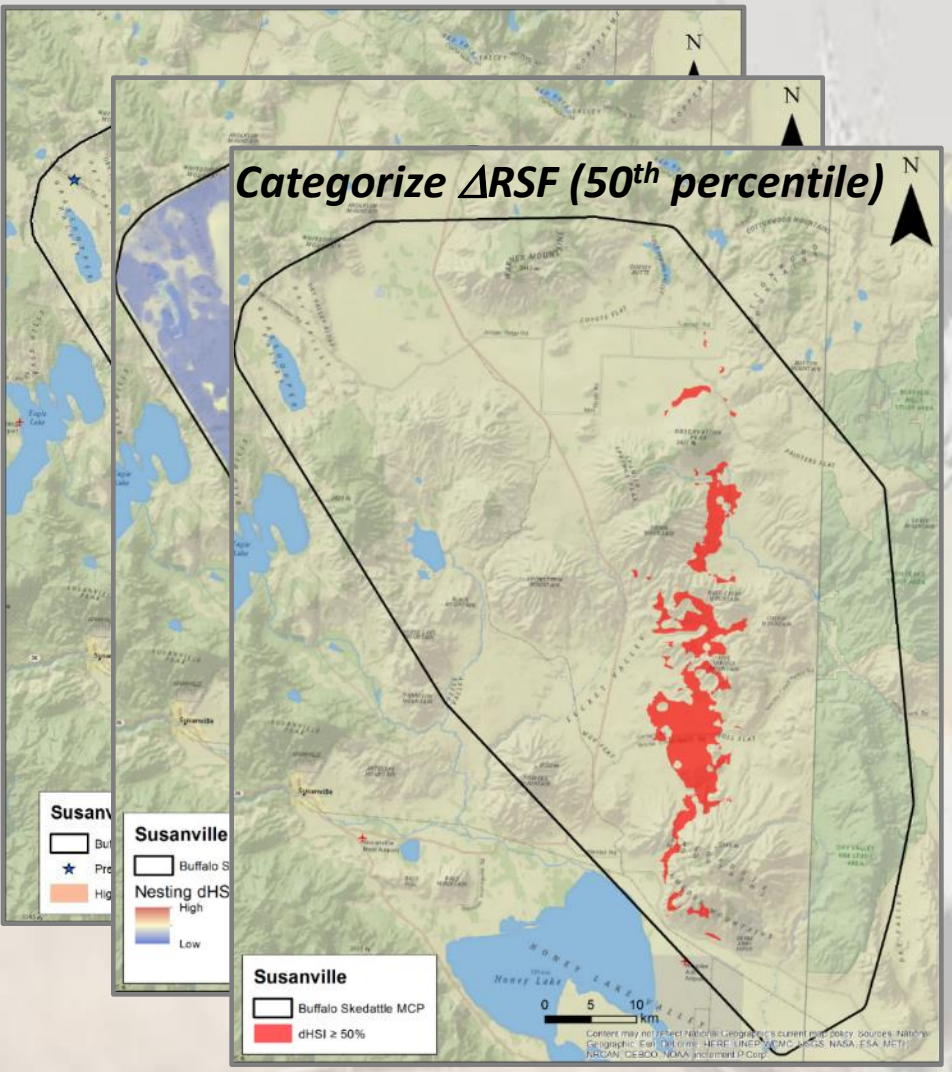
Efficiency of Sage-Grouse Centric Targeted Restoration



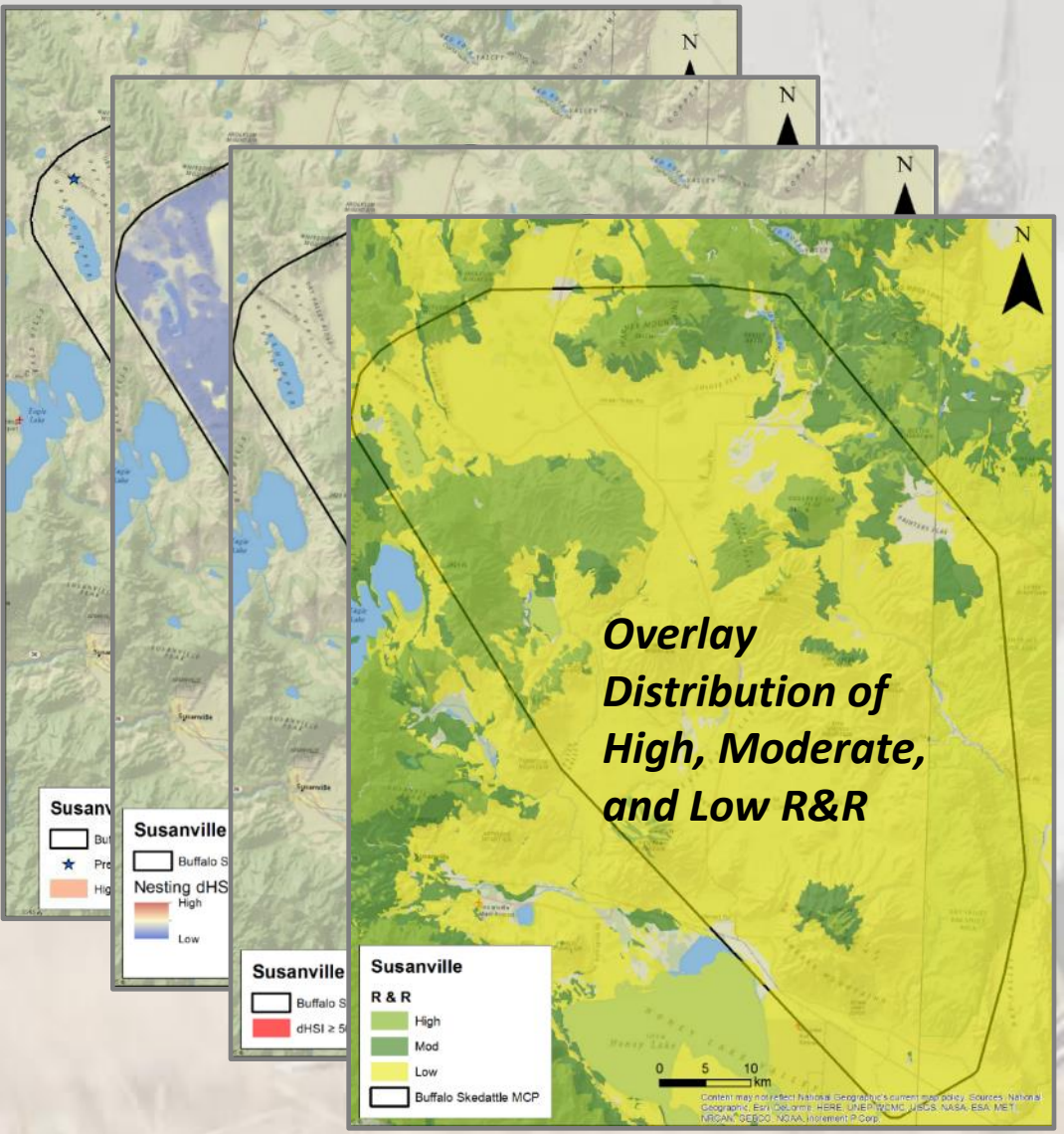
Efficiency of Sage-Grouse Centric Targeted Restoration



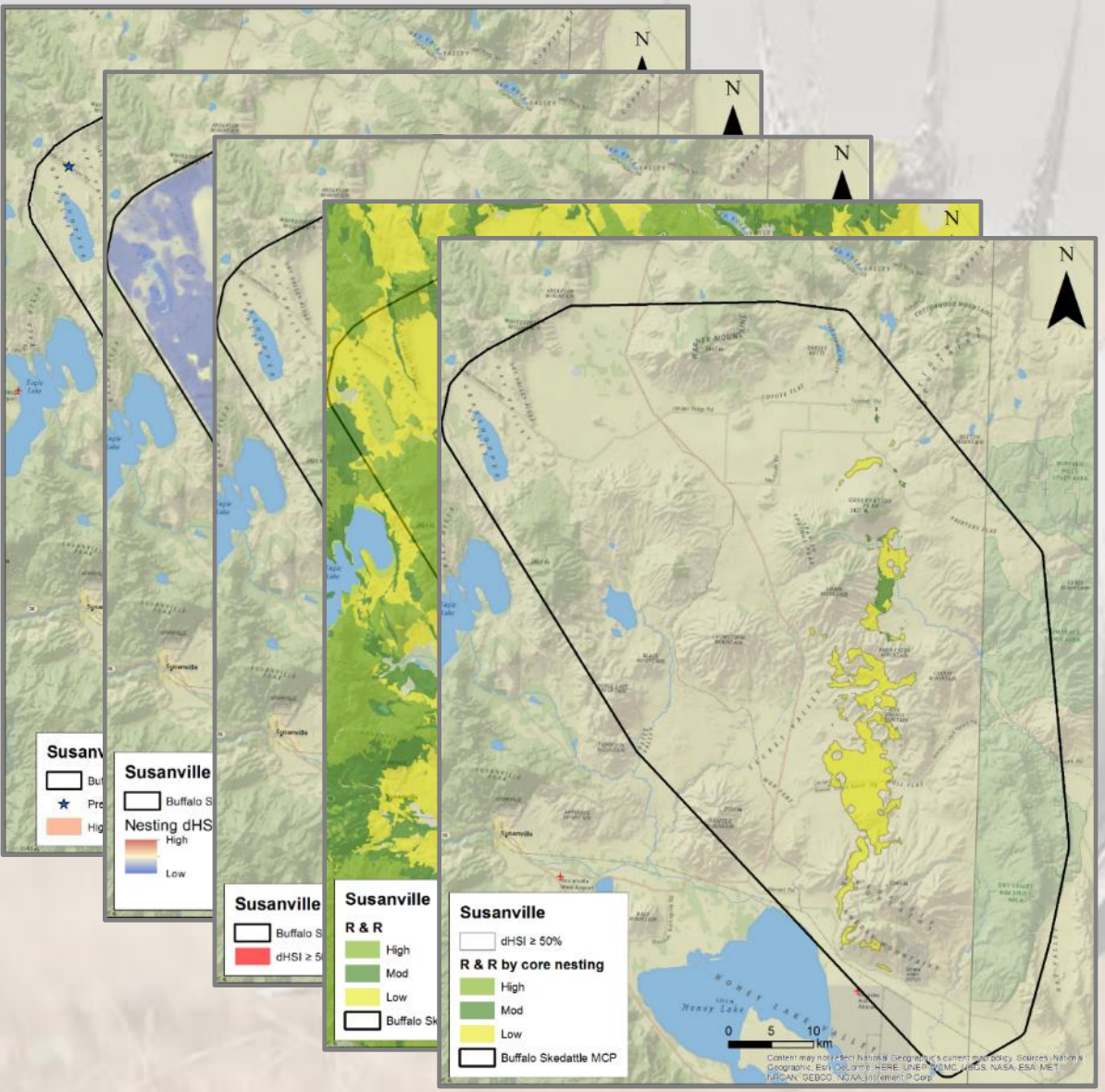
Efficiency of Sage-Grouse Centric Targeted Restoration



Efficiency of Sage-Grouse Centric Targeted Restoration



Efficiency of Sage-Grouse Centric Targeted Restoration



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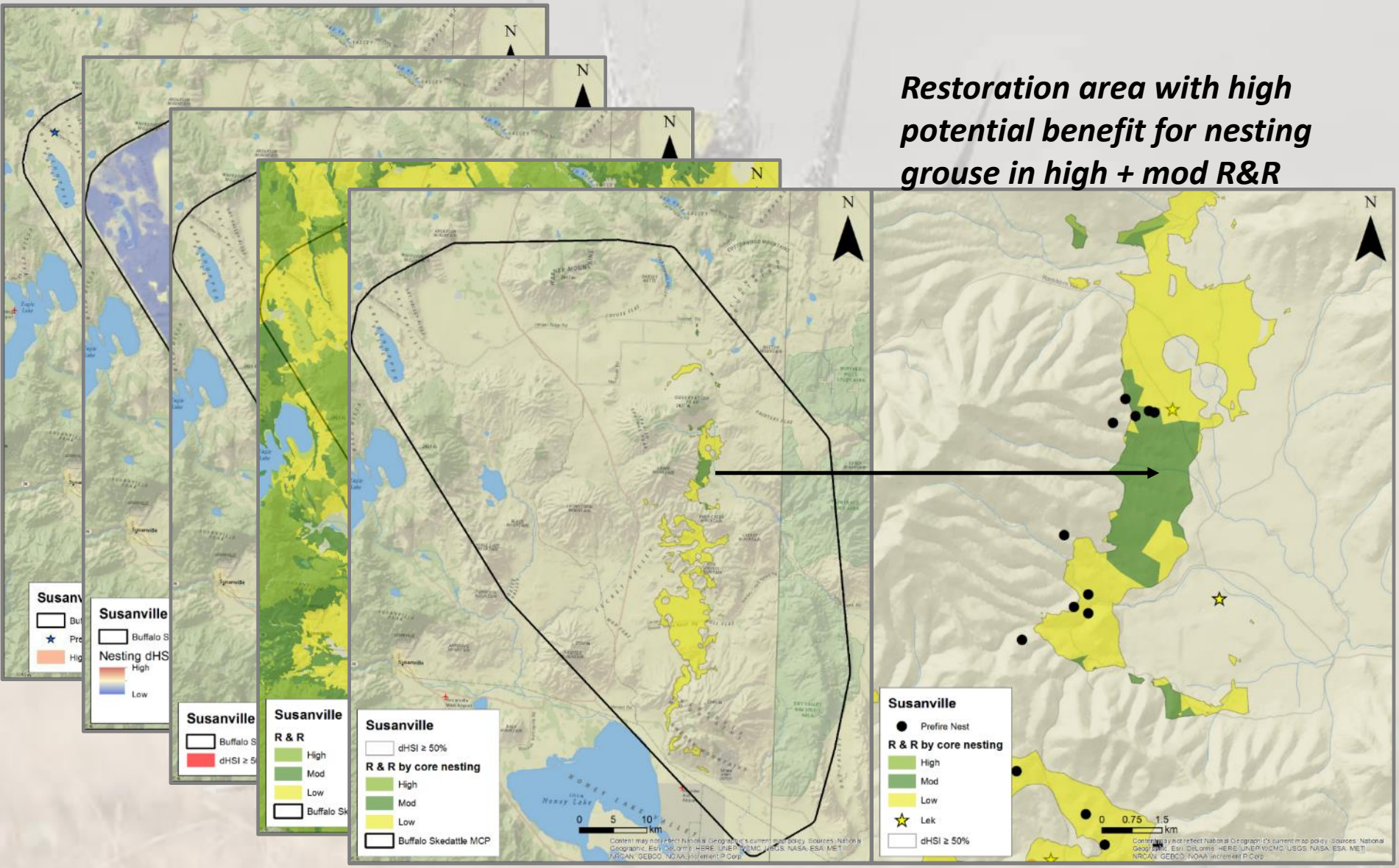
Efficiency of Sage-Grouse Centric Targeted Restoration

Restoration area with high potential benefit for nesting grouse in high + mod R&R



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USGS
science for a changing world

Wildfire Effects and Science Tools: Take Home

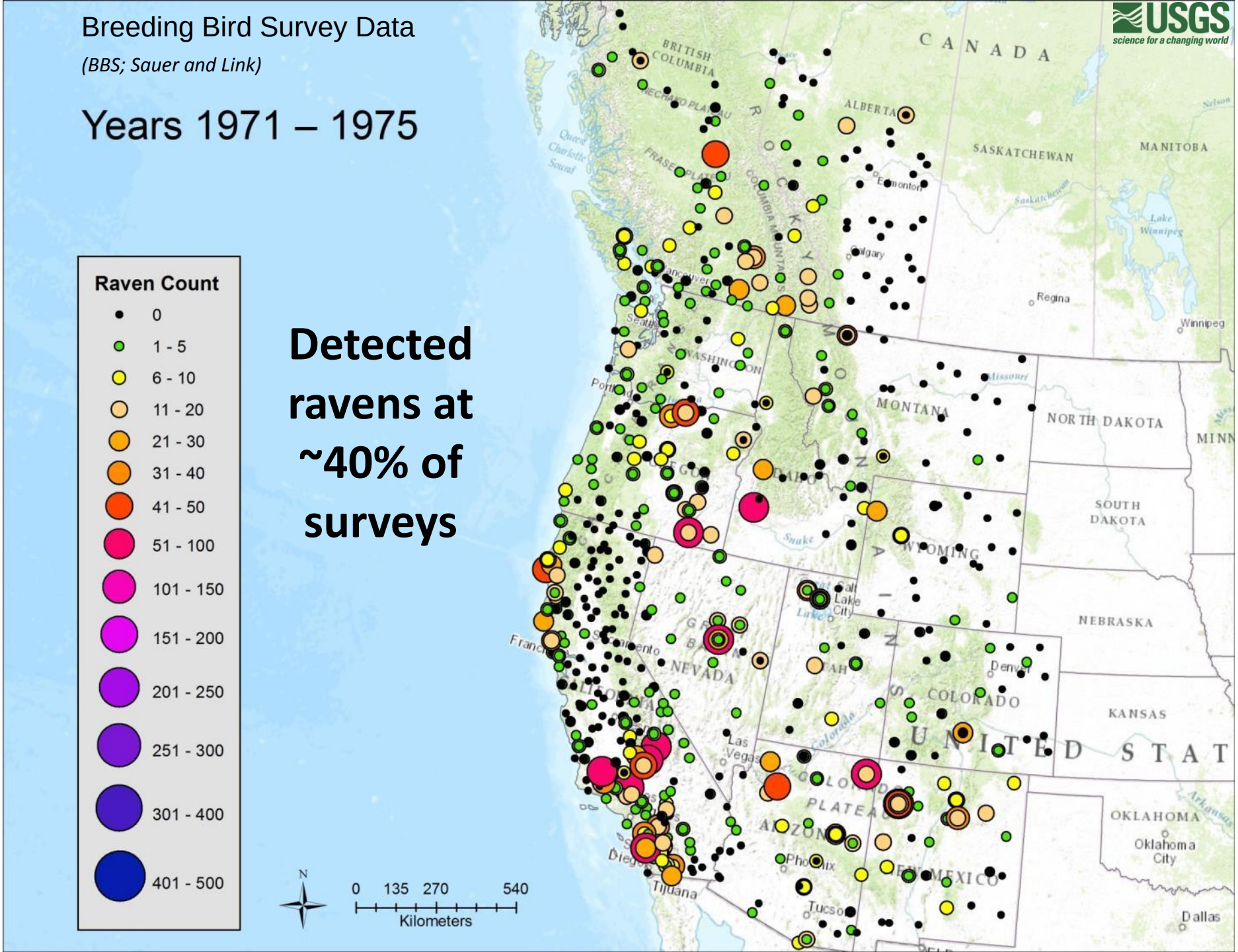
- Wildfire has negative impacts on sage-grouse population growth and mimics drought conditions
- Empirically derived target: 75% reduction in rate of CBA
- Targeted fire prevention suppression may be most effective at reducing the rate of CBA
- Restoration remains vital to post-fire management, particularly with a surgical approach

II. ANTHROPOGENIC INFLUENCES ON PREDATION EFFECTS

Breeding Bird Survey Data

(BBS; Sauer and Link)

Years 1971 – 1975

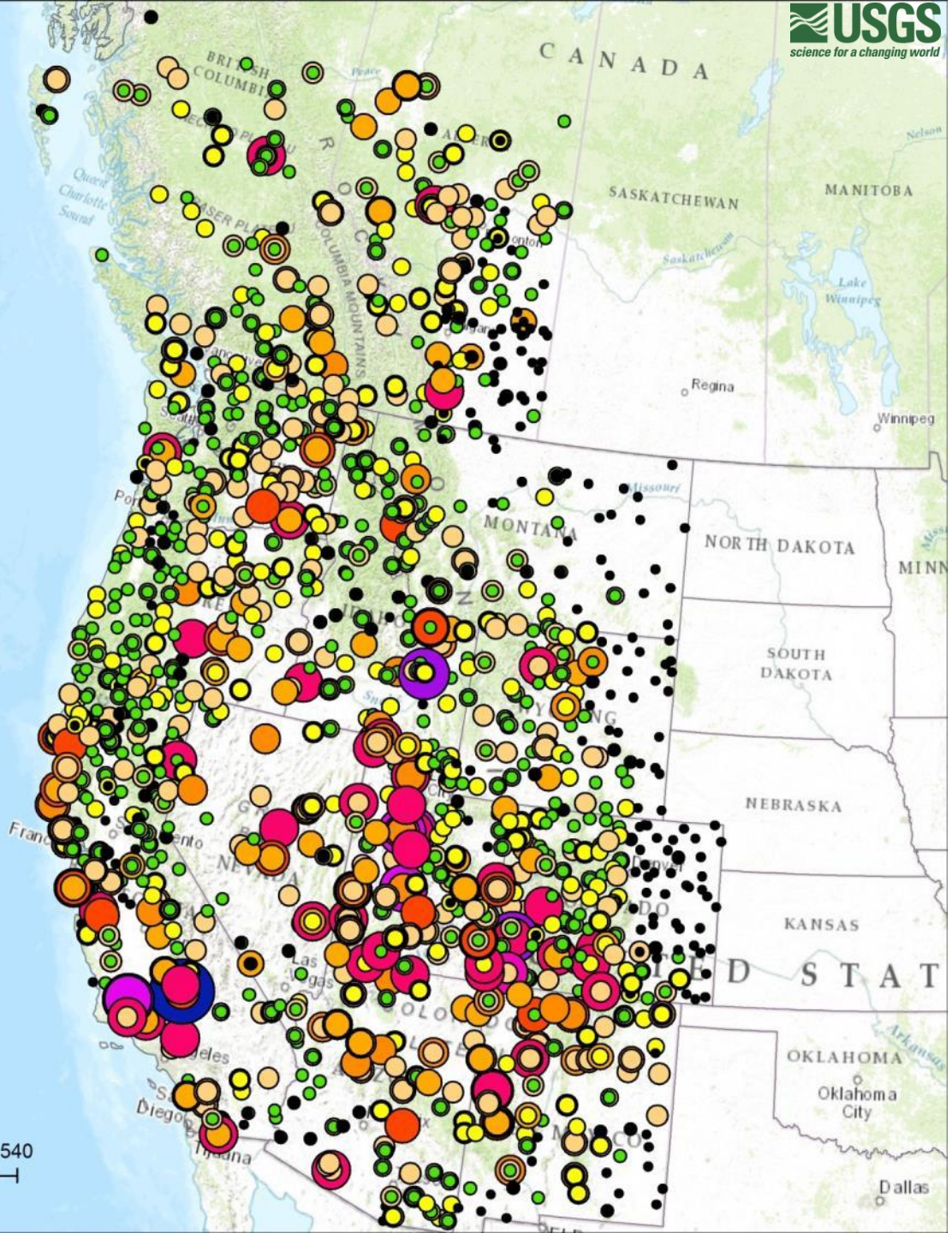


Detected ravens at ~40% of surveys

Breeding Bird Survey Data

(BBS; Sauer and Link)

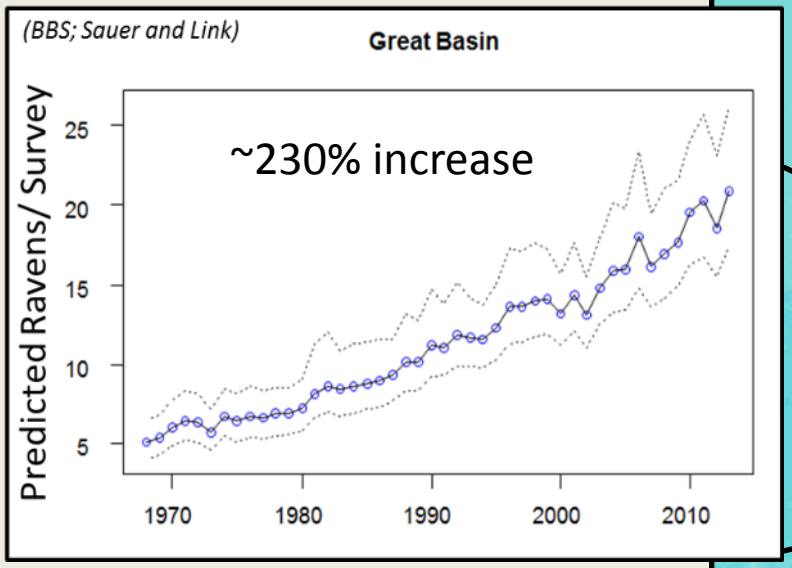
Years 2006 – 2010

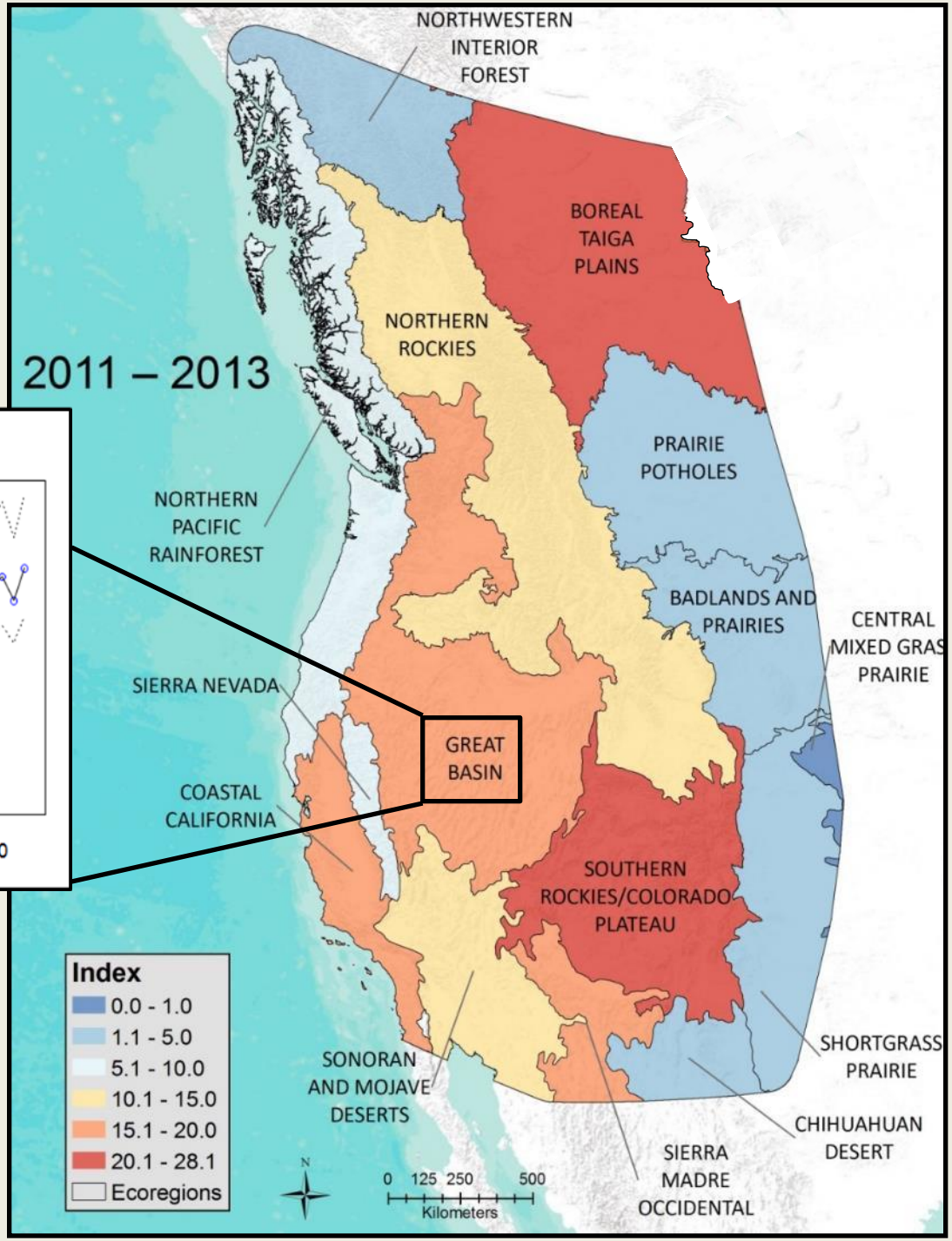


Detected ravens at ~80% of surveys

Increased number of observations per detection

Raven Population Growth within Great Basin BCR





Raven Counts Currently:

- ***Great Basin to >15***
- Sonoran and Mojave to >10
- Coastal CA to >15
- Southern Rockies/Colorado Plateau to >20

No Decreases

THE CONDOR
Ornithological Applications
www.cooper.org
Volume 116, 2014, pp. 000–000
DOI

RESEARCH ARTICLE

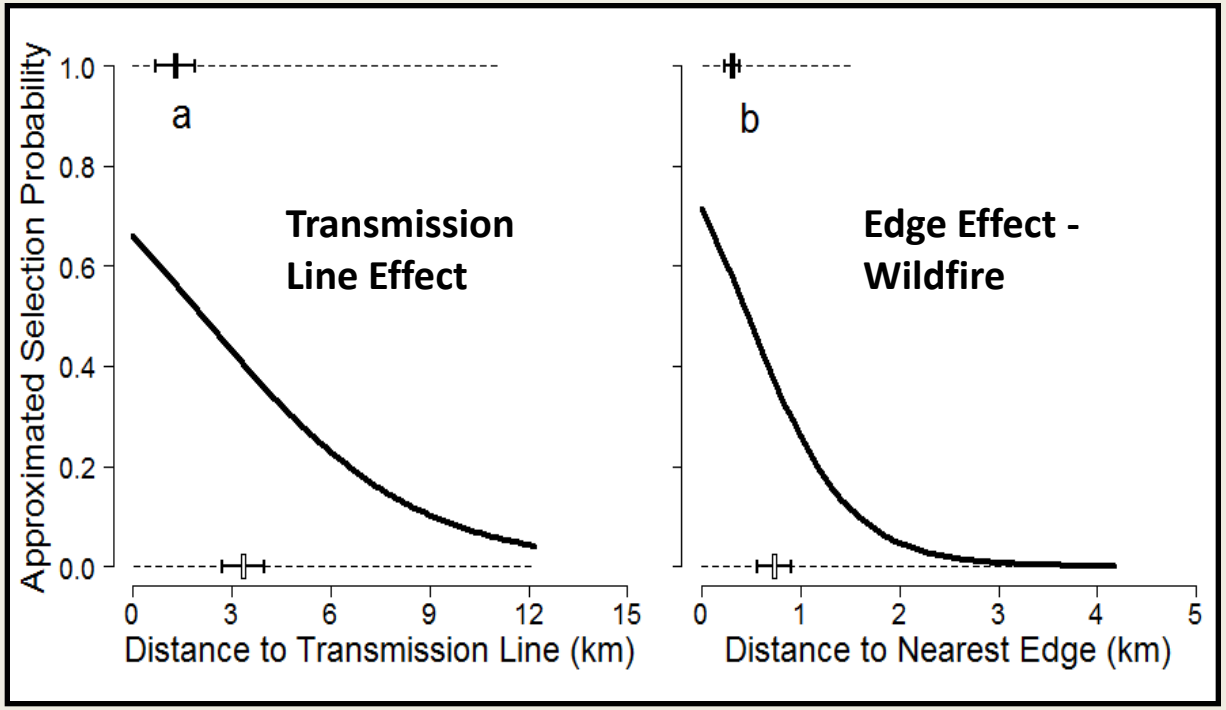
Selection of anthropogenic features and vegetation characteristics by nesting Common Ravens in the sagebrush ecosystem

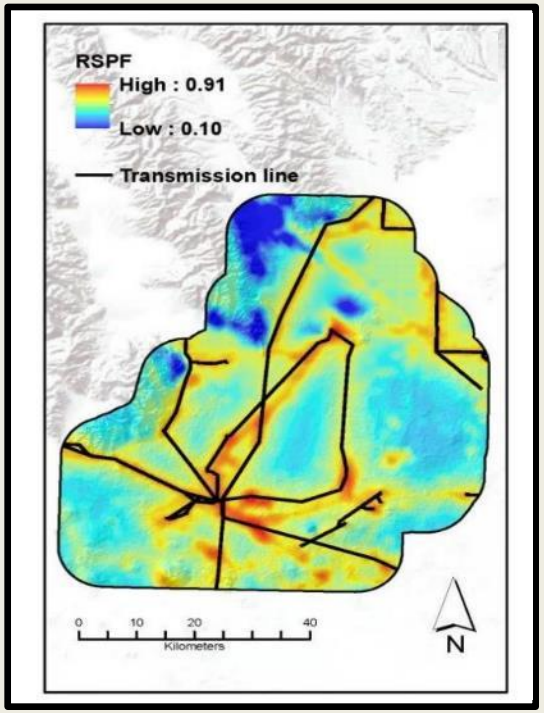
Kristy B. Howe,[1,2] Peter S. Coates,[3]* and David J. Delehanty [1]

Journal of Arid Environments 111 (2014) 68–78
Contents lists available at ScienceDirect
Journal of Arid Environments
journal homepage: www.elsevier.com/locate/jaridenv

Common raven occurrence in relation to energy transmission line corridors transiting human-altered sagebrush steppe

Peter S. Coates [a,*], Kristy B. Howe [a,b,c], Michael L. Casazza [a], David J. Delehanty [b]





Findings

- **1-km increase in distance to power line decreased selection by 31%**
- **100-m increase in distance from edge decreased selections by 20%**

Webb et al. 2004 Condor 106:517-528
Juvenile survival (%)
80
70
60
50
40
30
20
10
0
73
41
28
21
16
27
38
0-.5
.5-1.0
1.0-1.5
1.5-2.0
2.0-3.5
3.5-5.0
5.0 +
Nest distance to nearest anthropogenic resource (km)
Bill Boarman, USGS, 2003

esa ECOSPHERE

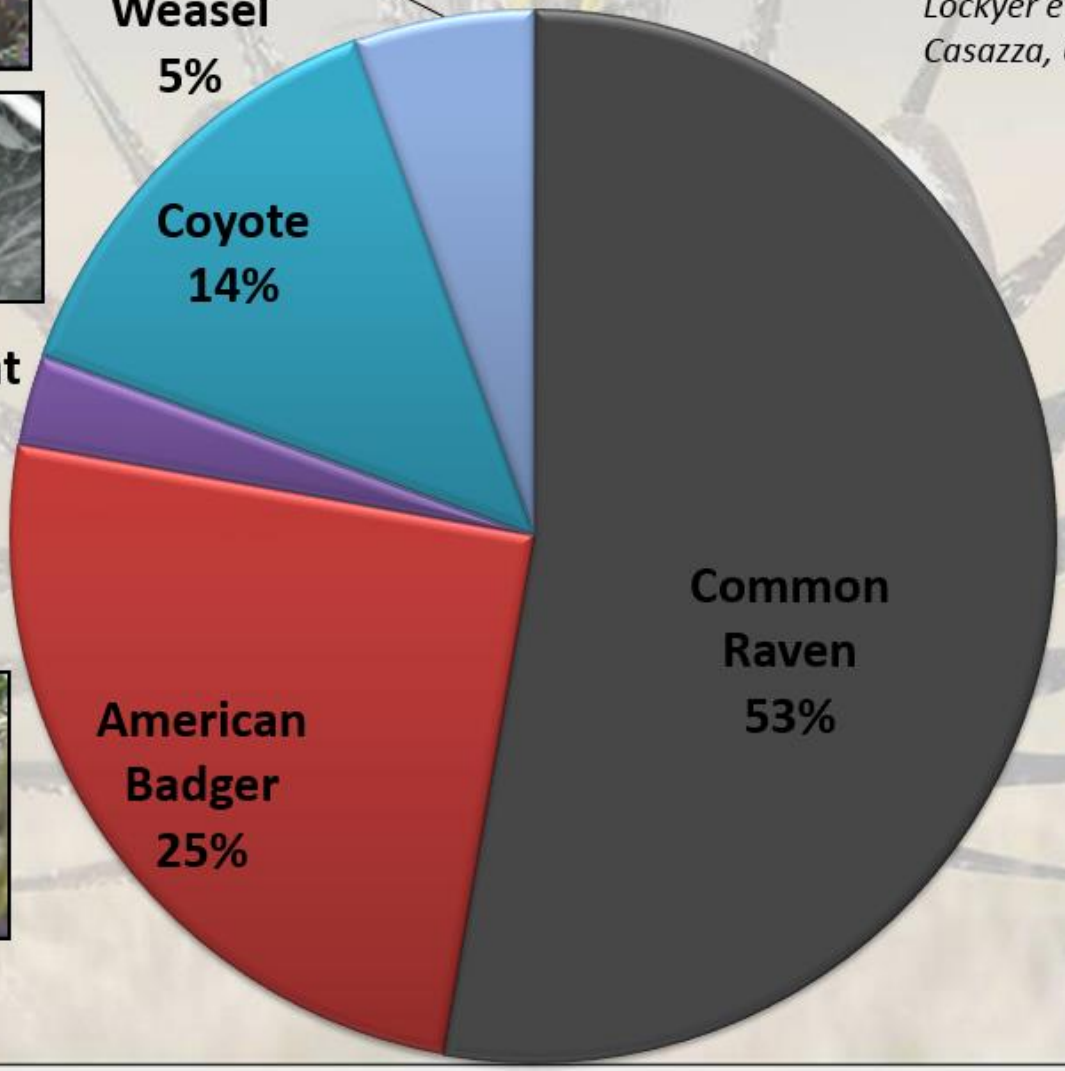
Landscape characteristics and livestock presence influence common ravens: relevance to greater sage-grouse conservation

Peter S. Coates,[1,†] Brianne E. Brussee,[1] Kristy B. Howe,[1,2]
Kit Benjamin Gustafson,[1] Michael L.Casazza,[1] and David J. Delehanty[2]

Proximity to cropland influenced odds of occurrence
Greatest effects within 0.5 km

Odds of raven occurrence increased 45.8% in areas where livestock were present

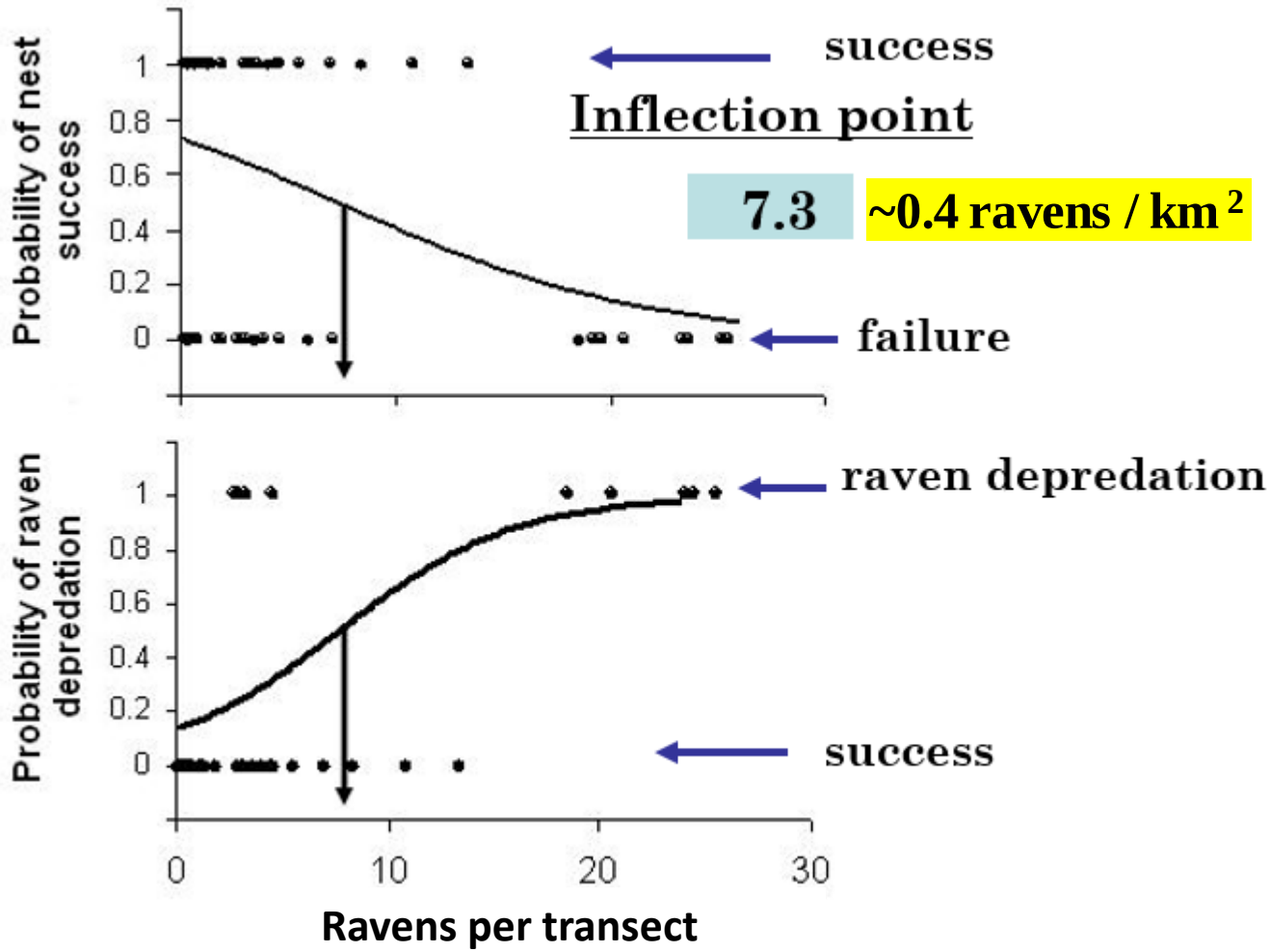
Ravens are most frequent predator of Sage-Grouse (9 years of video data)



Literature:

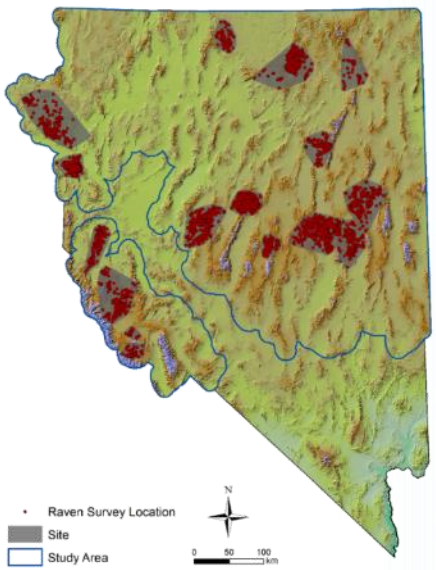
Coates et al. 2008. JFO 79:421–428.
Lockyer et al. 2013. JFWM 4: 242 – 254.
Casazza, USGS, unpublished

Nests fail in areas of high raven abundance



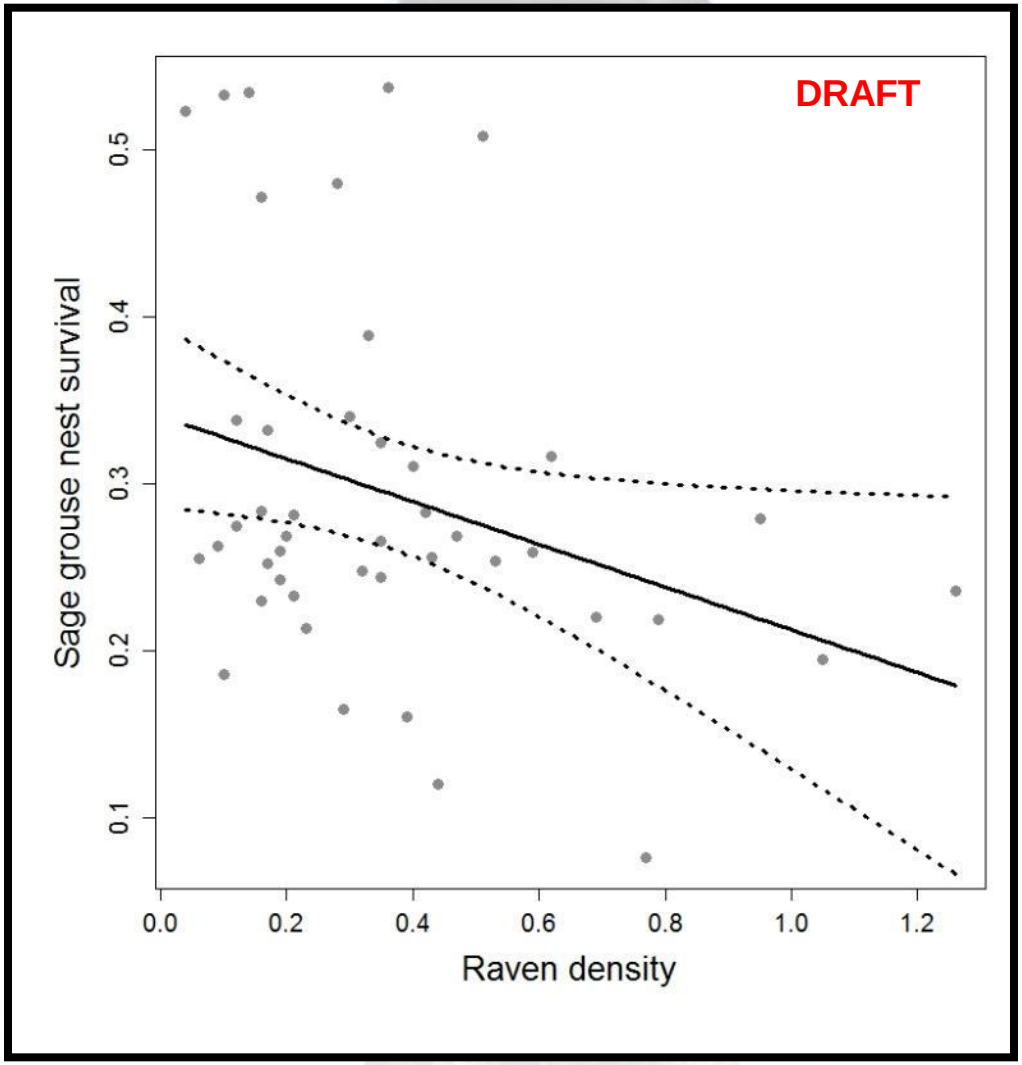
Coates 2007

Widespread Impacts of Increased Raven Numbers on Sage-Grouse Populations



Recent Population-level analysis:

- 14 sites
- ~400 nests
- ~12,000 raven surveys



Previous Finding:

Effect on sage-grouse nesting in NE Nevada

~0.4 ravens / km ^{2}

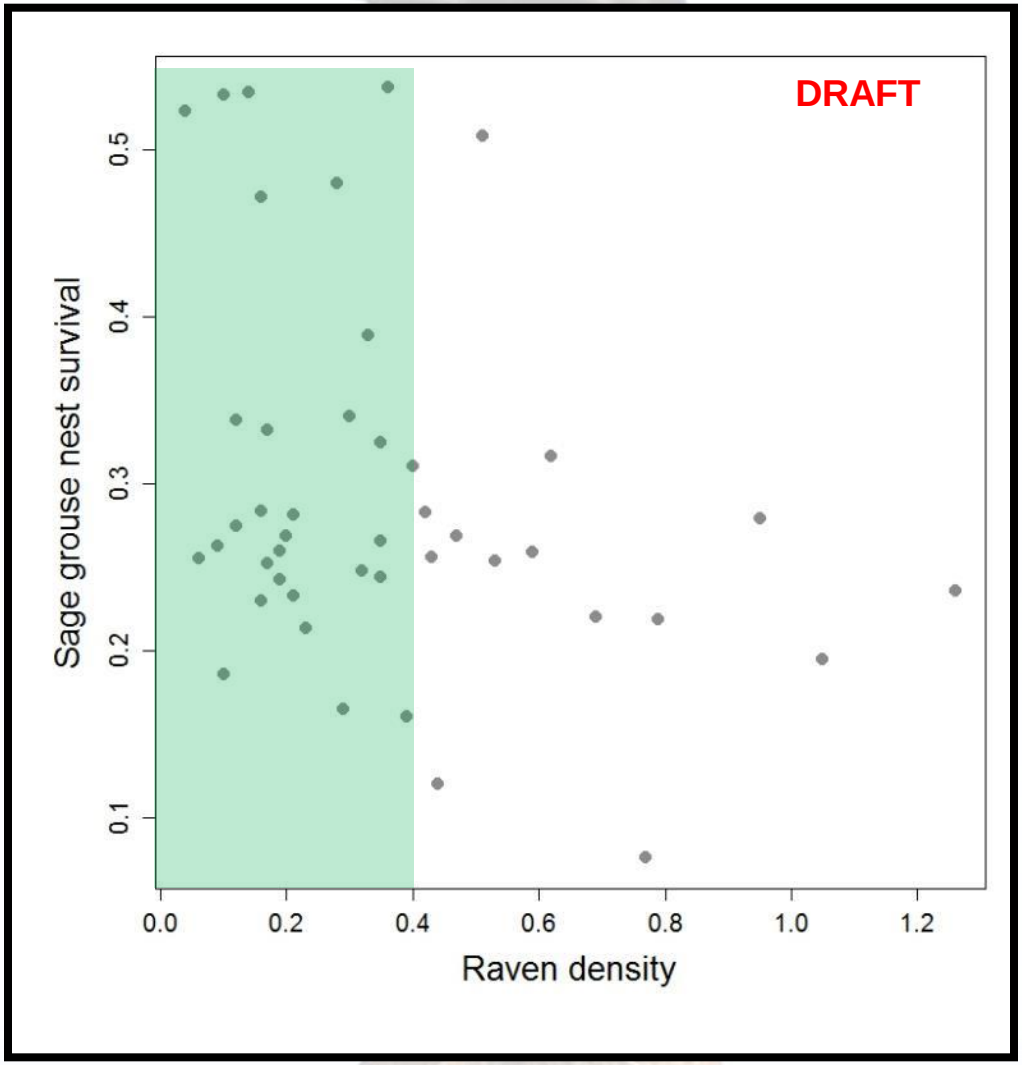
Preliminary Information, Not for Citation

Widespread Impacts of Increased Raven Numbers on Sage-Grouse Populations

Low raven density

=

increased variation in sage-grouse nest survival



Preliminary Information, Not for Citation

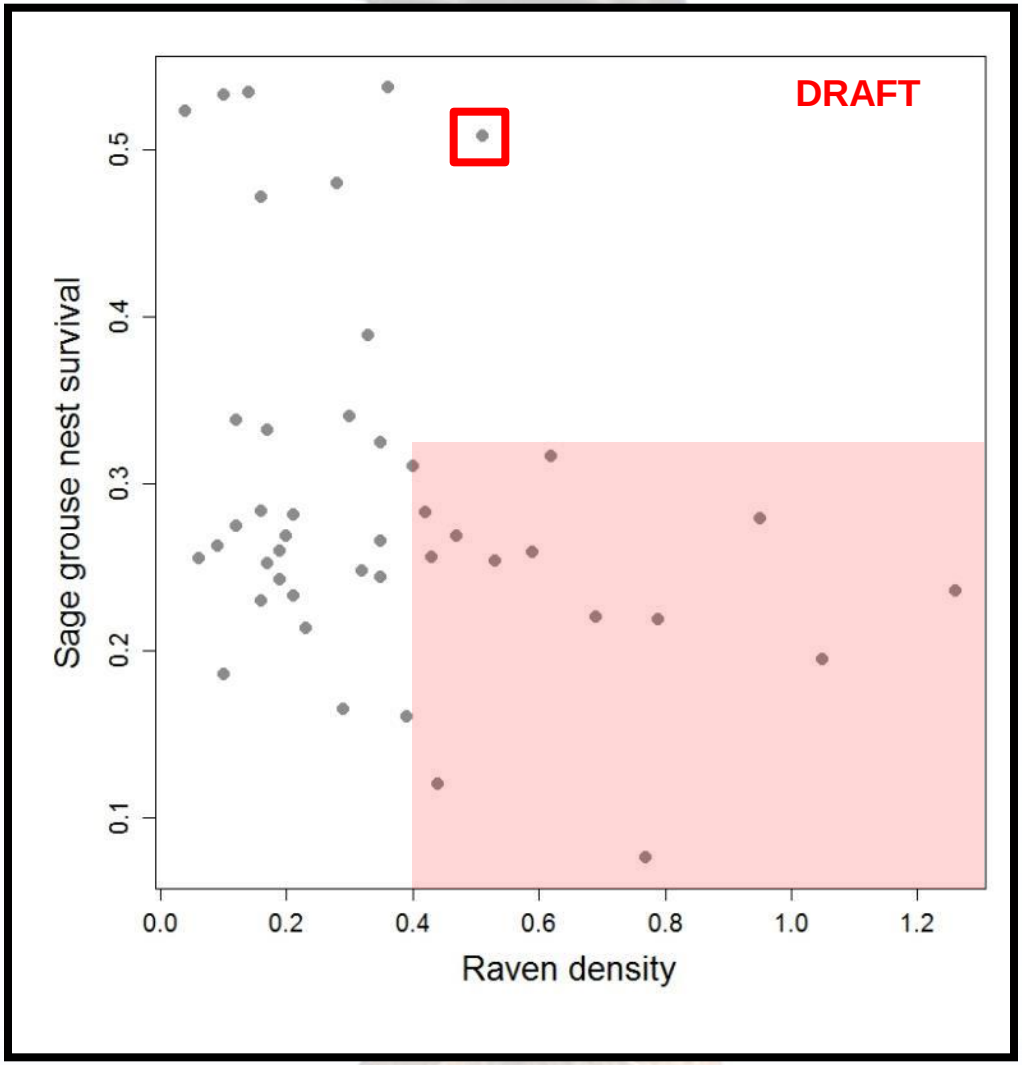
Widespread Impacts of Increased Raven Numbers on Sage-Grouse Populations

Collective Findings:

Impact on nest survival

~0.4 ravens / km ^{2}

Average raven density:
~ 0.39 ravens / km^2



Preliminary Information, Not for Citation

Ravens predation increases with less shrub cover

Resp.	Covariate	Estimate	95% CI lower	95% CI upper
Raven	raven	0.23	0.11	0.41*
	shrub cover	-0.08	-0.15	-0.02*
	grass	0.17	-0.63	0.41
	forb	0.16	-0.40	0.70
	understory	0.02	-0.04	0.08
	shrub height	0.00	-0.06	0.06

- 1% decrease in shrub cover increased the odds of raven predation by 7.5%
- 20–25% sagebrush cover and 25–30% total shrub cover

Coates and Delehanty 2010

Important Interaction

Example of Science-based Adaptive Management Strategy

1. *Course-scale site selection for targeted management actions*

2. *Local-scale surveys at selected sites for density estimates*

3. *Three-tiered management action approach*

4. *Conduct post management monitoring*

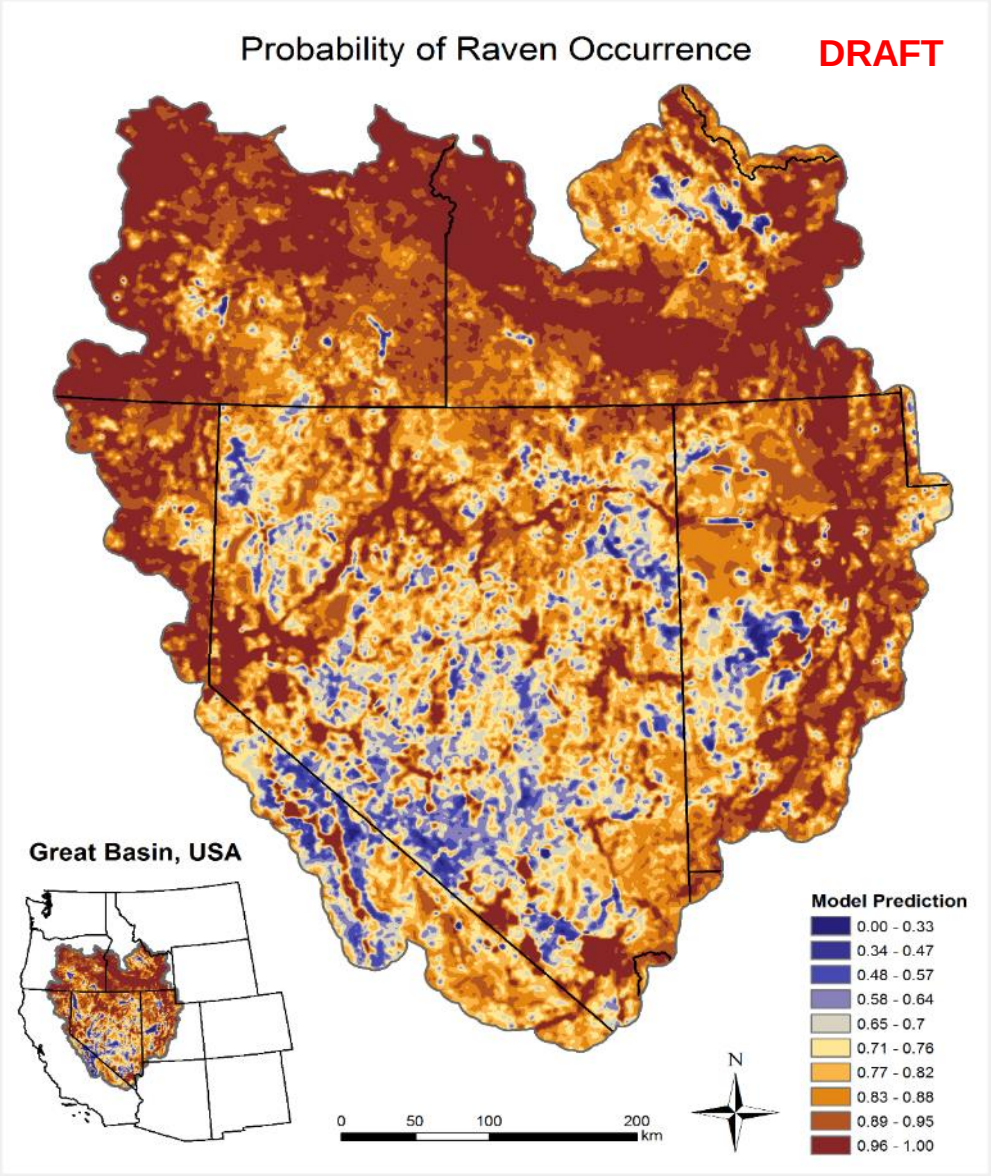
Example of Science-based Adaptive Management Strategy

Tier 1 –Maintain or improve habitat conditions that reduce predation

Tier 2 – Reduce access to anthropogenic subsidies (concurrent with Tier 1 actions)

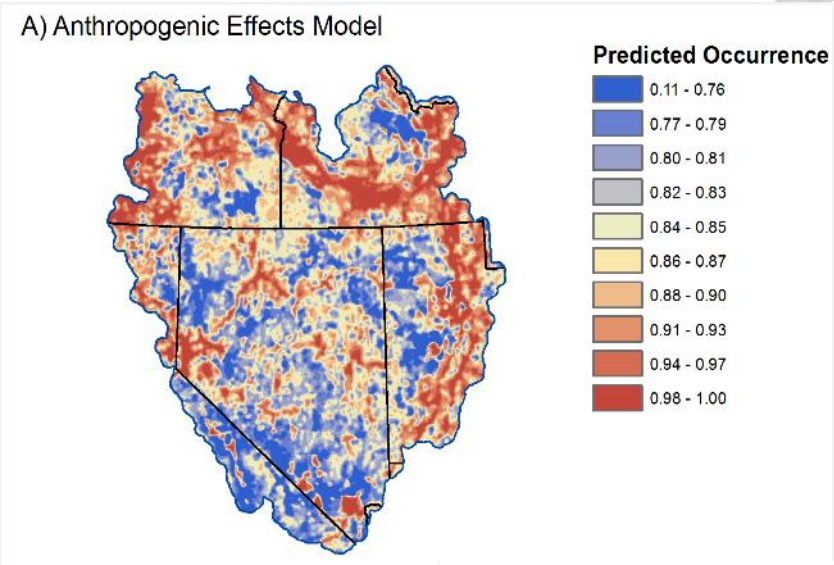
Tier 3 – Lethal raven removal (concurrent with Tier 1 and 2 actions)

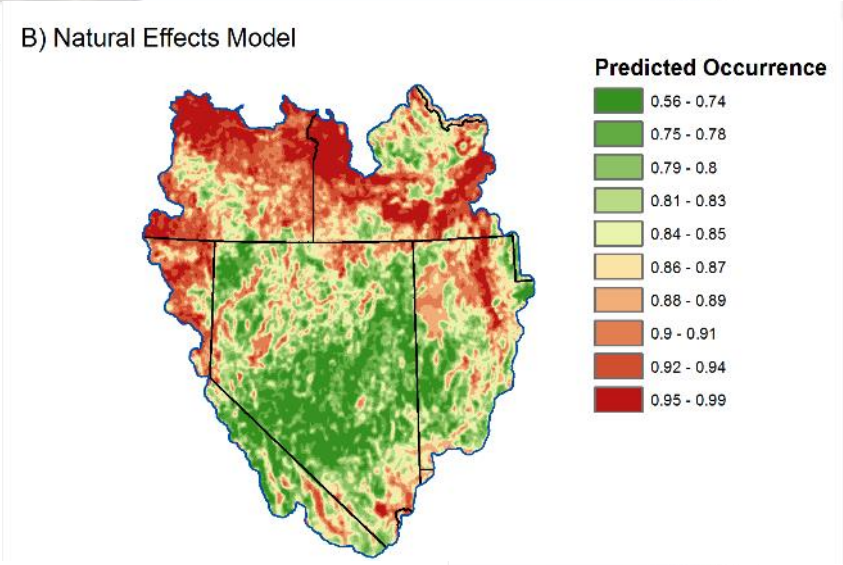
Landscape Scale Management Tools

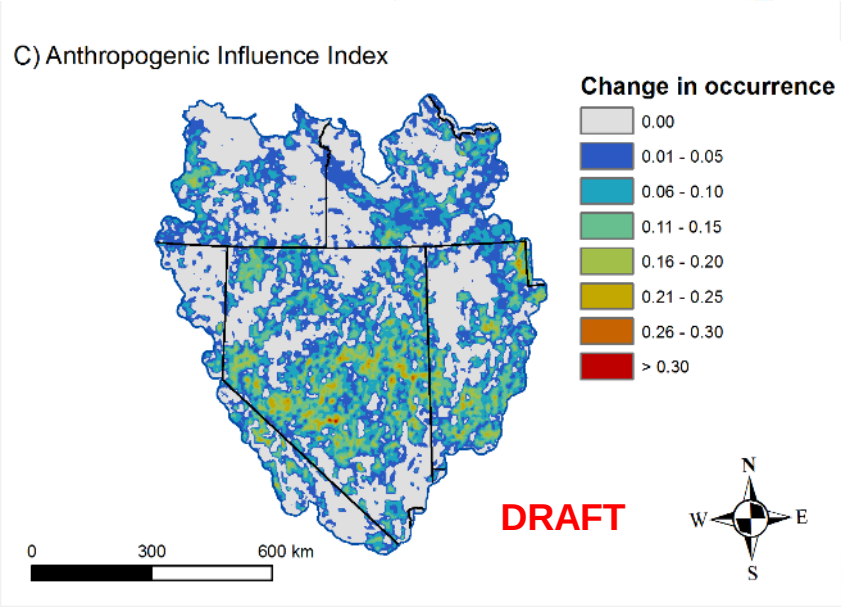


Preliminary Information, Not for Citation

Landscape Scale Management Tools





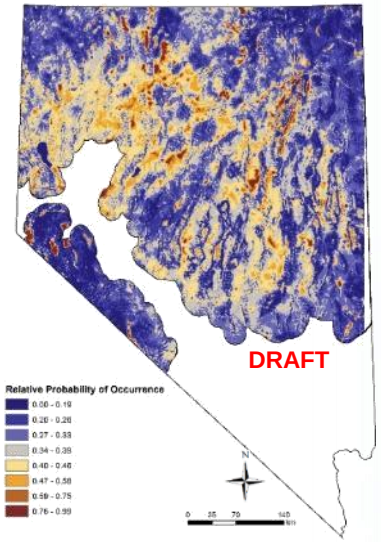


Preliminary Information, Not for Citation

Example

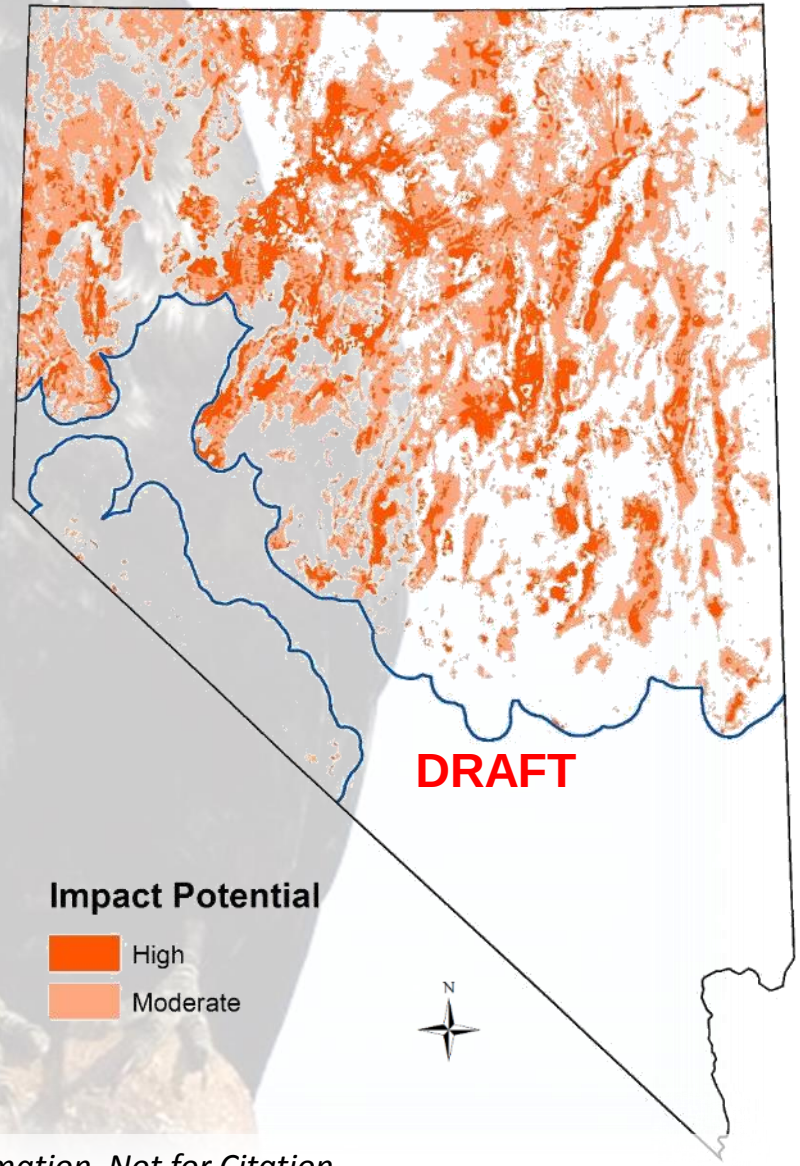
Course-scale site selection for targeted management actions

Preliminary State-wide Impact Map



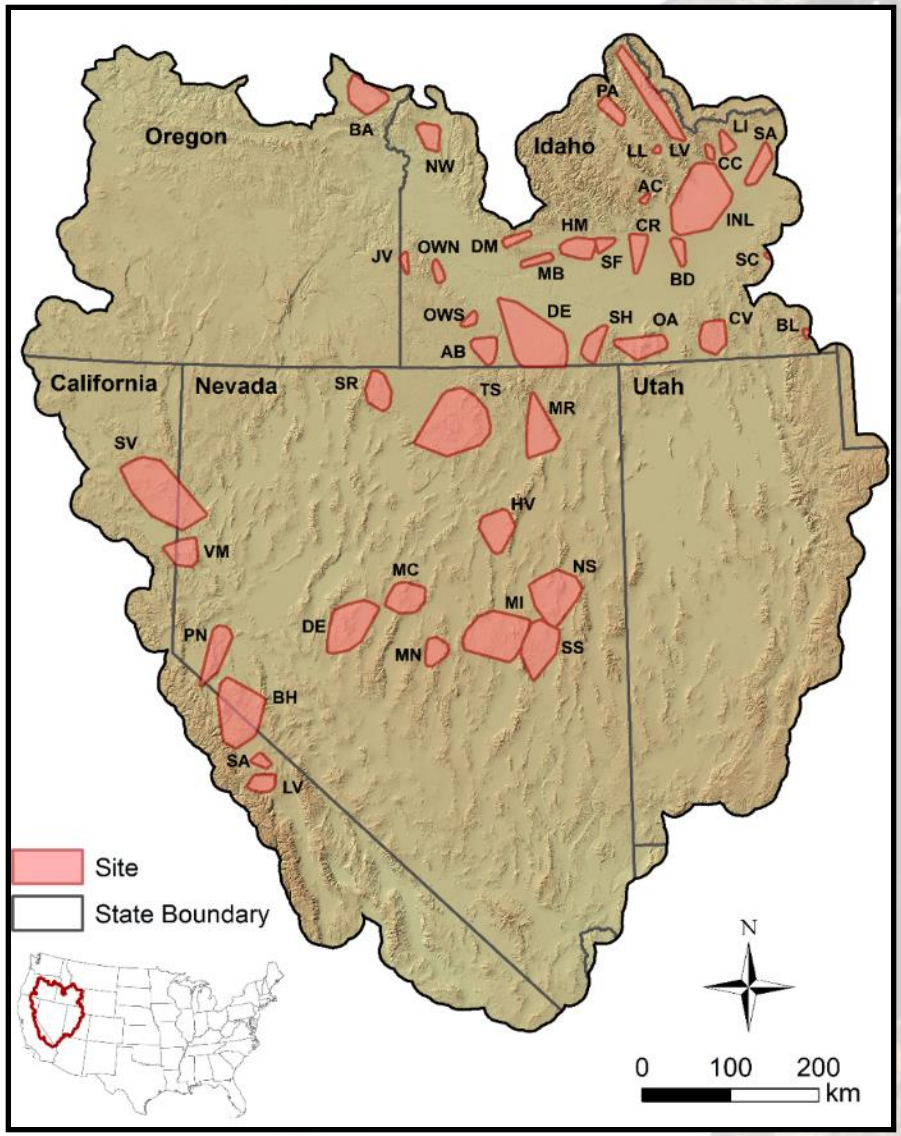
Raven Probability of Occurrence

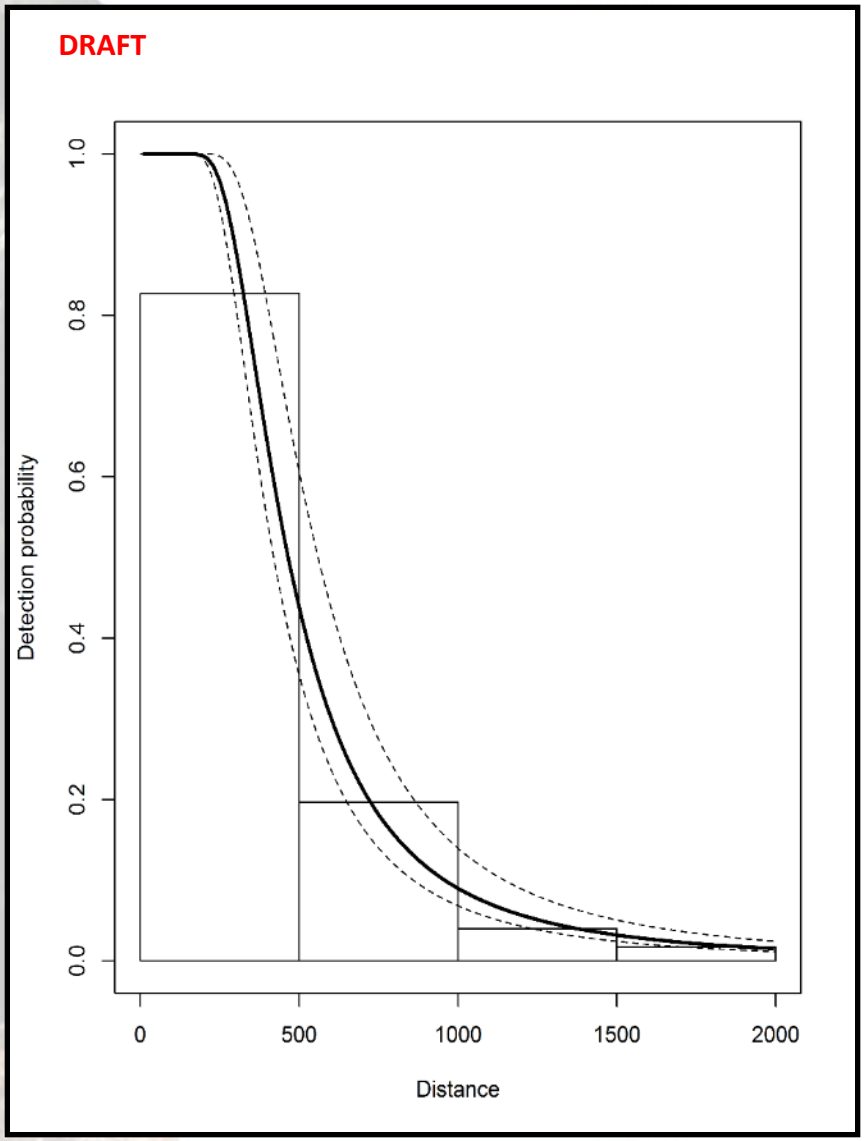
Sage-grouse Habitat *(Coates et al. 2016)*



Preliminary Information, Not for Citation

2. *Local-scale surveys at selected sites for density estimates*





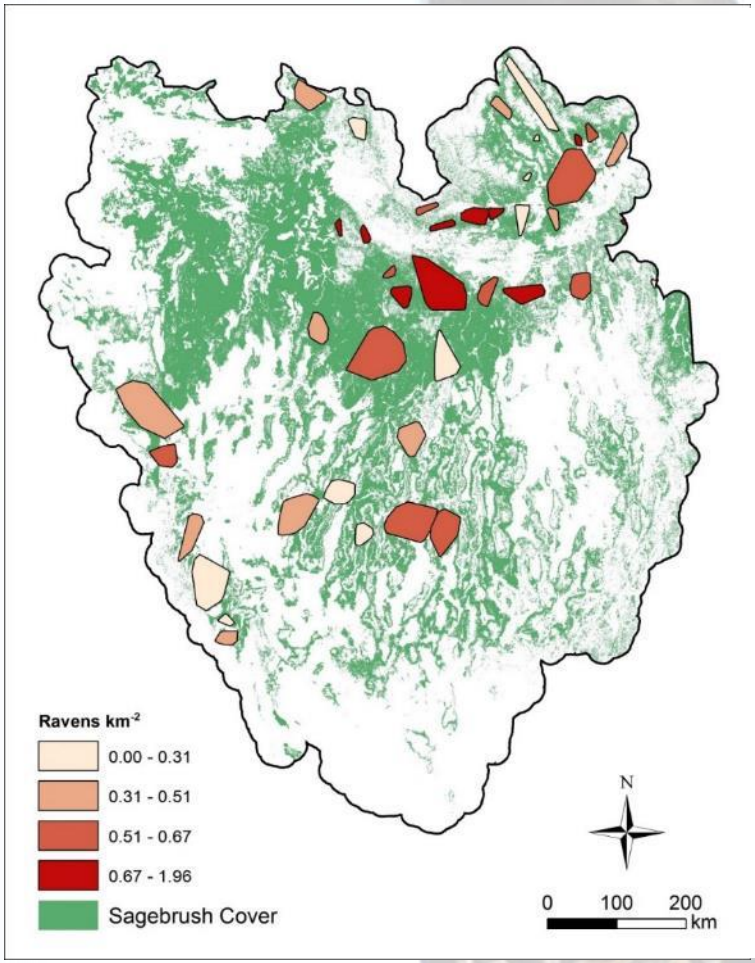
2. *Local-scale surveys at selected sites for density estimates*

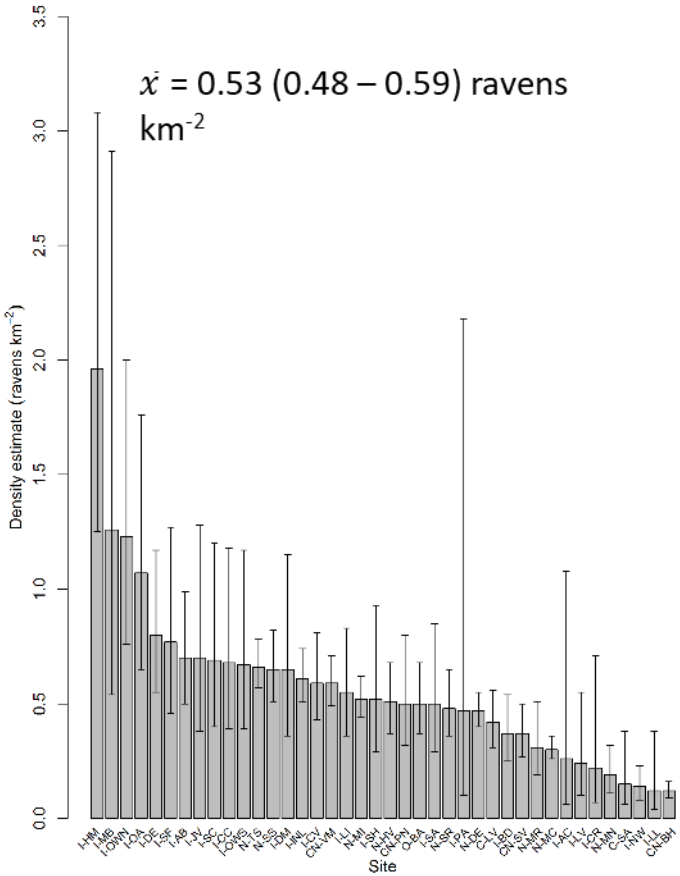
Density and Abundance Estimates

Range: 0 – 1.96 ravens km^{-2}

Mean across sites: 0.53 ravens km^{-2}

~ 147,000 (136,000 – 160,000) occupying Great Basin sagebrush ecosystems





Assignment of Tier and Actions Based on Raven Density Estimates

Tier 1 –Maintain or improve habitat conditions that reduce predation

Tier 2 – Reduce access to anthropogenic subsidies (concurrent with Tier 1 actions)

Tier 3 – Lethal raven removal (concurrent with Tier 1 and 2 actions)

2. *Local-scale surveys at selected sites for density estimates*

Density and Abundance Estimates

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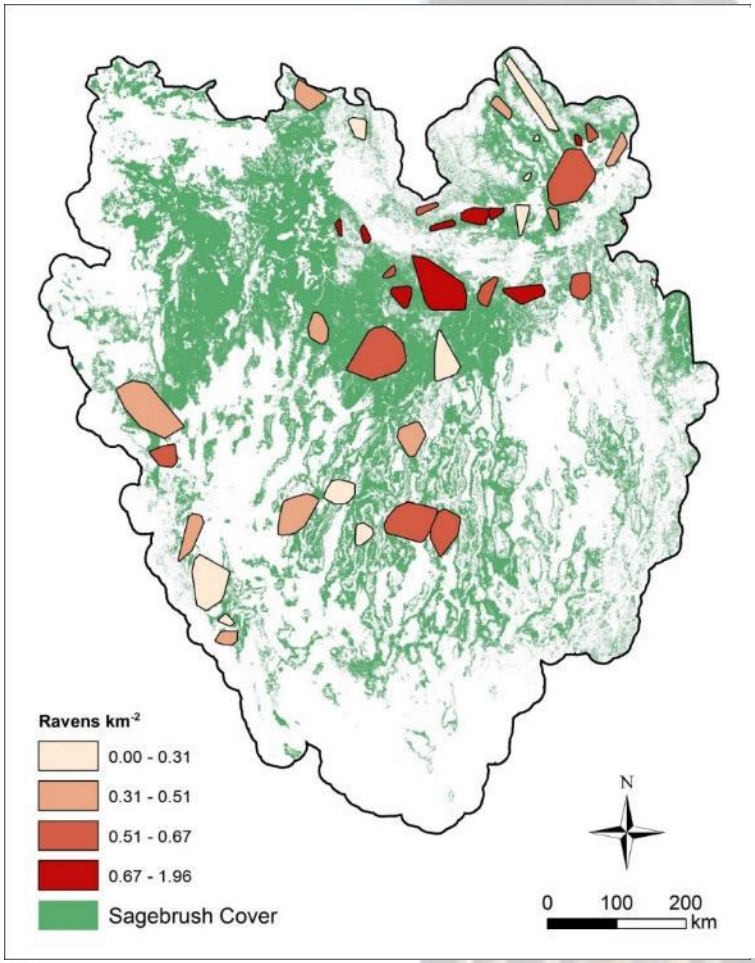
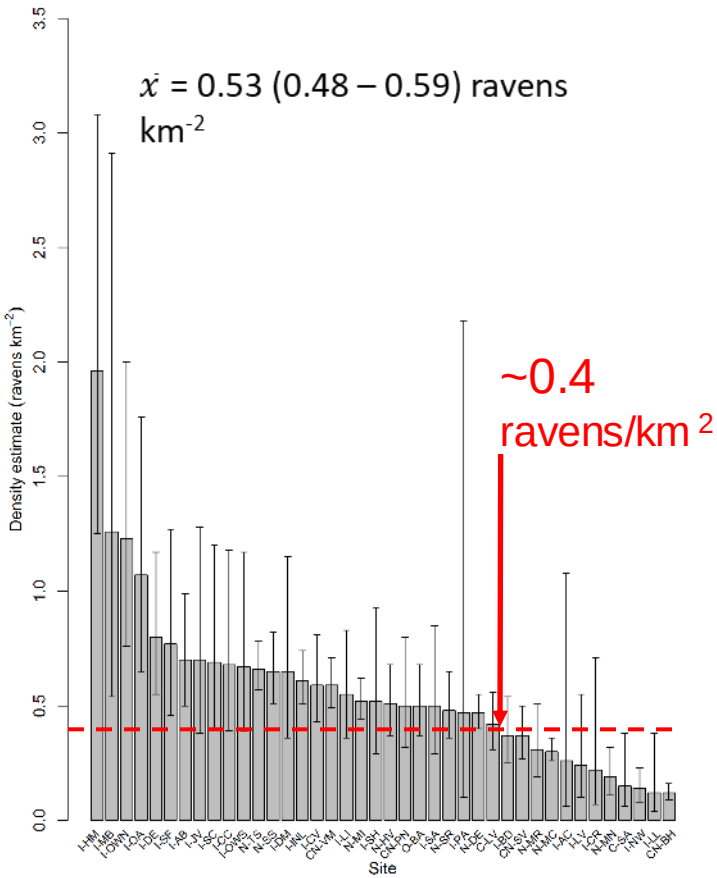
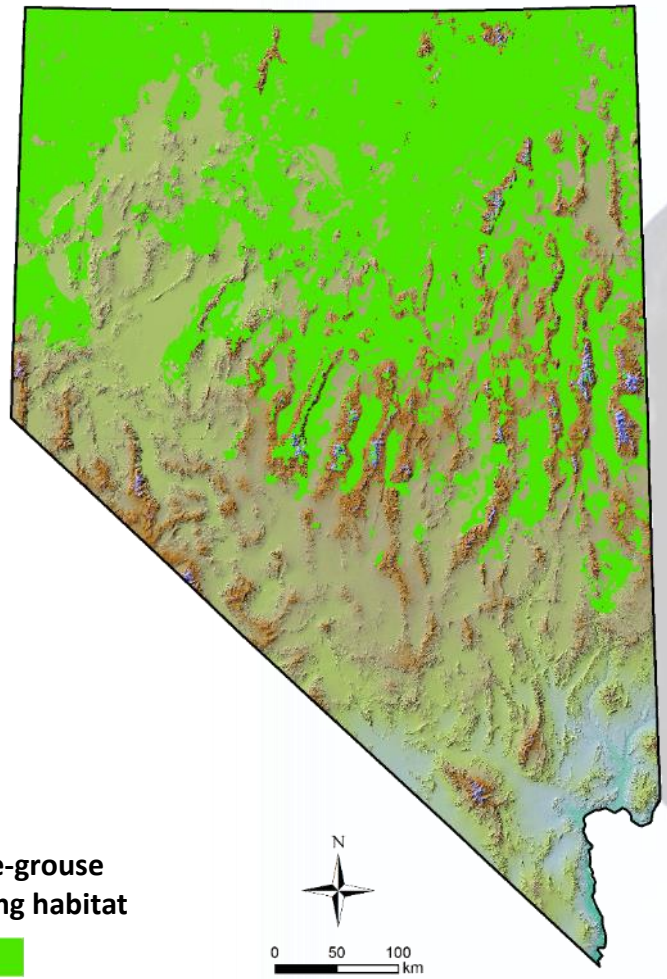




Preliminary Information—Subject to Revision. Not for Citation or Distribution

Preliminary Abundance Estimates of Ravens



Sage-grouse spring habitat

Number of Ravens in sagebrush cover types across Great Basin

~145,000

Number in Nevada sage-grouse habitat

~40,000

Number across state

~110,000

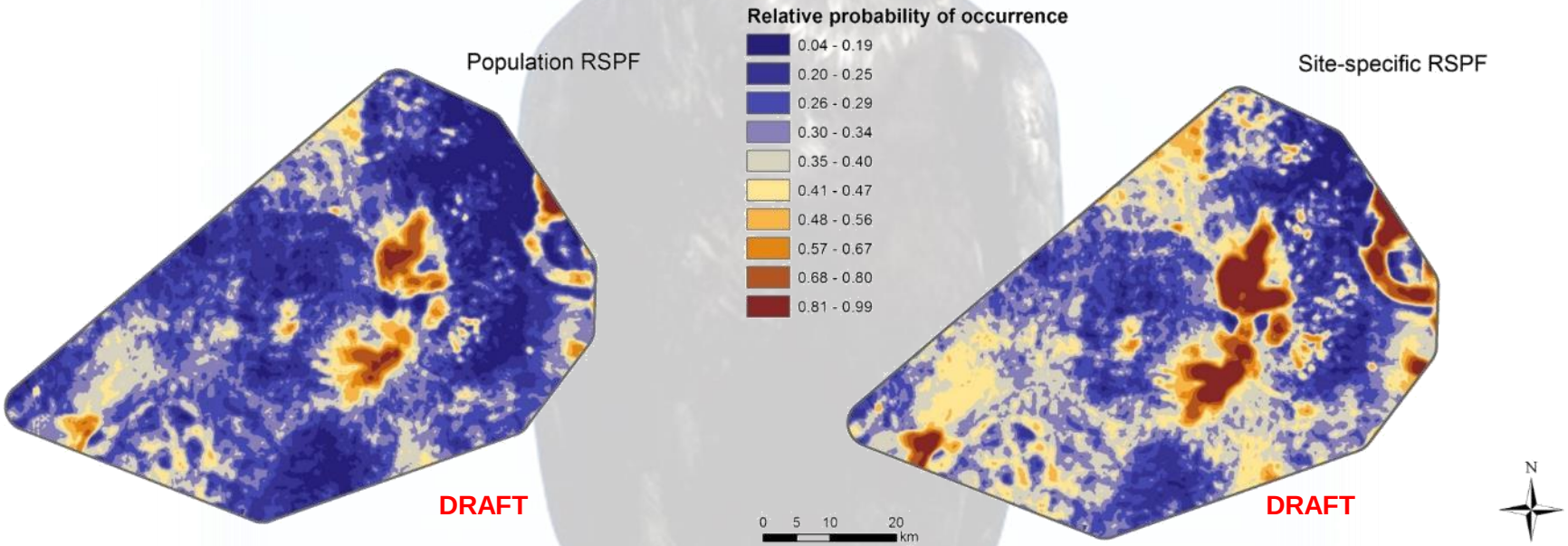
Preliminary Information, Not for Citation

Example

3. *Three-tiered management action approach*

Specific Areas to Target for Management

Local Scale Analysis



Developing model and user-friendly interface for agencies to develop spatially explicit maps for targeting areas for management actions

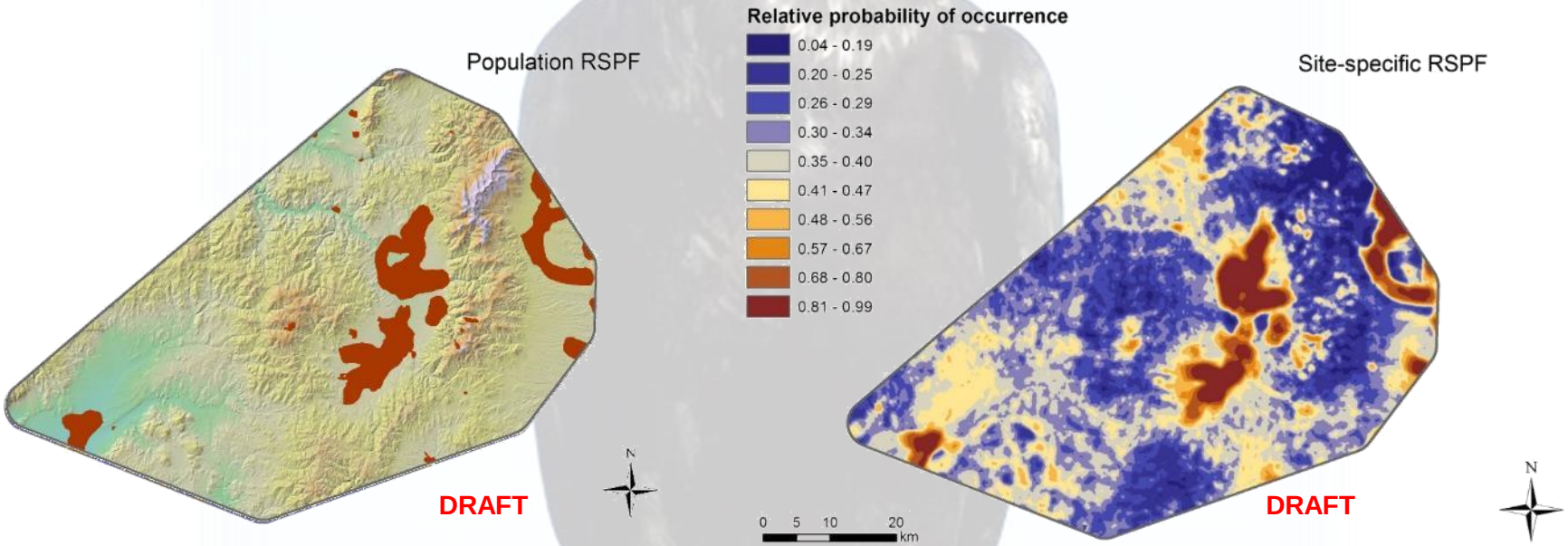
Preliminary Information, Not for Citation

Example

3. *Three-tiered management action approach*

Specific Areas to Target for Management

Local Scale Analysis



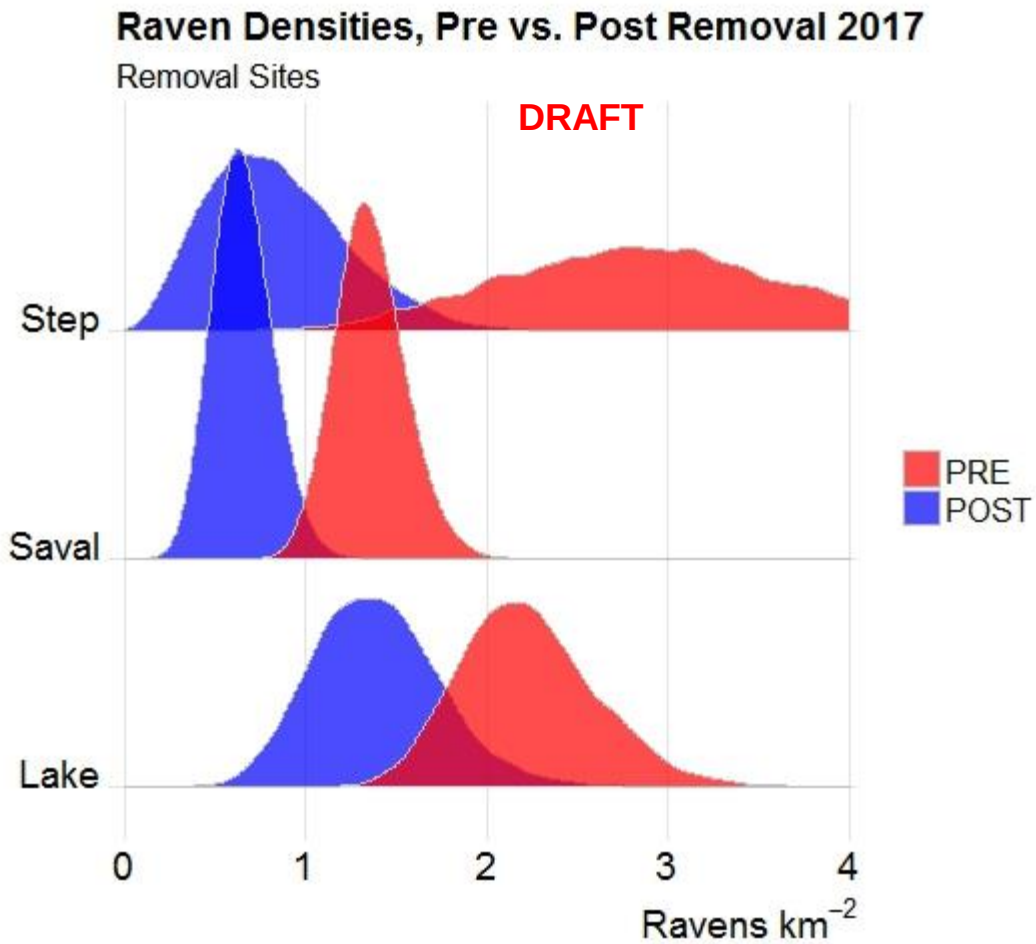
Developing model and user-friendly interface for agencies to develop spatially explicit maps for targeting areas for management actions

Preliminary Information, Not for Citation

Example

4. *Conduct post management monitoring*

Measuring Effectiveness of Actions



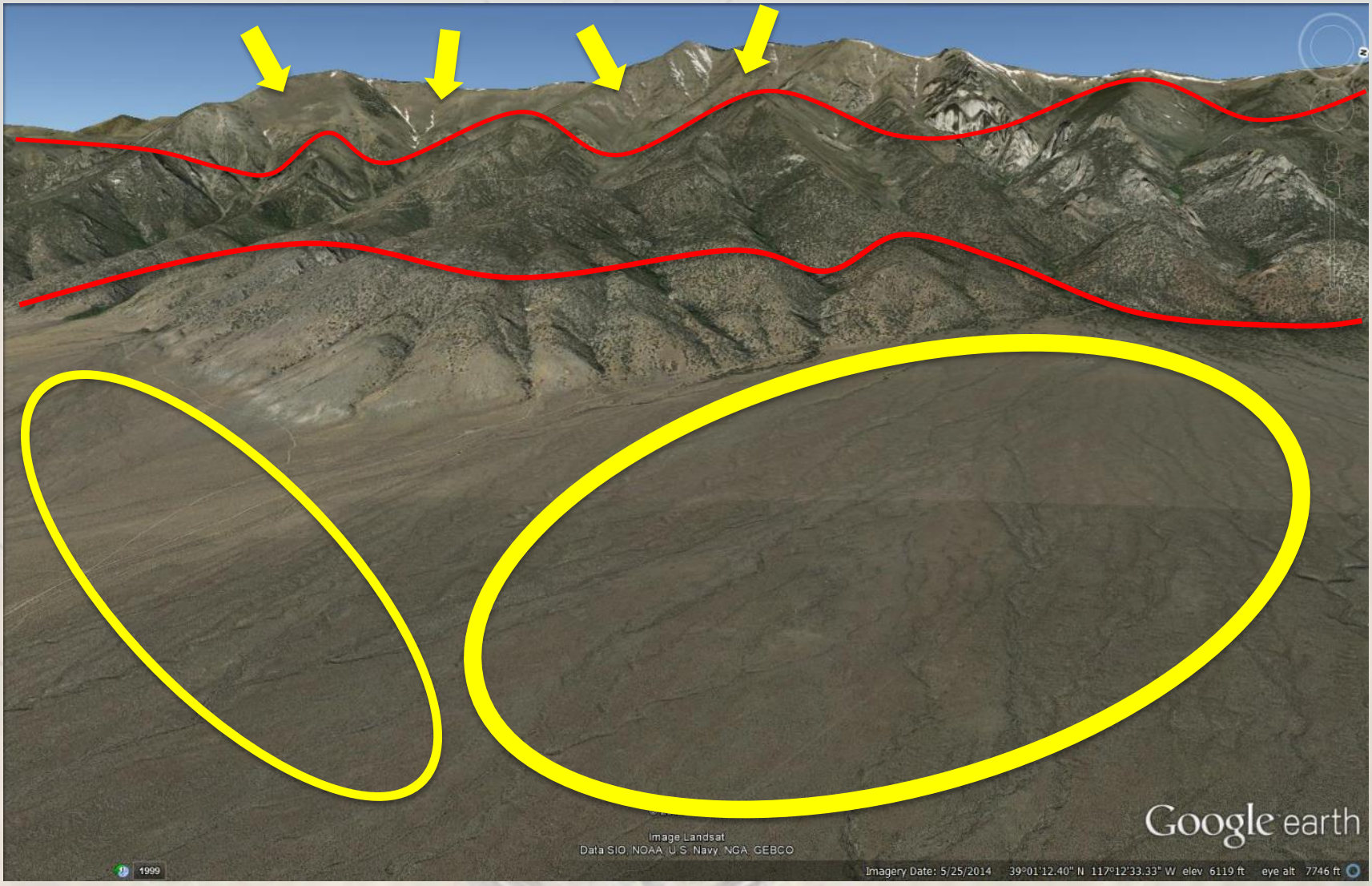
Preliminary Information, Not for Citation

Next Steps

- Continue to improve state-wide occurrence, density, and impact maps
- Develop user-friendly interface to generate local scale maps and density estimates with survey data
- Incorporate new information on relationships between ravens, habitat and sage-grouse populations
- Incorporate findings using GPS data to inform dispersal, movement patterns, and space use of ravens

III. Pinyon and Juniper Encroachment into Sagebrush Ecosystems Impacts Distribution and Survival of Greater Sage-Grouse

Local Population Effects



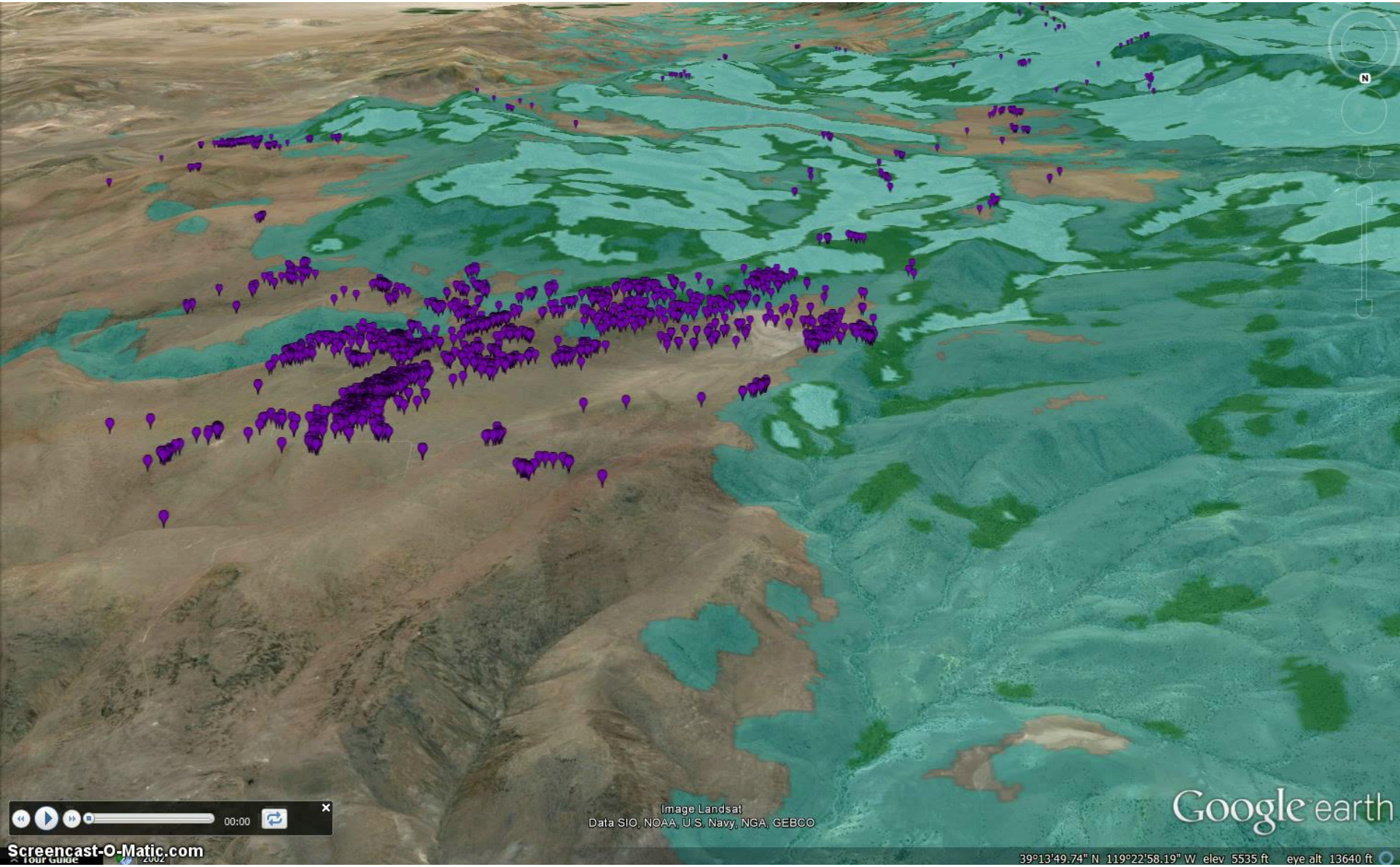


Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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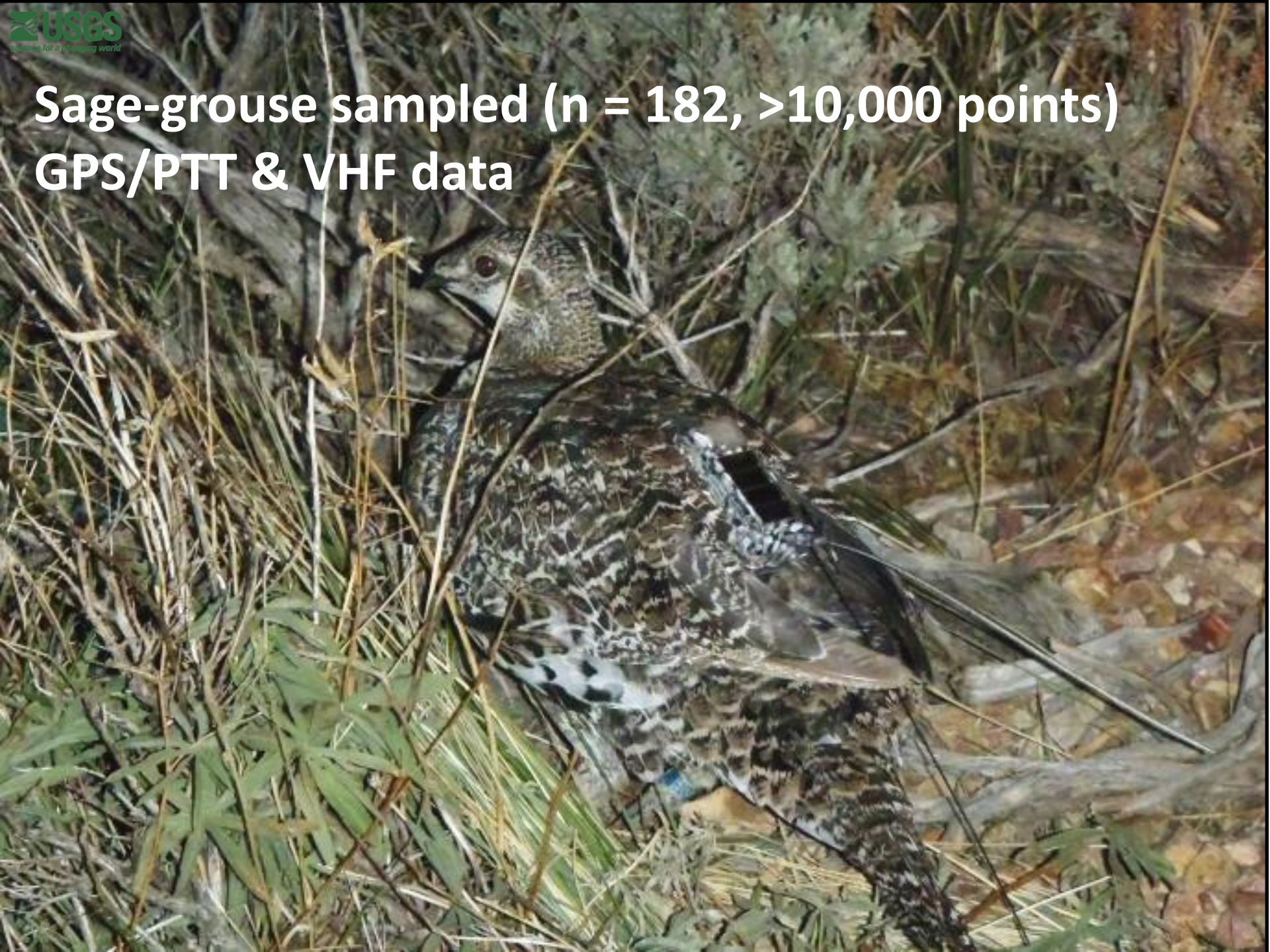
Screencast-O-Matic.com
39°13'49.74" N 119°22'58.19" W elev 5535 ft eye alt 13640 ft


Sage-grouse sampled (n = 182, >10,000 points)
GPS/PTT & VHF data

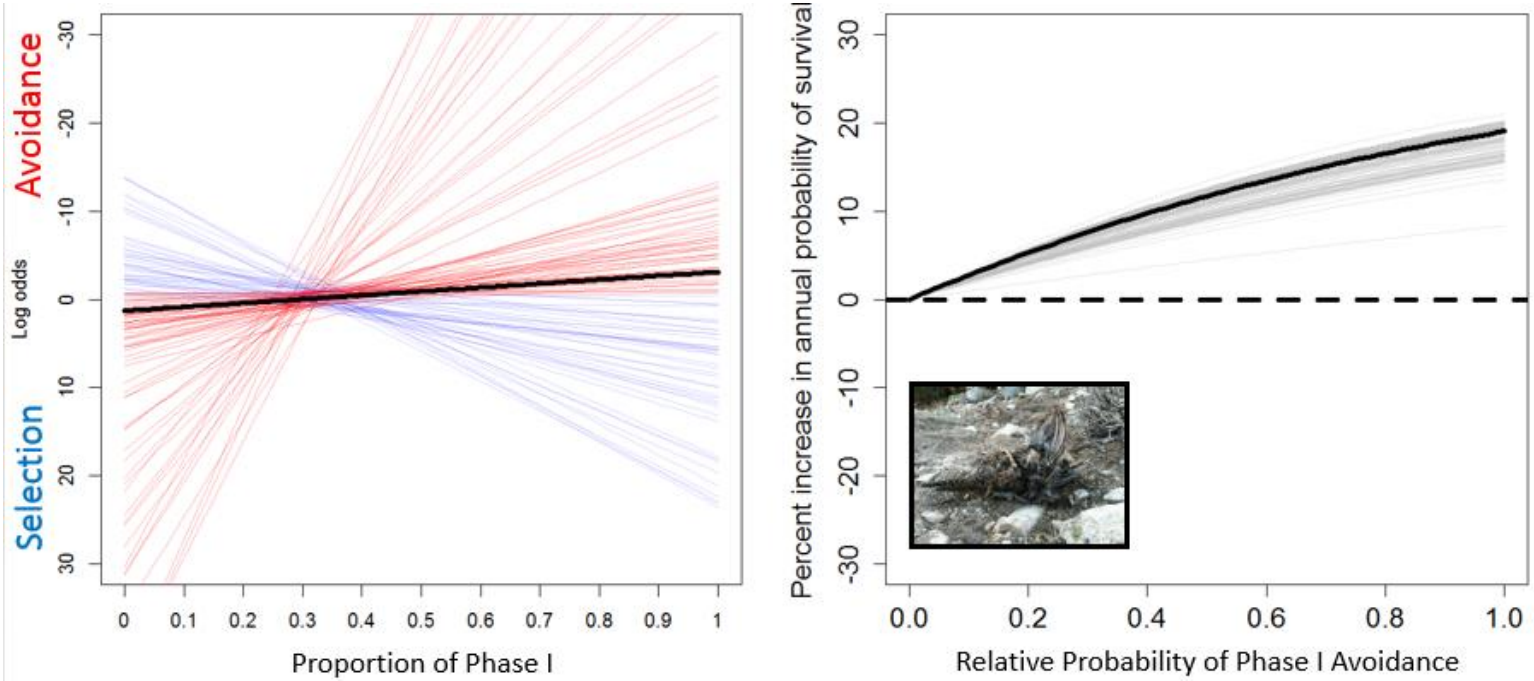
Rangeland Ecology & Management
Volume 70, Issue 1, January 2017, Pages 25–38

Cover image

Pinyon and Juniper Encroachment into Sagebrush Ecosystems Impacts Distribution and Survival of Greater Sage-Grouse

Peter S. Coates[a], Brian G. Prochazka[a], Mark A. Ricca[a], K. Ben Gustafson[a], Pilar Ziegler[b], Michael L. Casazza[a]

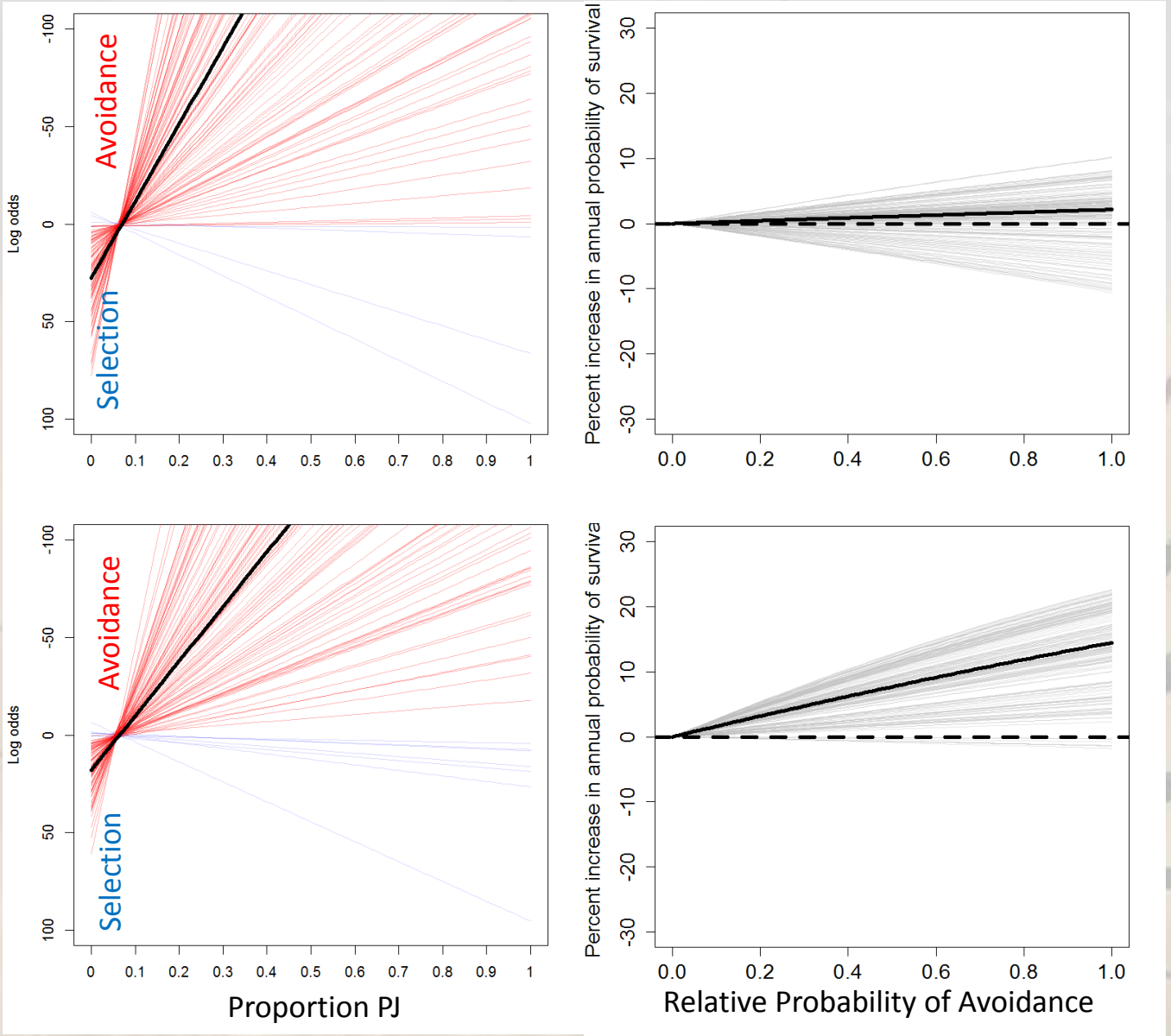
- **50% probability of selection was ~30% of Cover Class 1 (or ~1.5% actual tree cover)**
- **Full avoidance increased annual survival by ~20%**



Coates et al. 2017

Cover Class 2

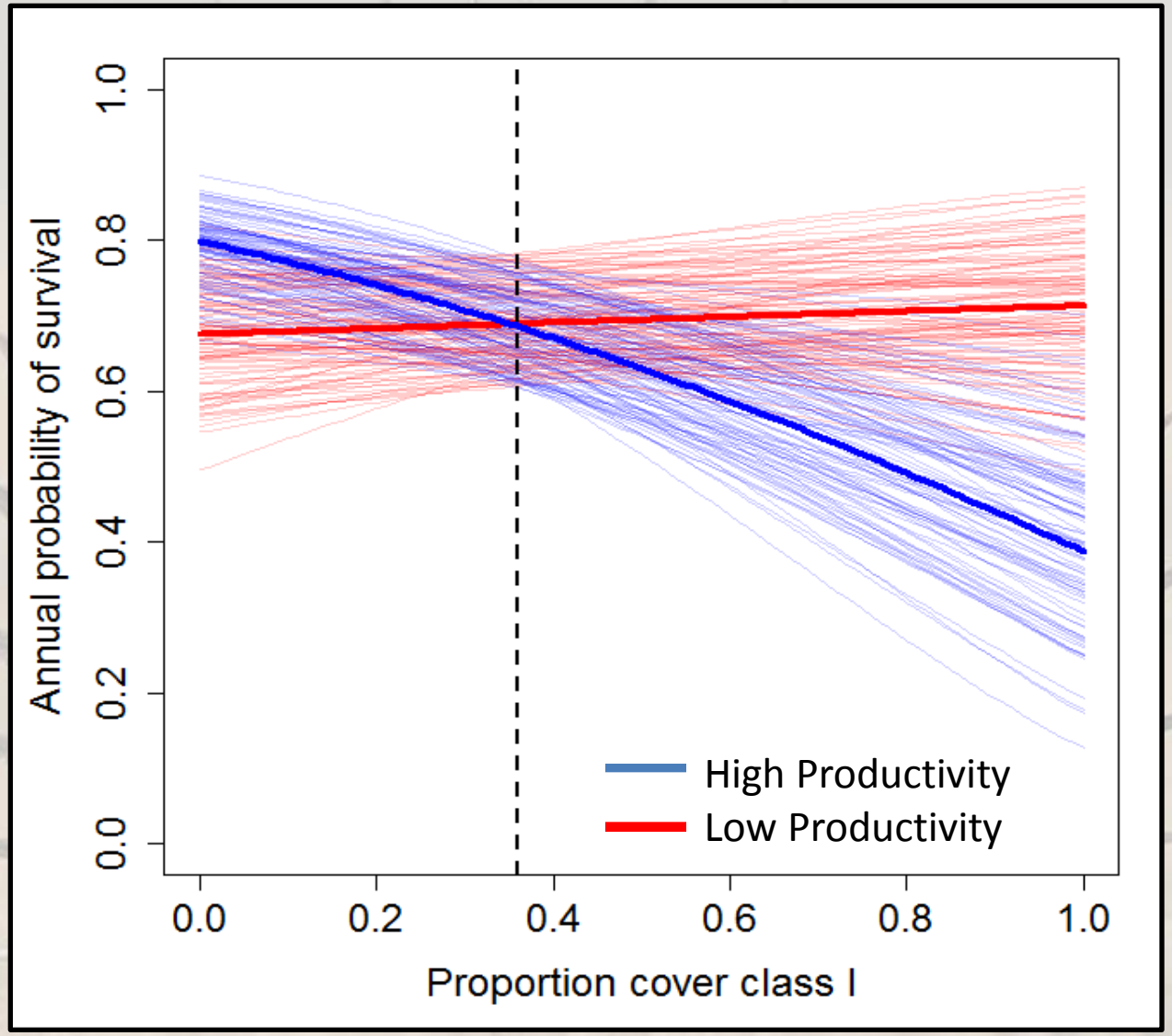
Cover Class 3



- **Consistent avoidance when PJ co-dominant (CC2) or dominant (CC3) or dominant**
- **Survival consequences much more variable**

Coates et al. 2017

Productive Areas with Sparse PJ (CC1) have Higher Mortality Risk



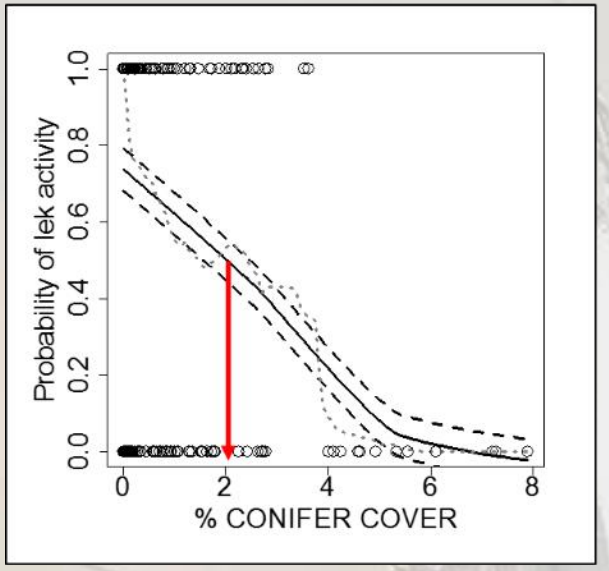
Coates et al. 2017

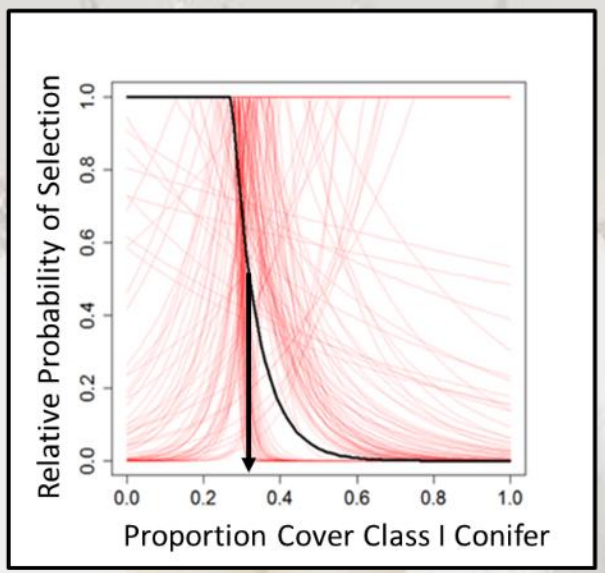
Processes: Ecological Traps

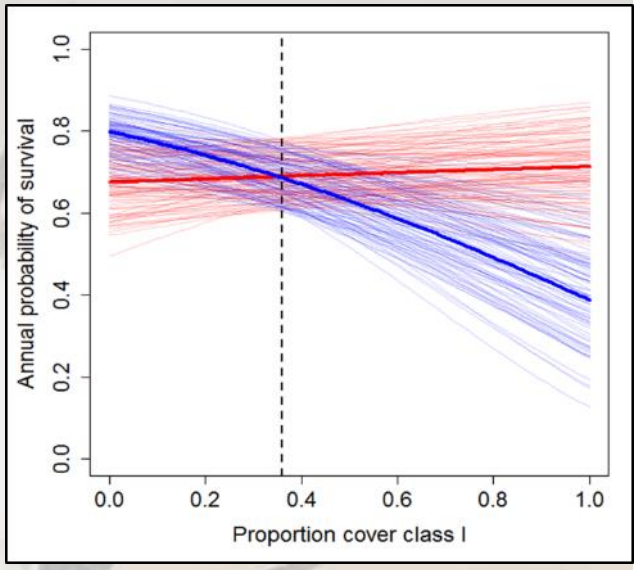
- Reduction in sage-grouse survival may result from of a decoupling of habitat selection cues in high productivity sagebrush with scattered trees

- Higher of risk of predation by *Buteo* hawks that prefer sagebrush areas with isolated trees for perching (Parrish et al. 2002, Coates et al. 2014)

Conifers Adversely Impact Sage-Grouse Survival and Lek Persistence







- **Baruch-Mordo et al. 2013 – lek inactivity study**
- **Similar inflection point between studies after converting cover class to individual tree cover (40% CC1 = 2% trees)**
- **At 80% cover class I (4% trees), survival is 10% below mean**

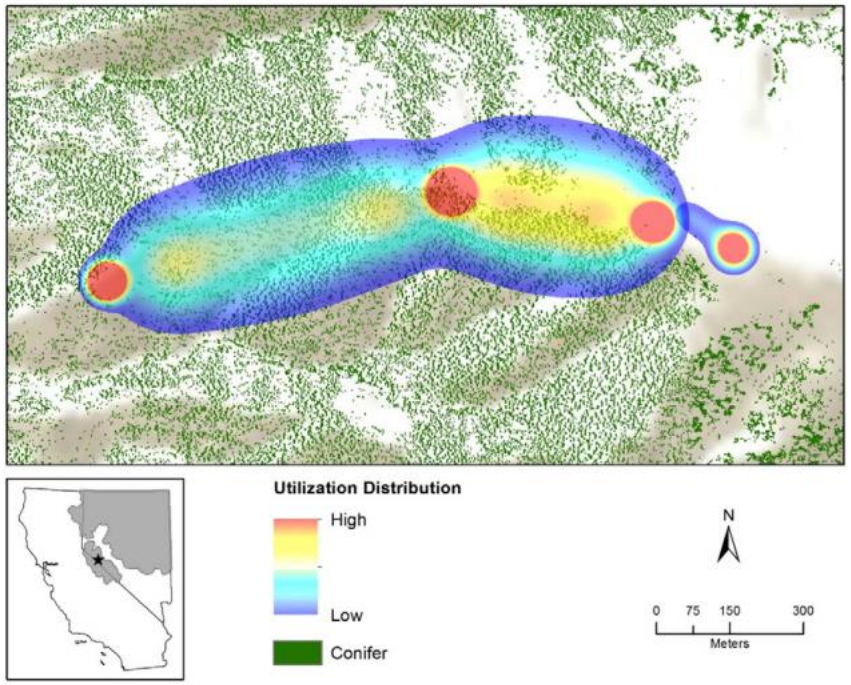
Baruch-Mordo et al. 2013, Coates et al. 2017

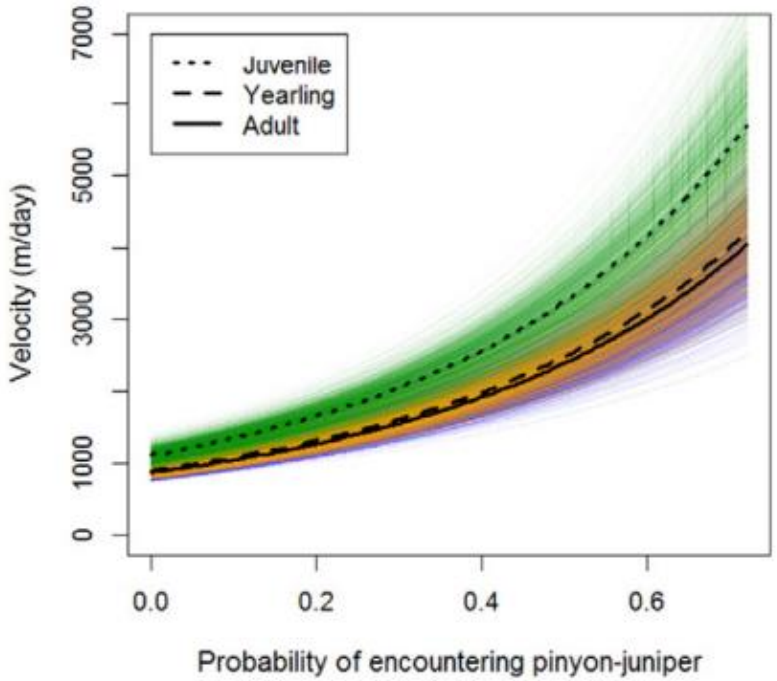
Rangeland Ecology & Management
Volume 70, Issue 1, January 2017, Pages 39–49

Encounters with Pinyon-Juniper Influence Riskier Movements in Greater Sage-Grouse Across the Great Basin ☆ ☆☆

Brian G. Prochazka[a, b], Peter S. Coates[a], Mark A. Ricca[a], Michael L. Casazza[a], K. Benjamin Gustafson[a], Josh M. Hull[b]

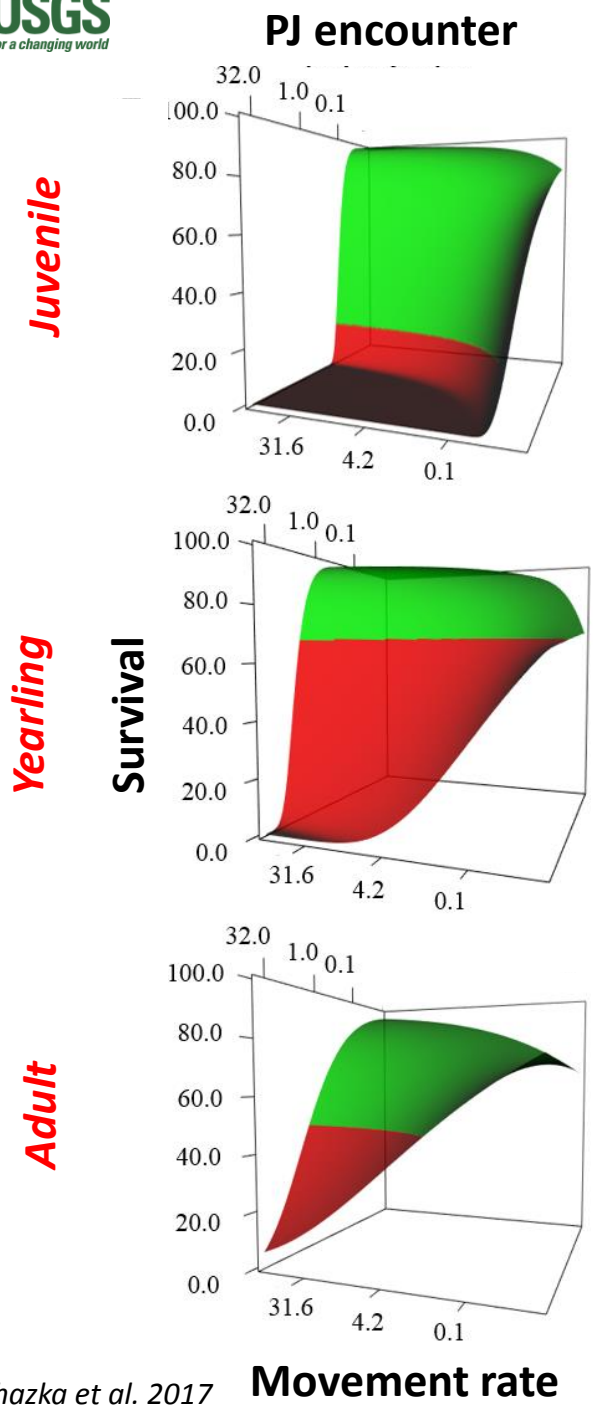
- **All age classes move faster as they encounter more PJ**
- **Juveniles move at a disproportionately faster rate through PJ**





Prochazka et al. 2017

Mechanisms: Negative Effect of PJ Encounter on Survival can Vary by Movement Rate and Age Class



Prochazka et al. 2017

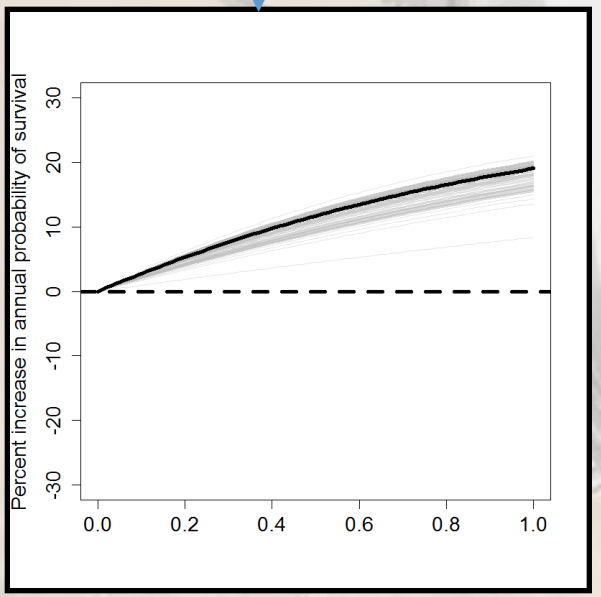
- All age classes likely to die when moving fast and likely encounter PJ
- Juveniles die when encountering PJ regardless if they move fast or slow
- Some Adults (and ~yearlings) may mitigate risk by moving more slowly through PJ

Prochazka et al. 2017

Sage-Grouse Behavioral Choices

Avoid PJ

Survive



Use PJ

Move Slow (less common)

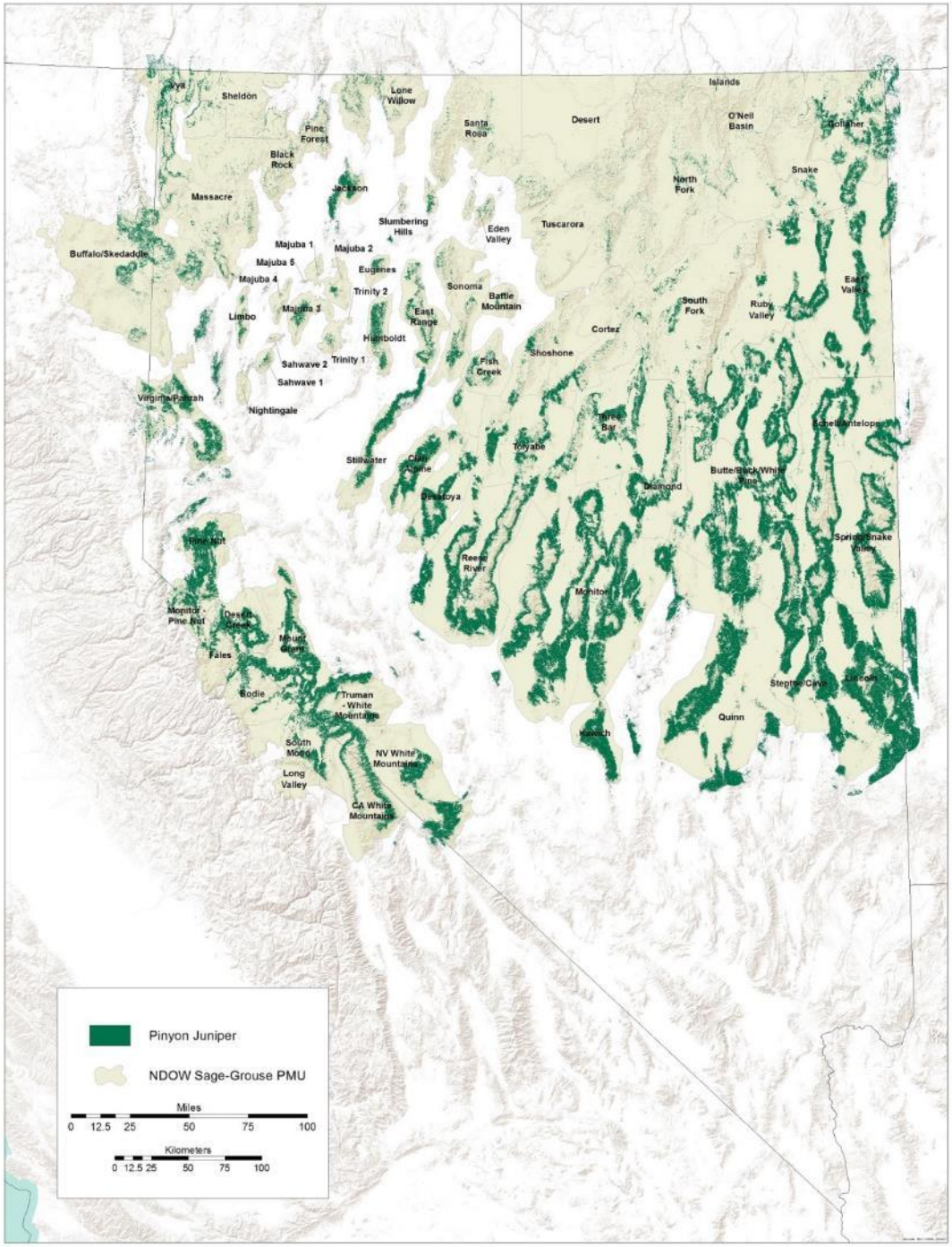
Survive
Adult
Yearling*

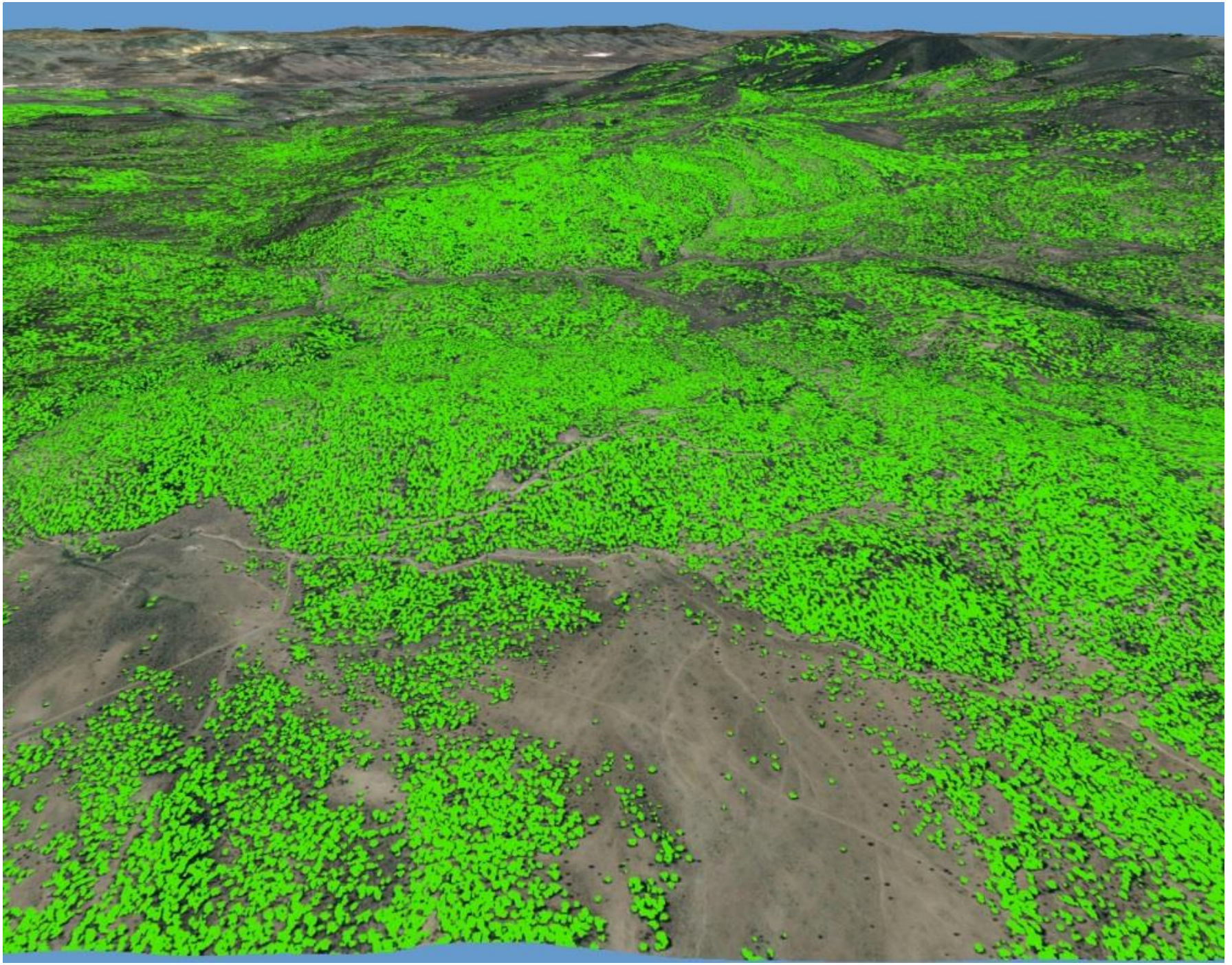
Move Fast (more common)

Die
Adult
Yearling*
Juvenile

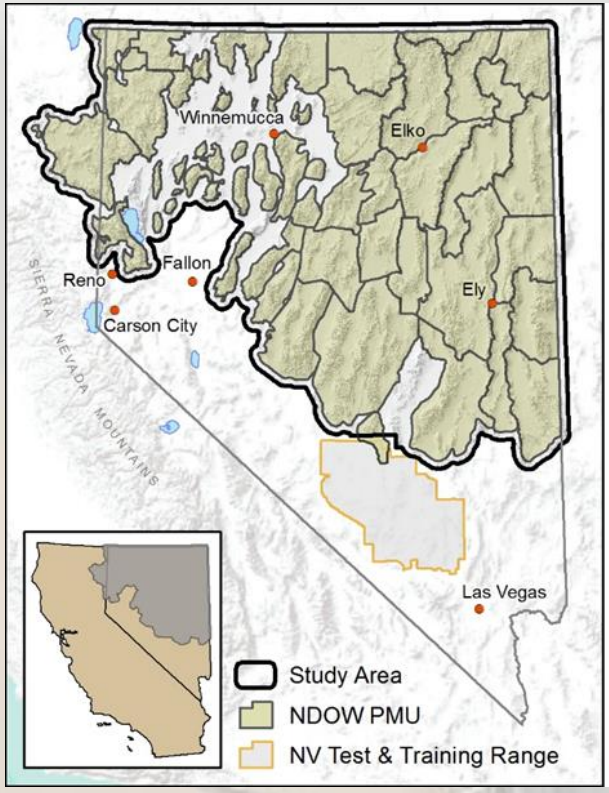
Conservation Planning for Informing Conifer Management

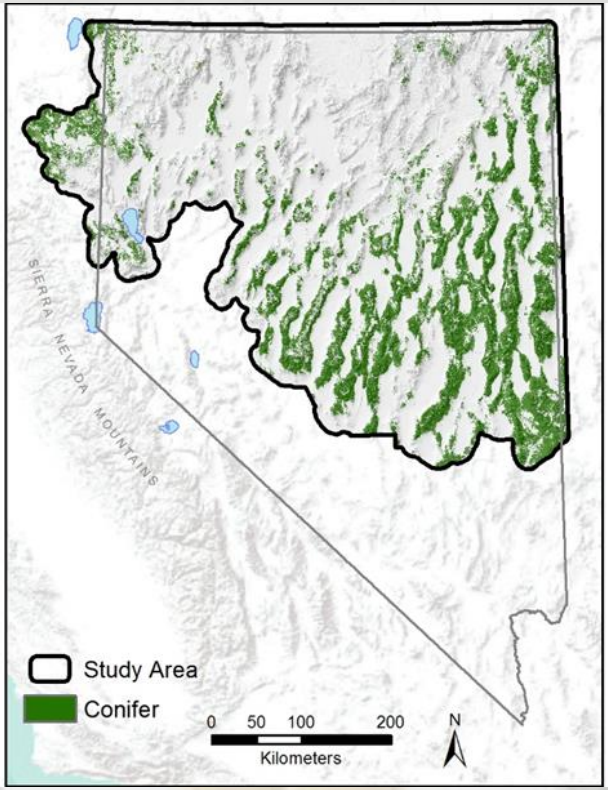
Course and Fine Resolutions Tools

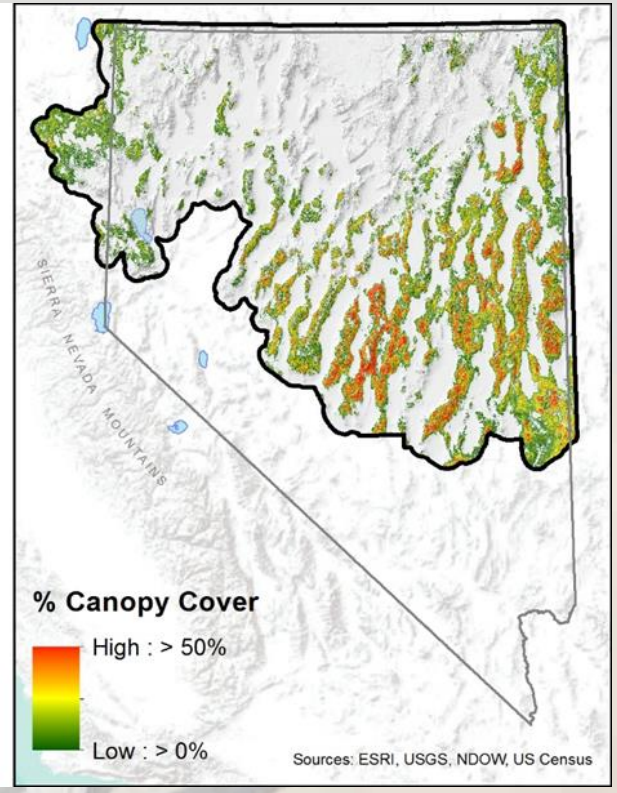


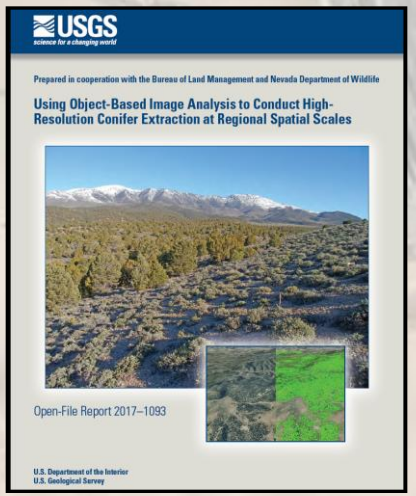


High resolution conifer mapping products



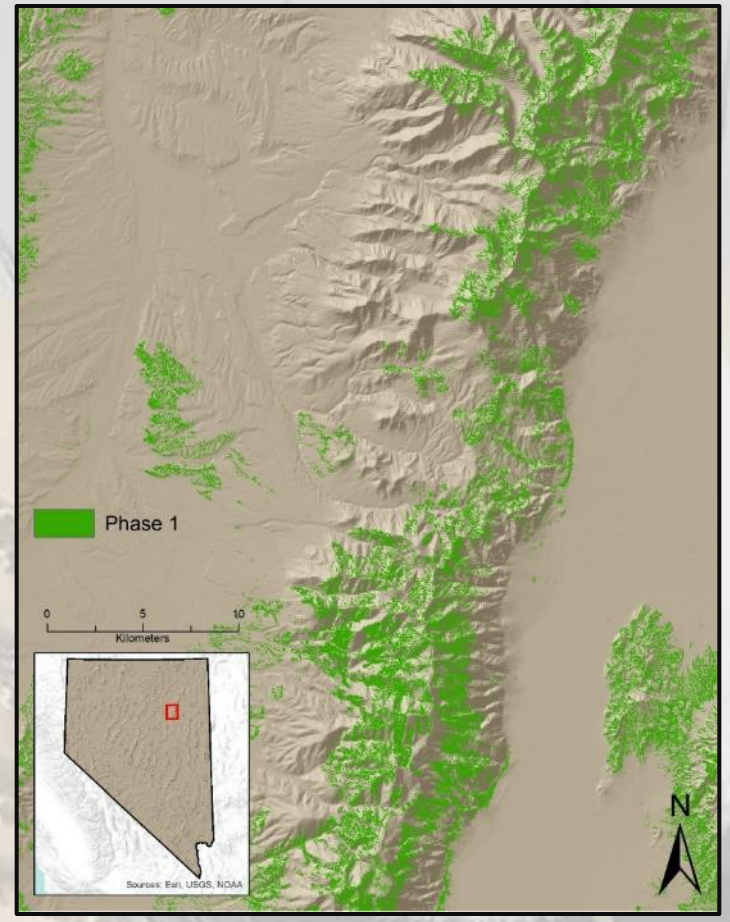






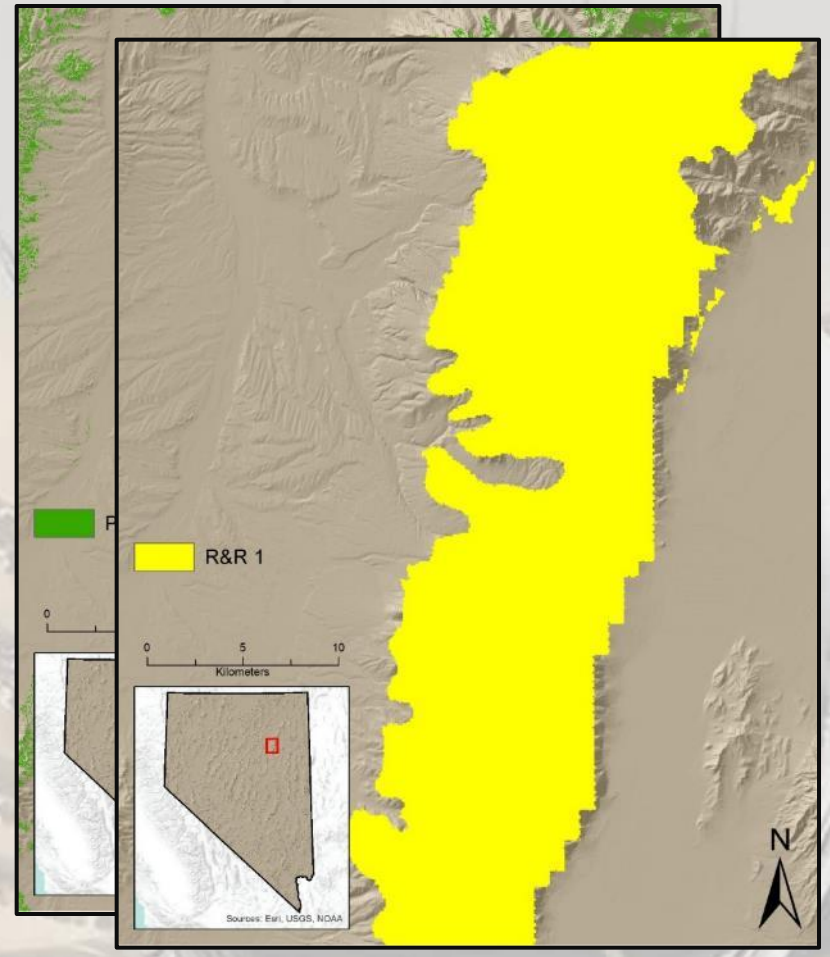
- Overall accuracy = 84.3% (field and image based)
- 1- m^2 and conifer class maps available for download at: https://www.sciencebase.gov/catalog/item/59160b60e4b044b359e32e67

Coarse Tools: Identifying Broad-Scale Ecological Traps



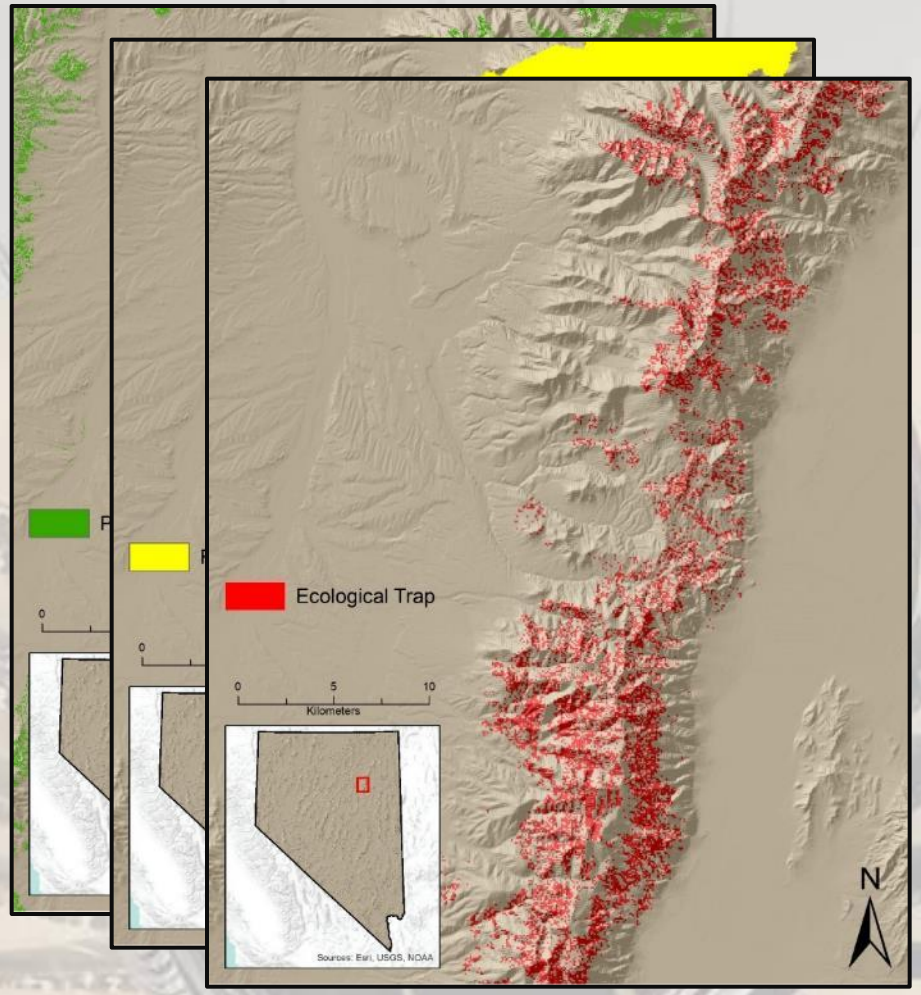
- *Step 1: Classify Map to represent ~ Phase 1 PJ (< 10% cover)*

Coarse Tools: Identifying Broad-Scale Ecological Traps



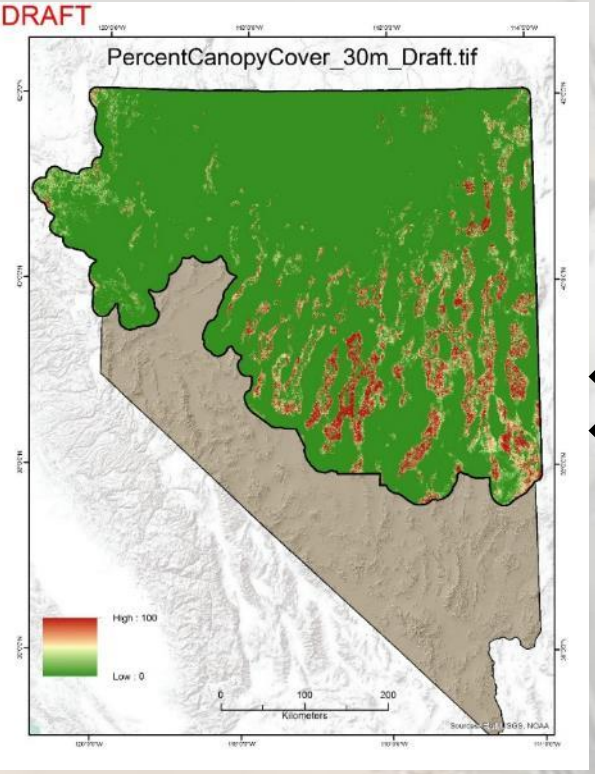
- *Step 2: Overlay map of High R&R (or other index of productivity)*

Coarse Tools: Identifying Broad-Scale Ecological Traps



Step 3: Intersect Phase 1 PJ With High R&R = Ecological Traps

Less Coarse Tools: Ecological Traps in Sage-Grouse Concentration Areas



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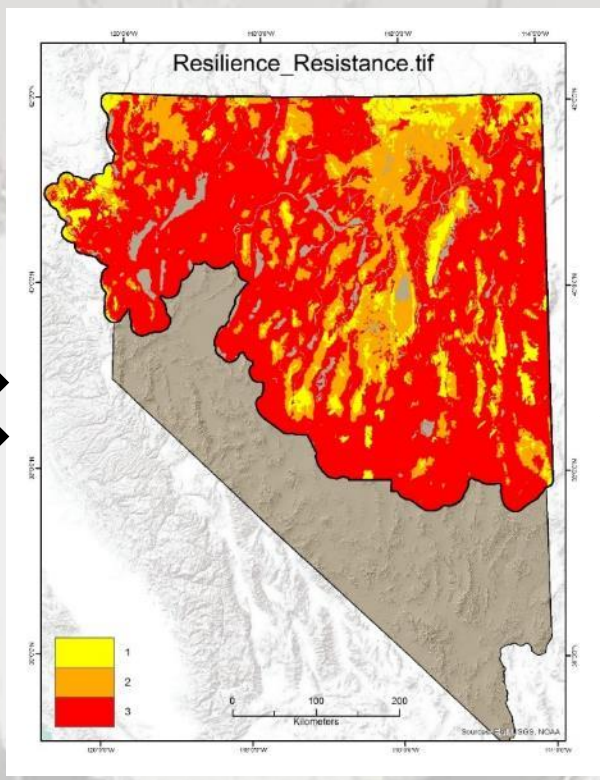

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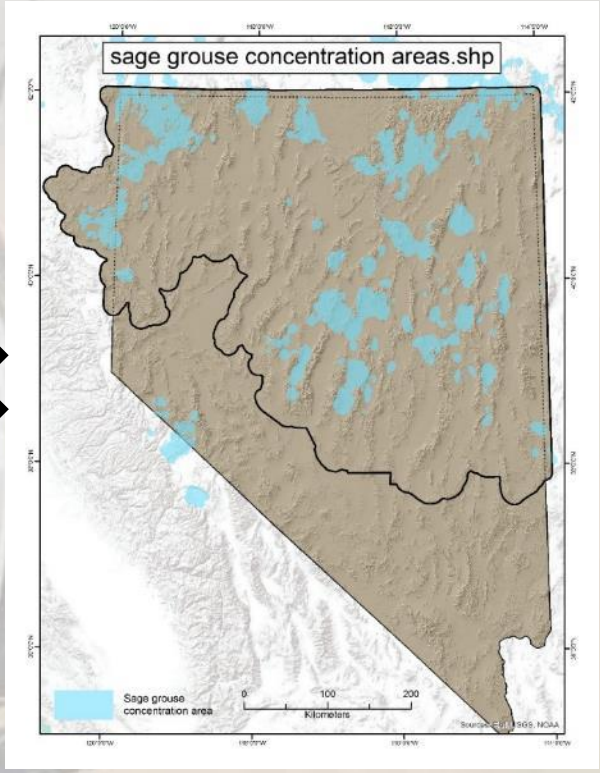
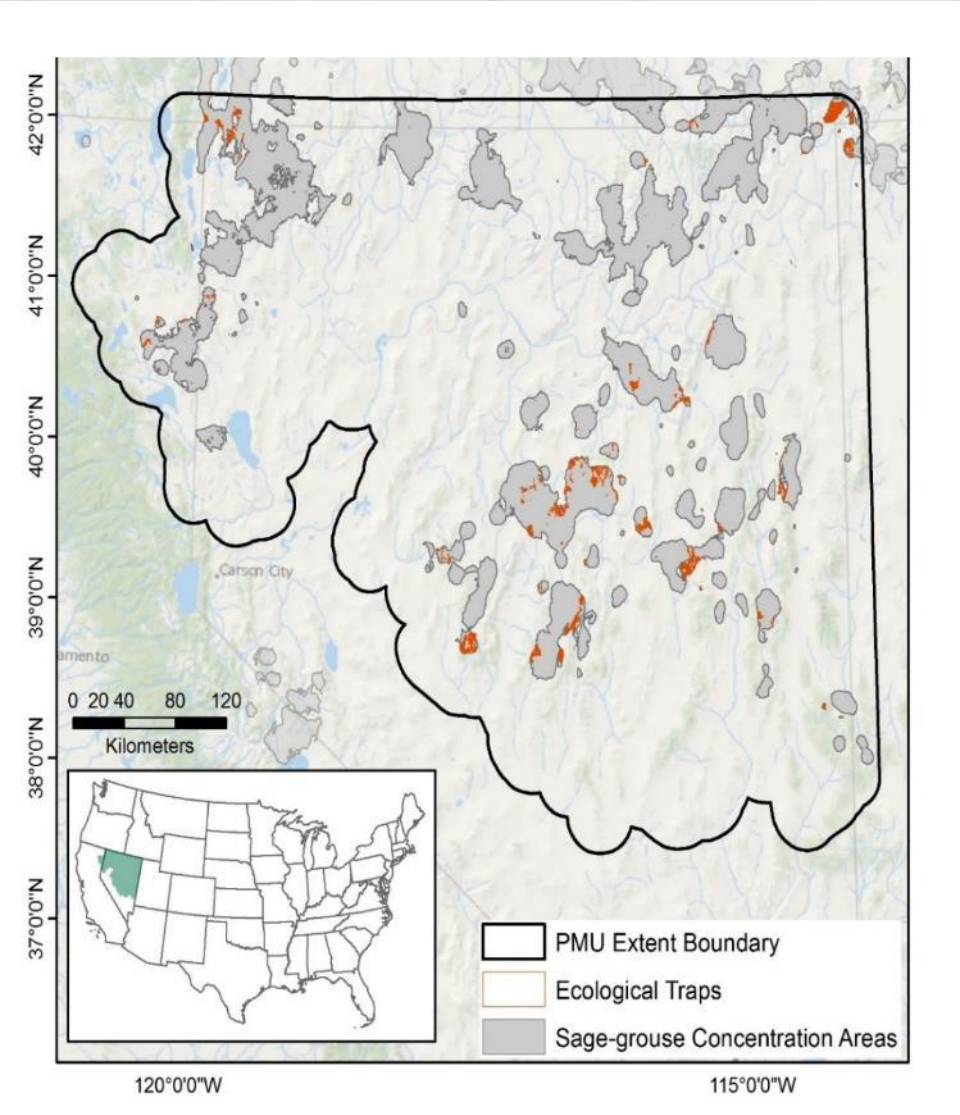
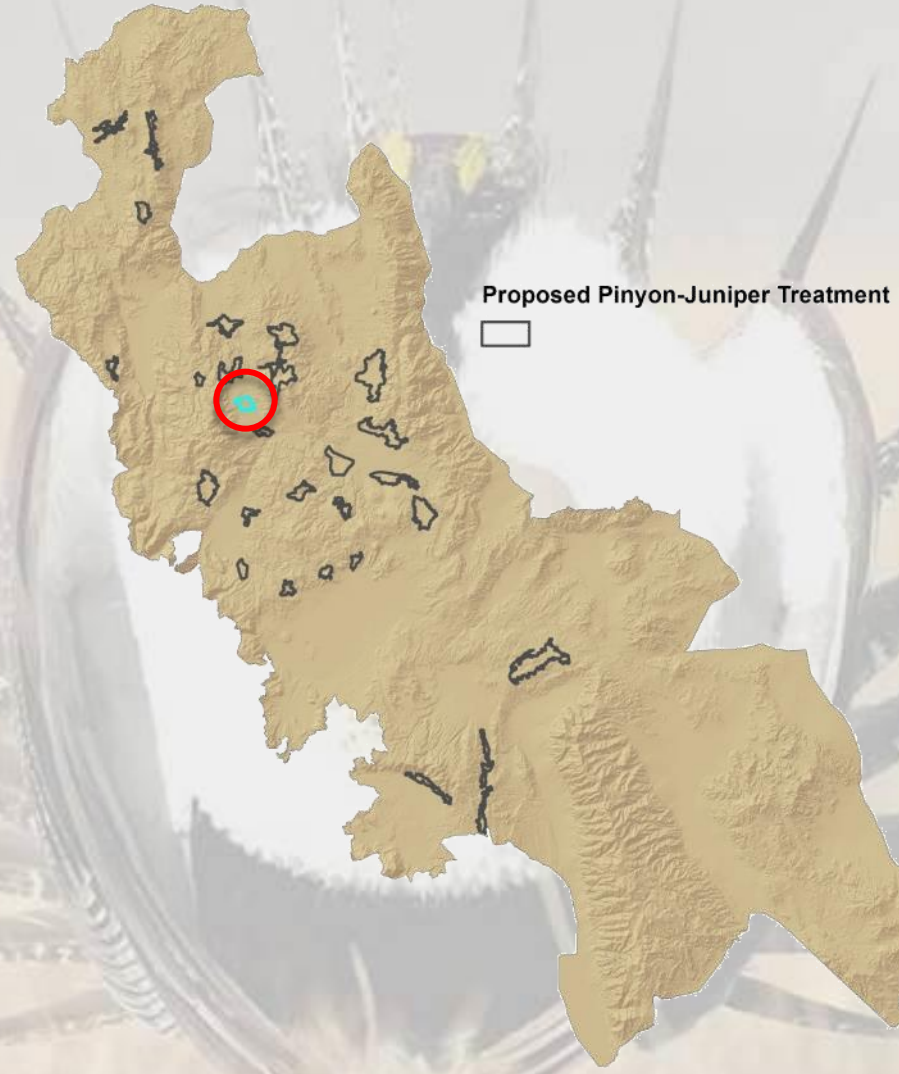
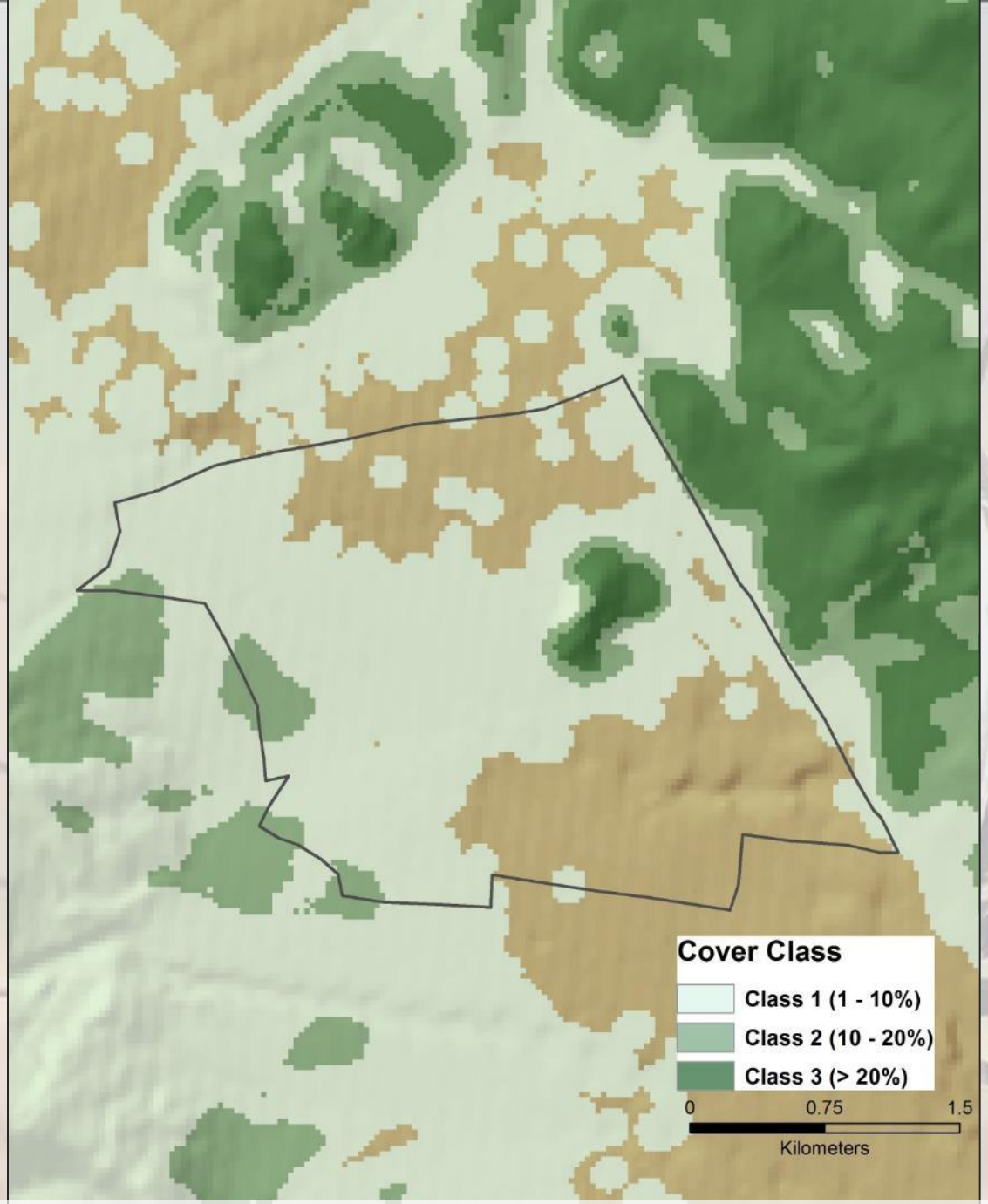


Less Coarse Tools: Ecological Traps in Sage-Grouse Concentration Areas



Finer Resolutions Tools for Ranking Restoration Areas (CPT)

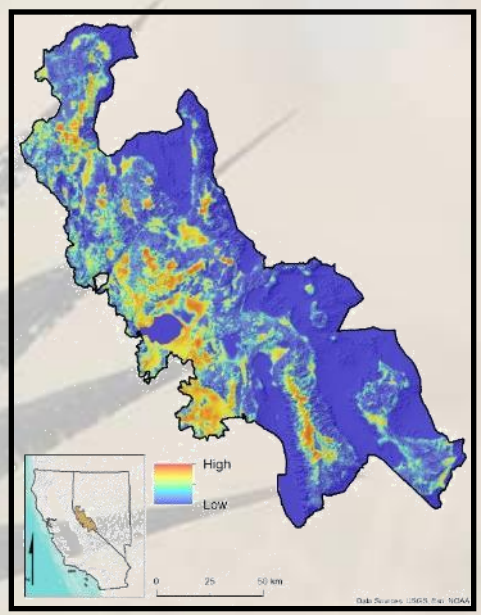




- **Classify into PJ Cover Classes:**
  - **CC1 ~ phase 1**
  - **CC2 ~ phase 2**
  - **CC3 ~ phase 3**

Ricca et al. In Press, Ecological Applications

- **Generate Baseline RSF surface (heat map) prior to simulated tree removal**



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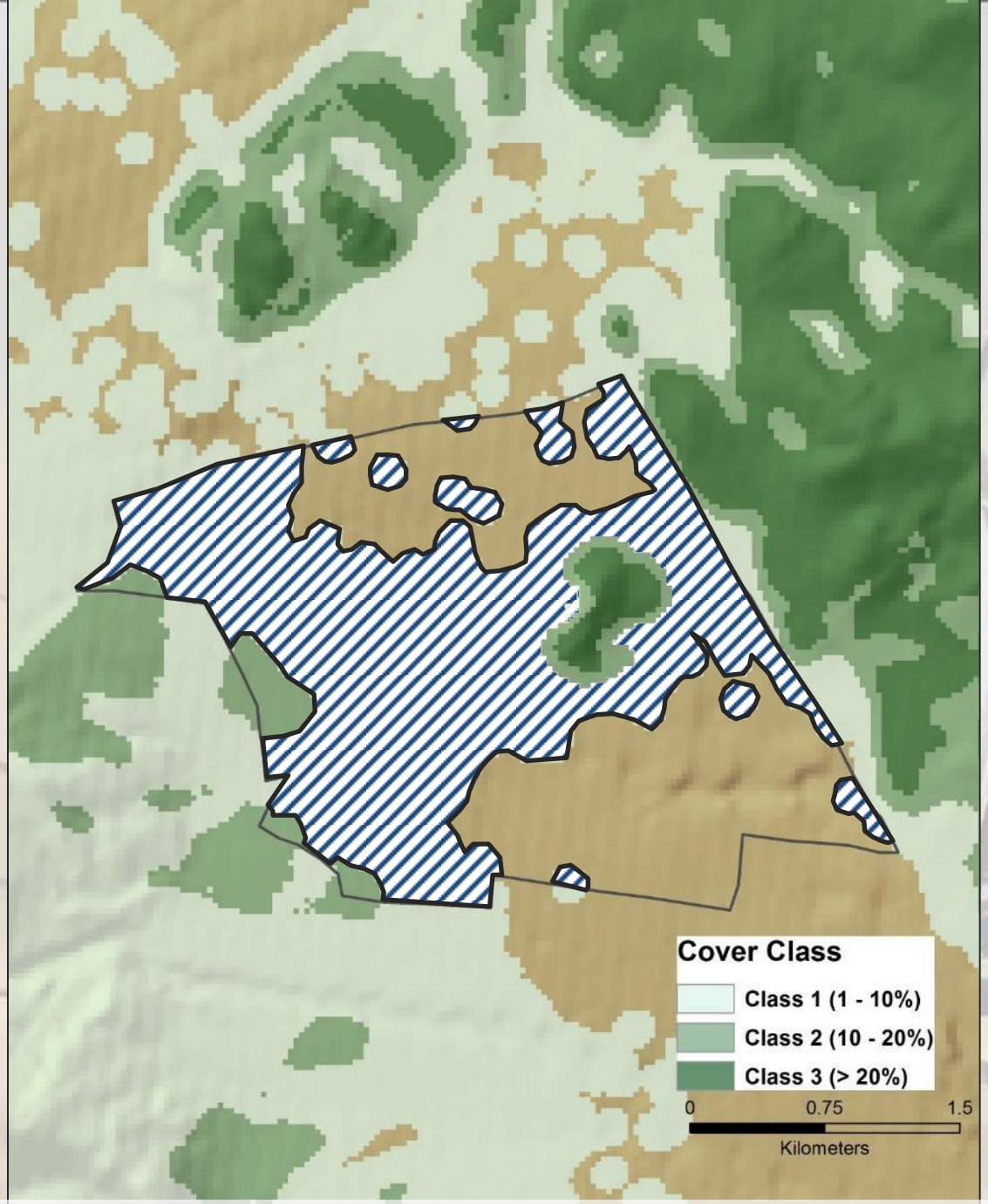
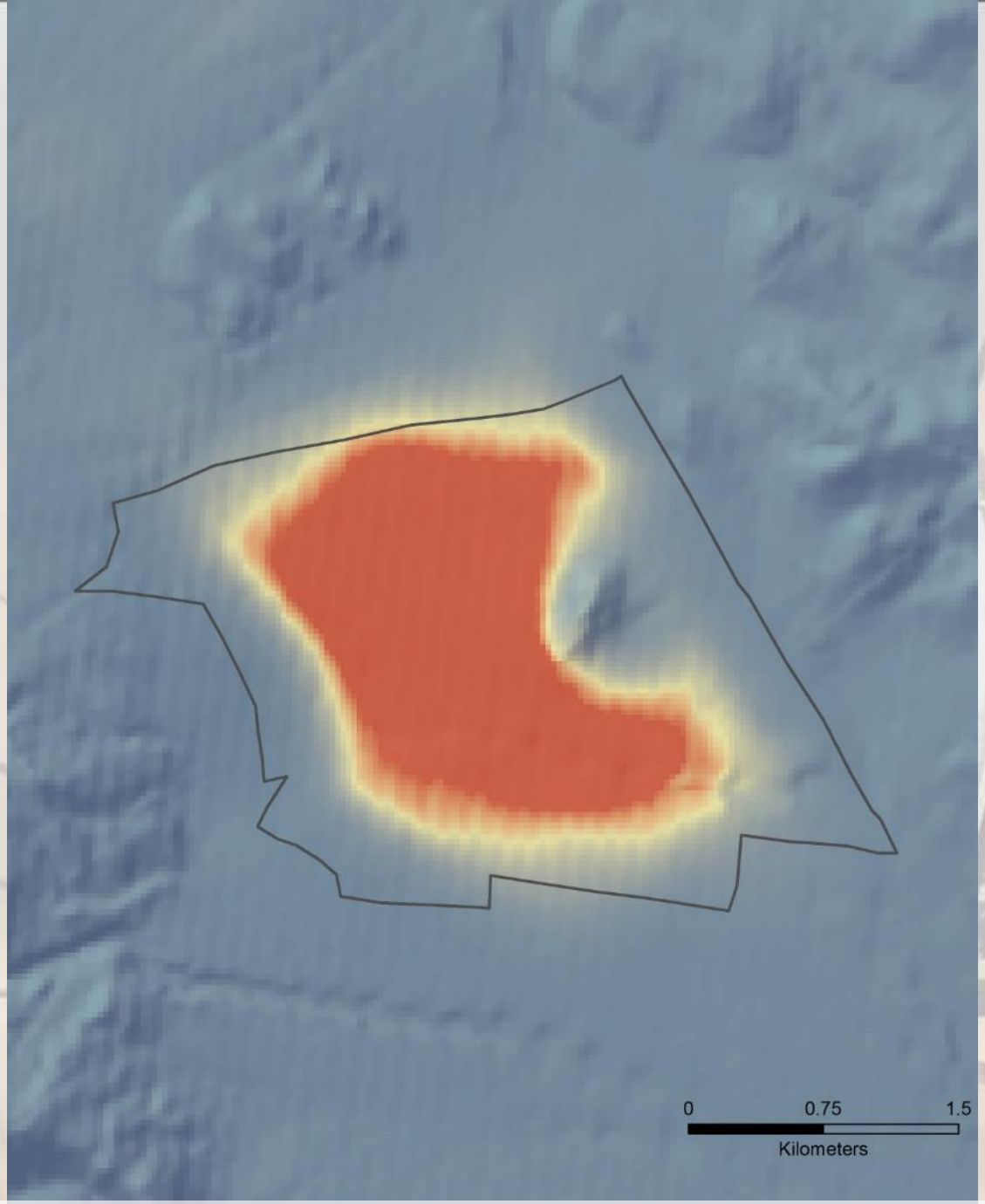


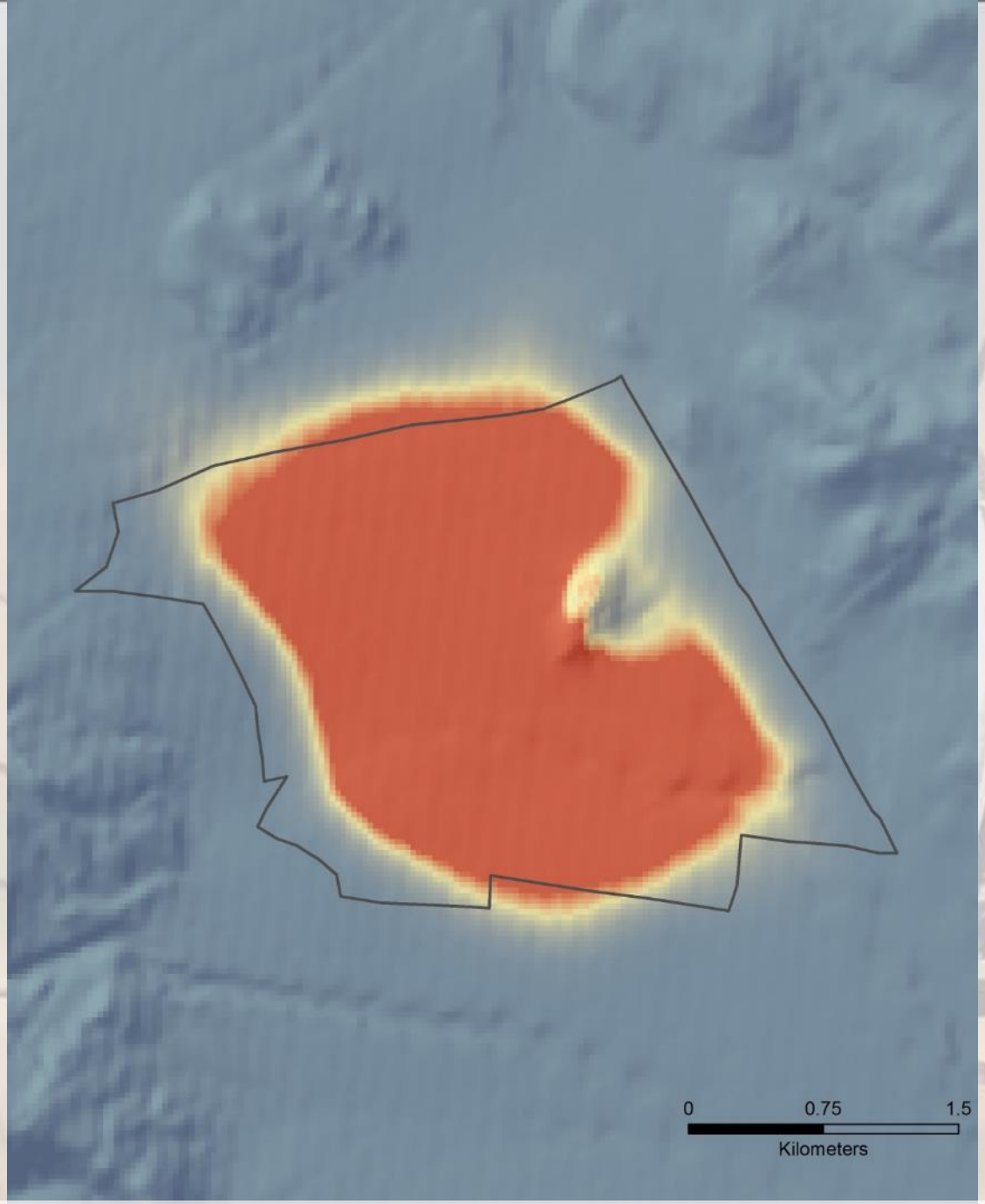
- **Simulate removal of PJ cover classes 1 (hashed area)**
- **Restore understory to sagebrush or nearby dominate cover type**

Ricca et al. In Press, Ecological Applications



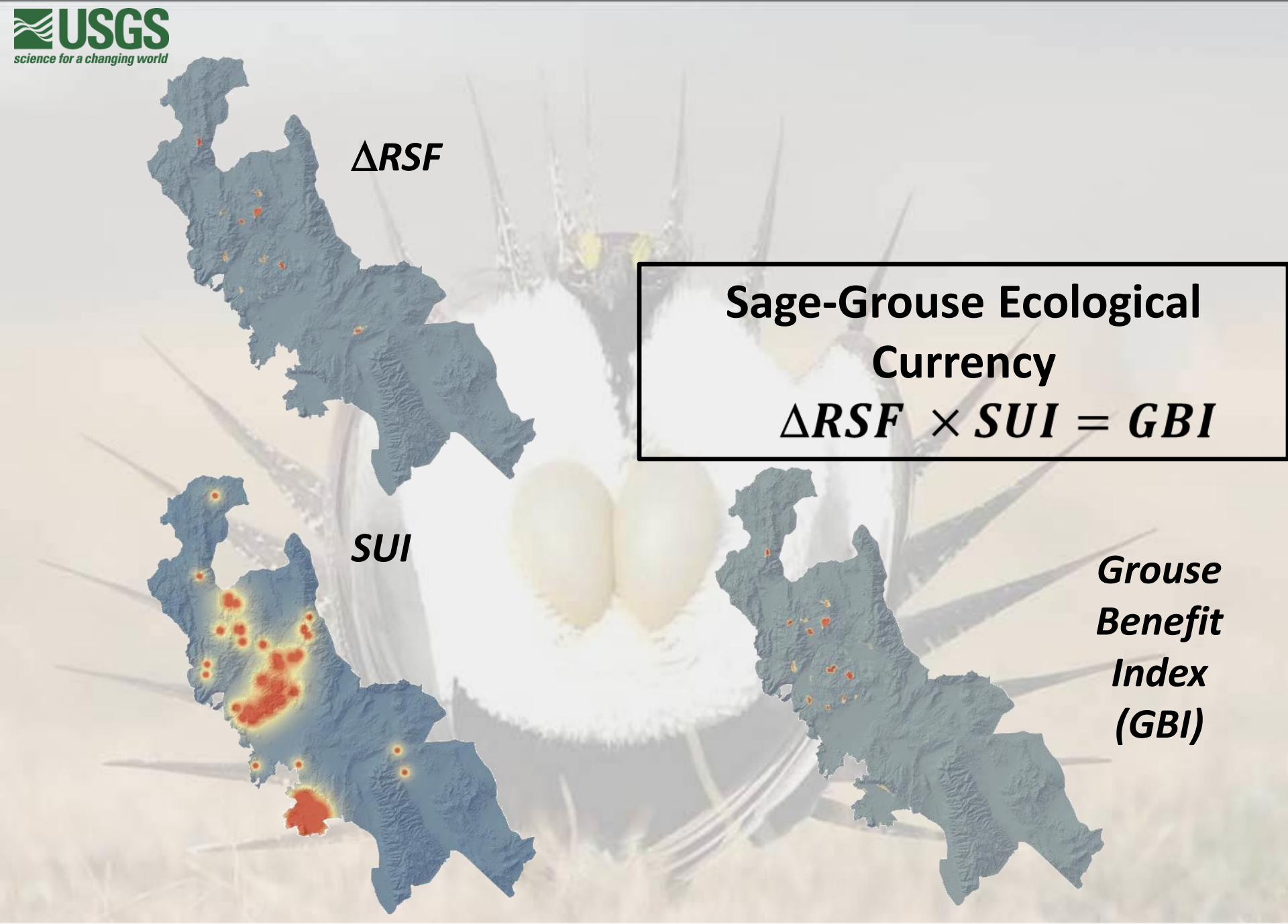
- **Re-generate RSF surface with Cover Class 1 removed and habitats restored**
- **Calculate Δ RSF (removal – baseline)**

Ricca et al. In Press, Ecological Applications



- **Multiply by a Space Use Index to calculate a 'Grouse Benefit Index'**
- **Ecological Currency for ranking proposed treatments**

Ricca et al. In Press, Ecological Applications



Sage-Grouse Ecological Currency

$$\Delta RSF \times SUI = GBI$$

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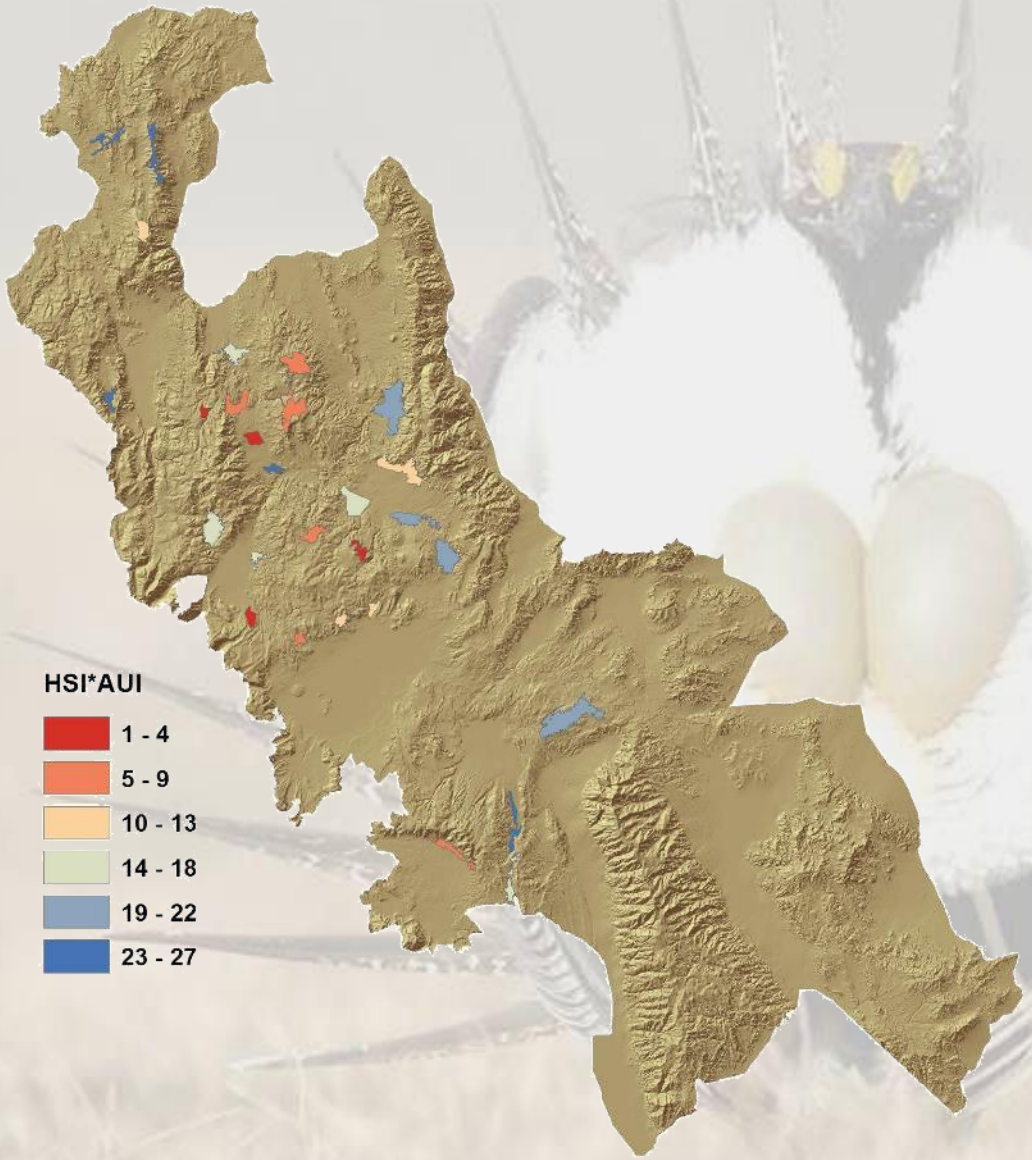
Conservation Planning Tool :

Simulate Predicted Outcomes and Quantify Predicted Sage-Grouse Performance



PJ Cut (ha)	Σ Cost	Rank (HSI* AUI)	GBI (HSI*AUI)	Total
182	$ 78,890	1	4.832	35%
257	$ 110,999	2	1.452	45%
92	$ 39,854	3	1.252	54%
108	$ 46,859	4	1.248	63%
444	$ 192,147	5	1.151	71%
-	-	-	-	-
-	-	-	-	-
117	$ 50,635	23	0.011	100%
284	$ 122,675	24	0.006	100%
110	$ 47,560	25	0.003	100%
322	$ 139,099	26	0.000	100%
182	$ 78,618	27	0.000	100%

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Articles

A conservation planning tool for greater sage-grouse using indices of species distribution, resilience, and resistance

Mark A. Ricca, Peter S. Coates, K. Benjamin Gustafson, Brianne E. Brussee, Jeanne C. Chambers, Shawn P. Espinosa, Scott C. Gardner, Sherri Lisius, Pilar Ziegler, David. J. Delehanty, Michael L. Casazza

Accepted manuscript online: 14 February 2018 Full publication history

DOI: 10.1002/eap.1690 View/save citation

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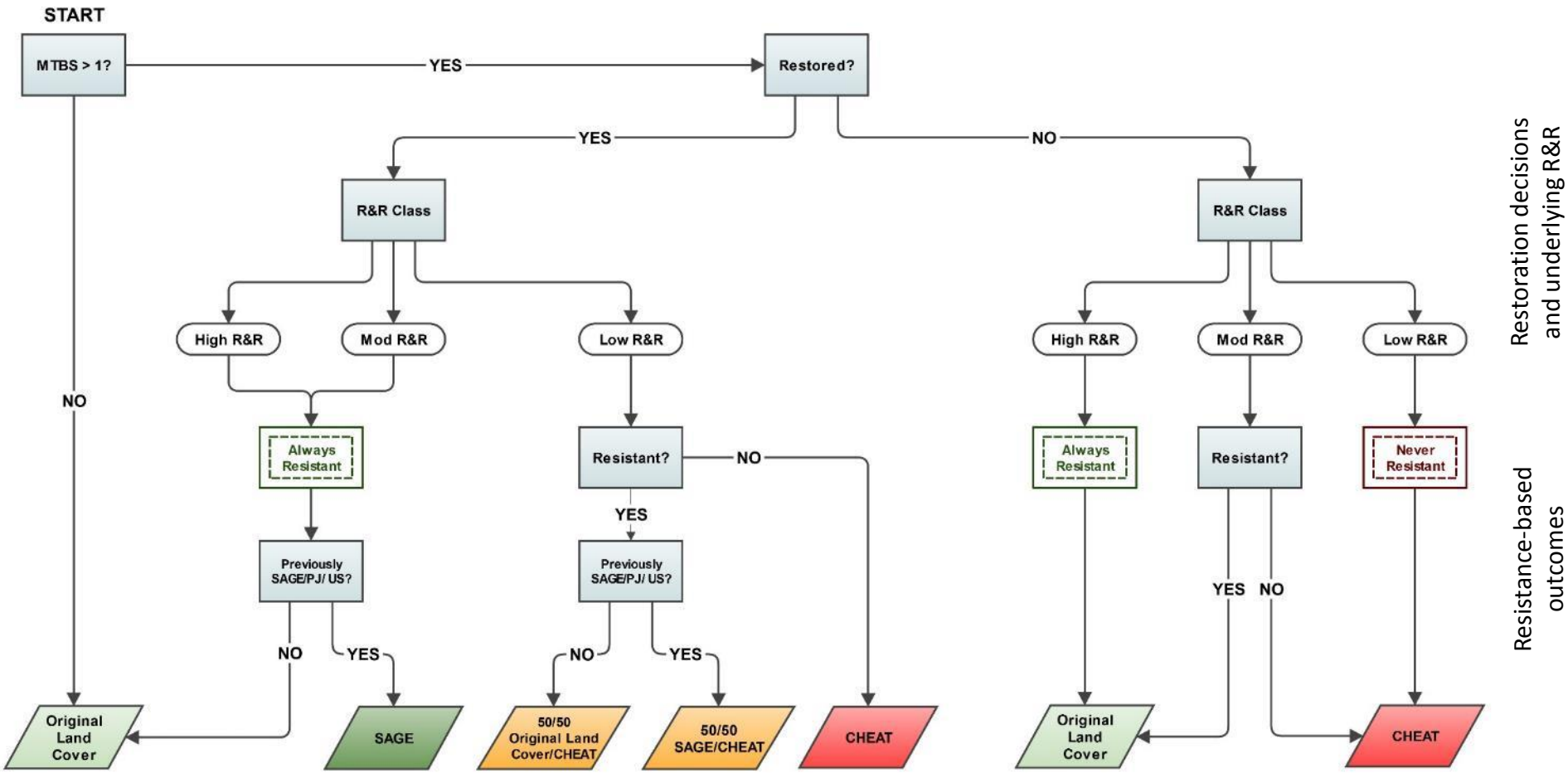
Ricca et al. In Press, Ecological Applications

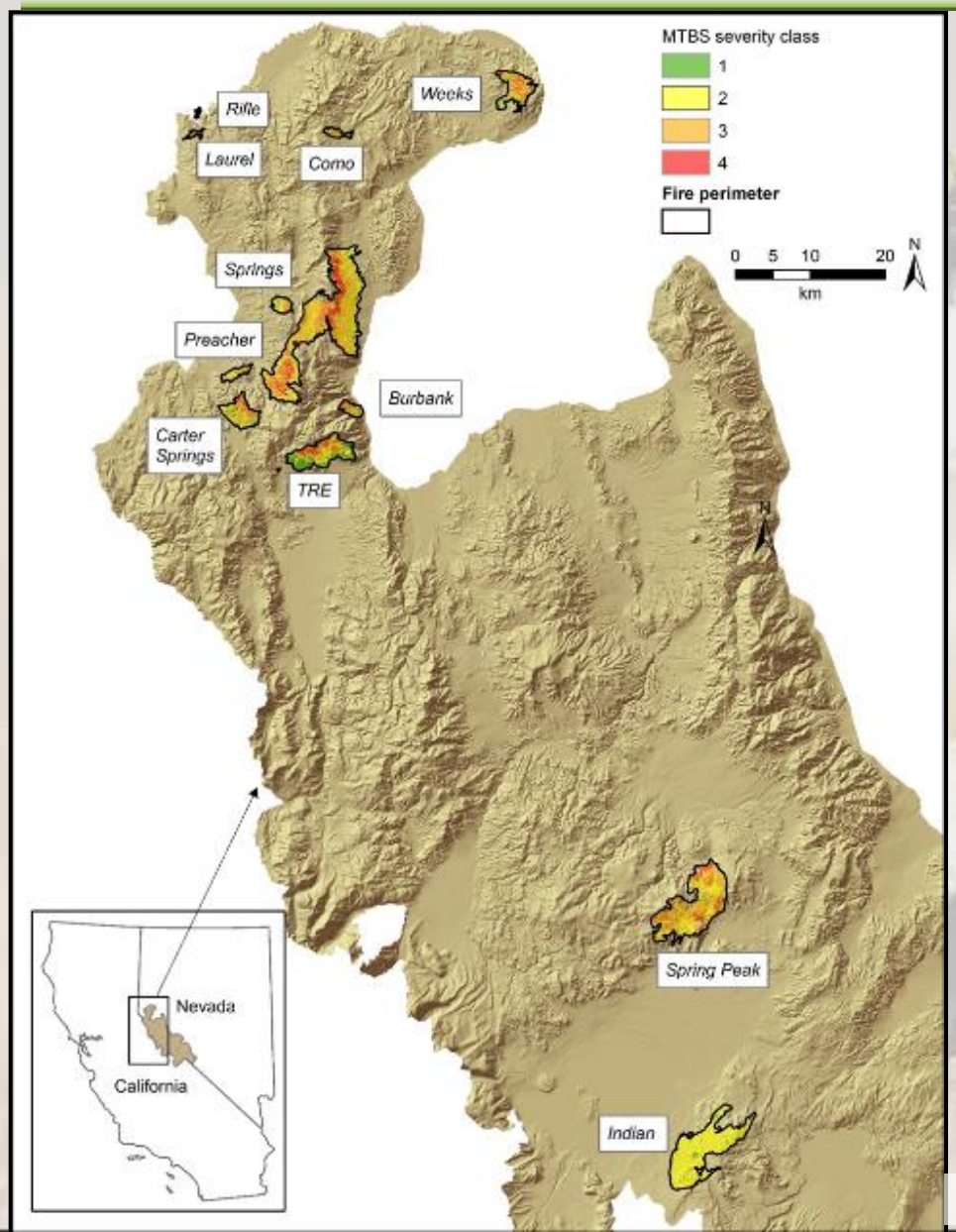
Conservation planning tool: Applications for fire restoration



Ricca et al., In Press; Ecological Application

Post-fire conservation planning tools

Identifying the 'best' burns to restore



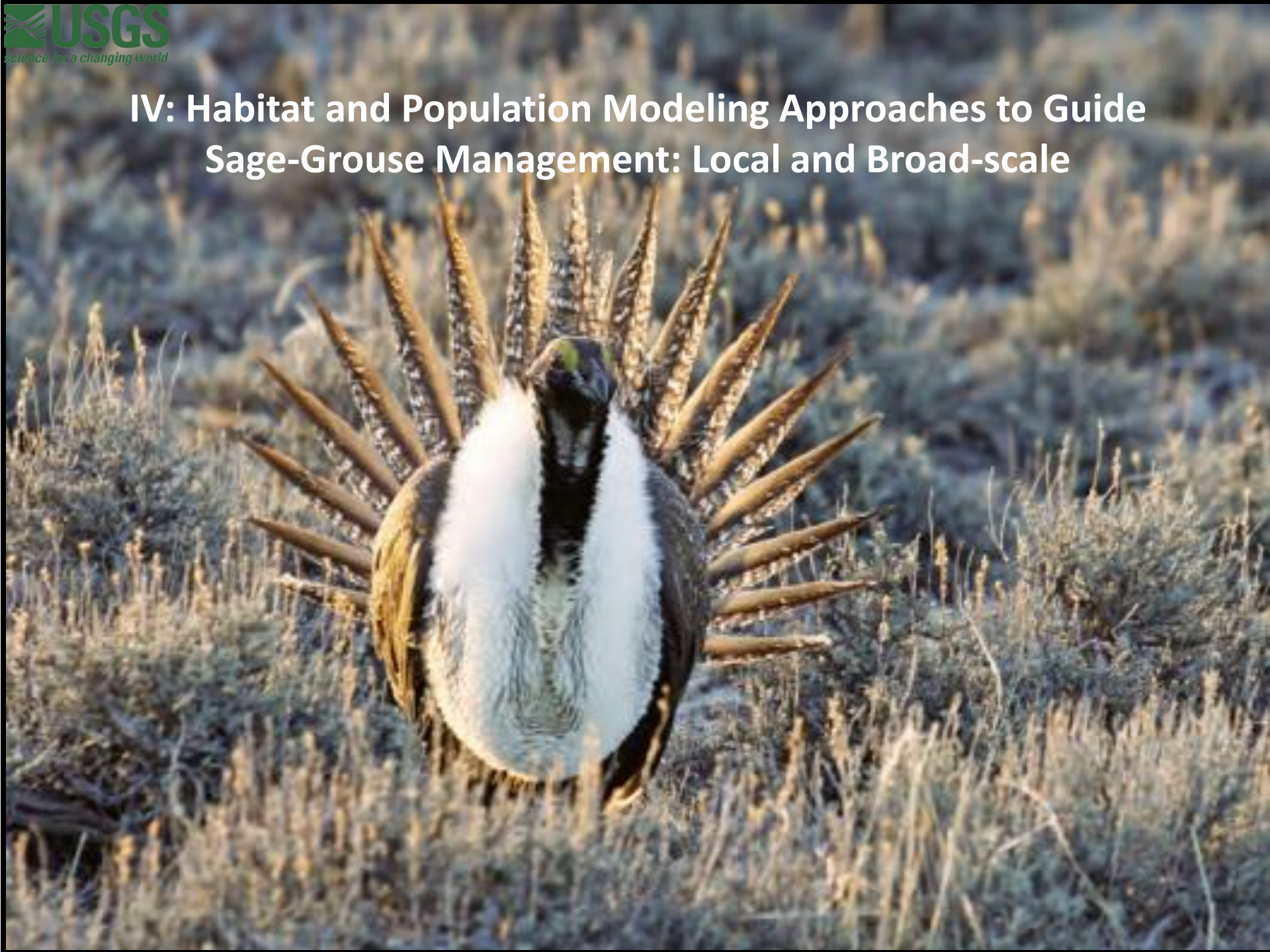
Fire	Area burned (ha)	Average ΔGBI / ha	Cumulative ΔGBI / ha	rank [a]
Spring Peak	5759	25.49	0.61	1 (1,1)
TRE	2471	8.75	0.81	2 (2,3)
Indian	5089	5.16	0.94	3 (3,2)
Como	311	0.96	0.96	4 (4,6)
Bison	9657	0.66	0.98	5 (5,4)
Carter Springs	1400	0.65	0.99	6 (6,5)
Burbank	450	0.19	1.00	7 (7,7)
Preacher	435	0.09	1.00	8 (8,8)
Springs	483	0.07	1.00	9 (9,9)
Laurel	130	0.00	1.00	10 (10,10)
Rifle	50	0.00	1.00	11 (11,11)
Weeks	1563	0.00	1.00	12 (12,12)

Ricca et al. In Press, Ecological Applications

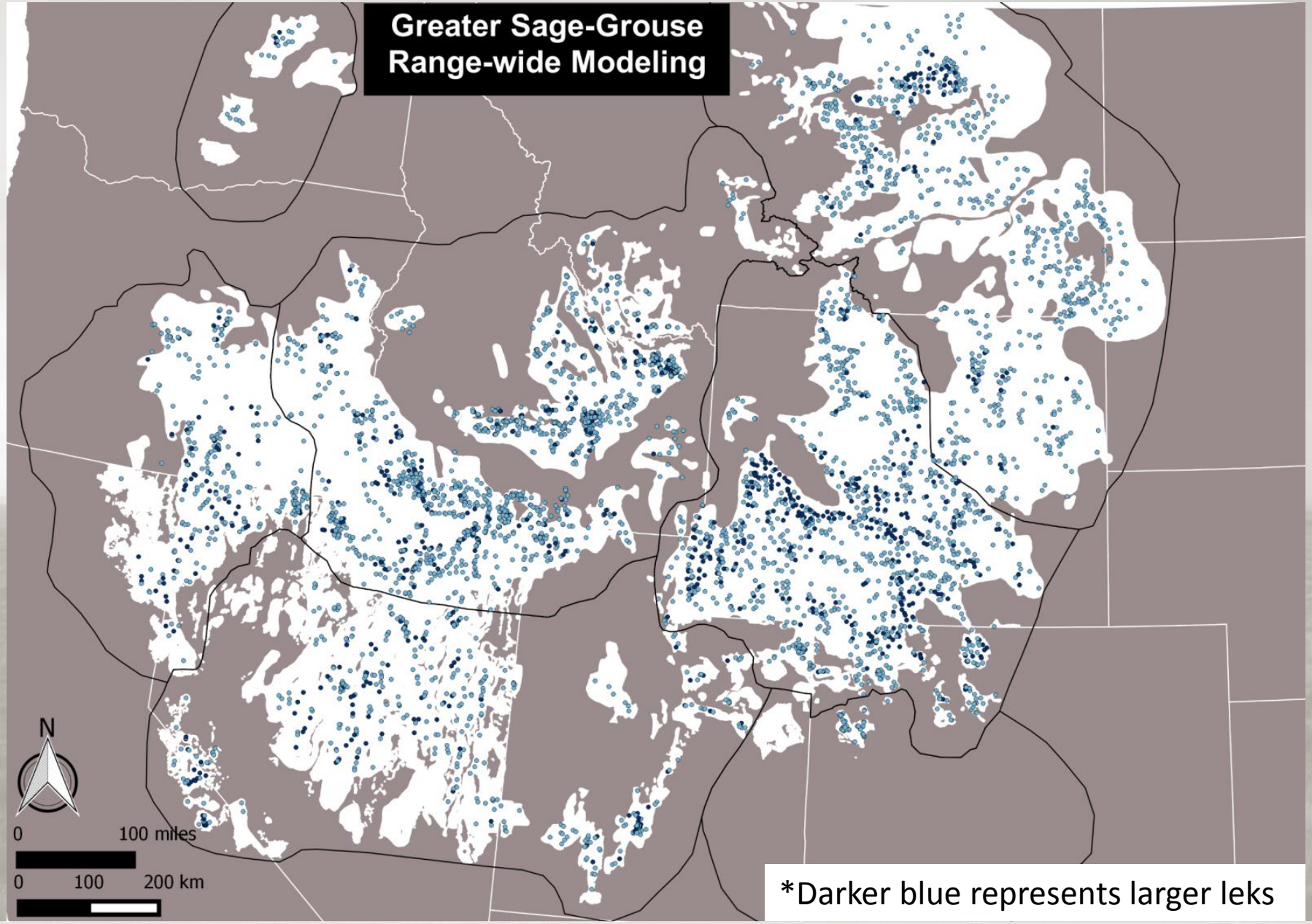
Conifer Effects and Science Tools: Take Home

- Increasing body of work quantifies liked effects of pinyon-juniper on sage-grouse behavioral choices and population dynamics
  - Patterns: Low cover (< 2%) PJ impacts lek persistence
  - Processes: Individual variation in PJ avoidance and fitness consequences → ecological traps with habitat productivity
  - Mechanisms: PJ alteration of movements with fitness consequences varies by age and experience.
- Translate into Management:
  - Models support reducing actual pinyon-juniper cover < 2%.
  - Integrate into multi-scale conservation planning tools

IV: Habitat and Population Modeling Approaches to Guide Sage-Grouse Management: Local and Broad-scale



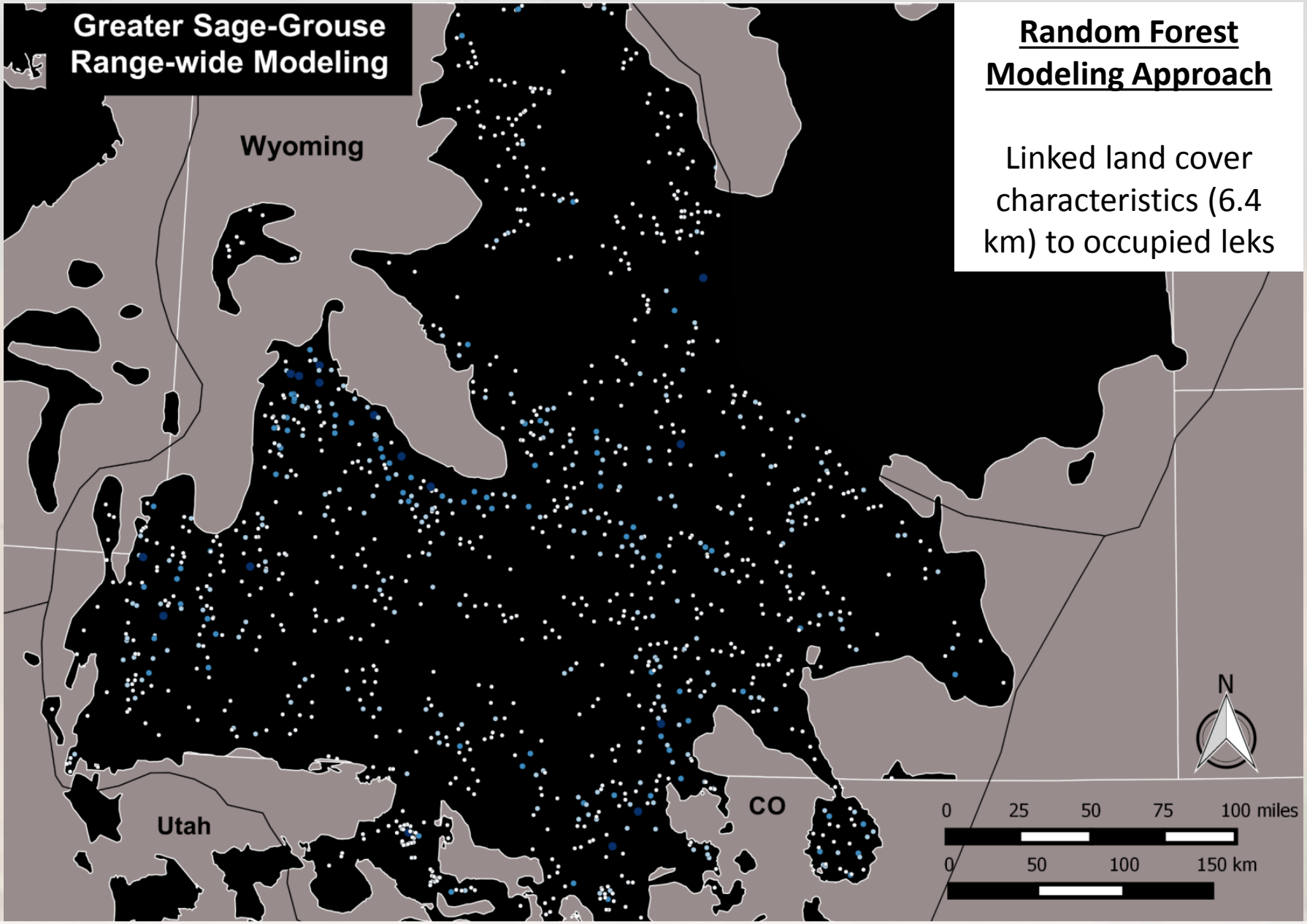
Modeling GRSG Breeding Habitat Using Lek Sites



*Darker blue represents larger leks

Doherty et al. 2016

GRSG Breeding Habitat Model (Example Area)

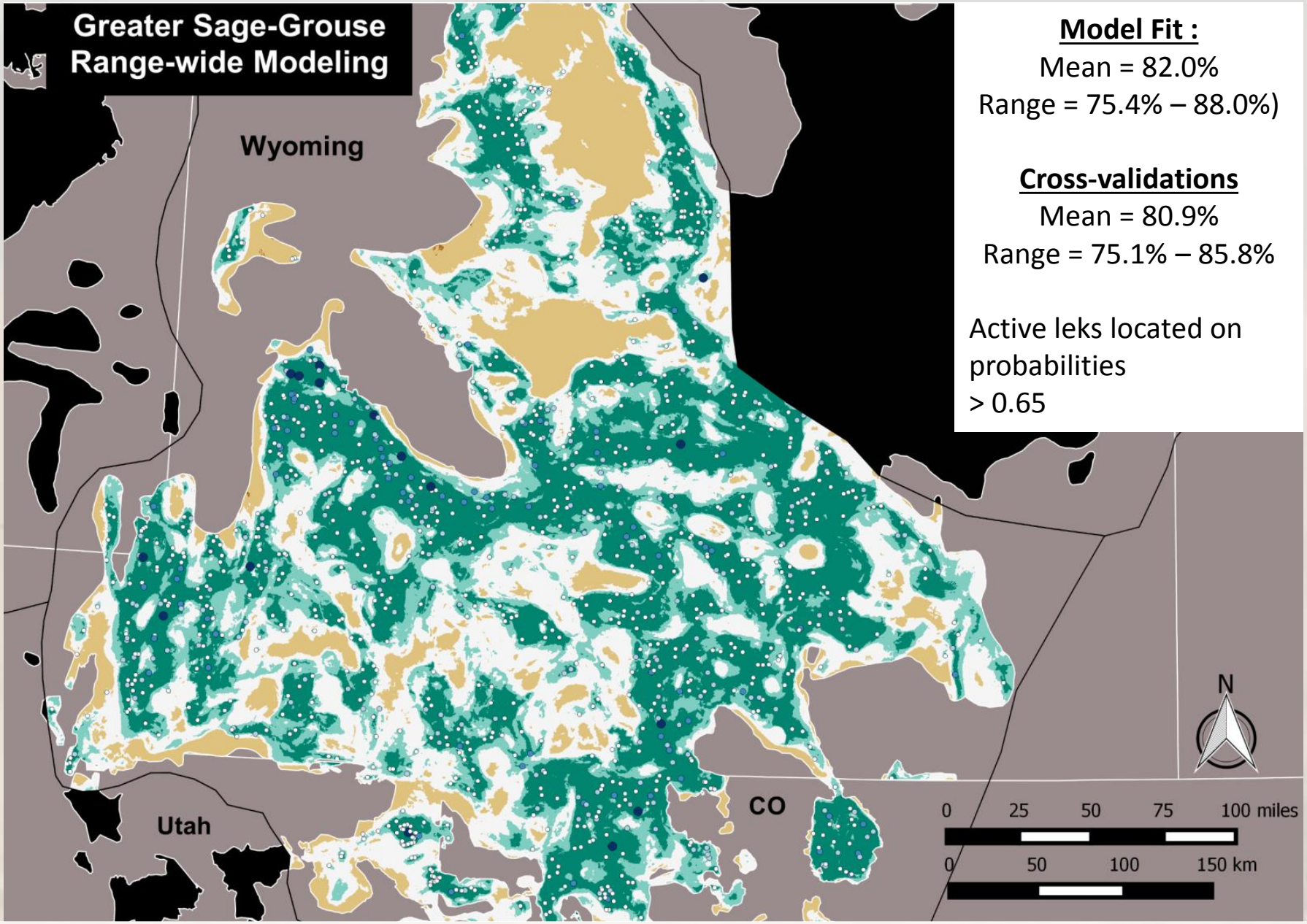


Random Forest Modeling Approach

Linked land cover characteristics (6.4 km) to occupied leks

Doherty et al. 2016

GRSG Breeding Habitat Model (Example Area)



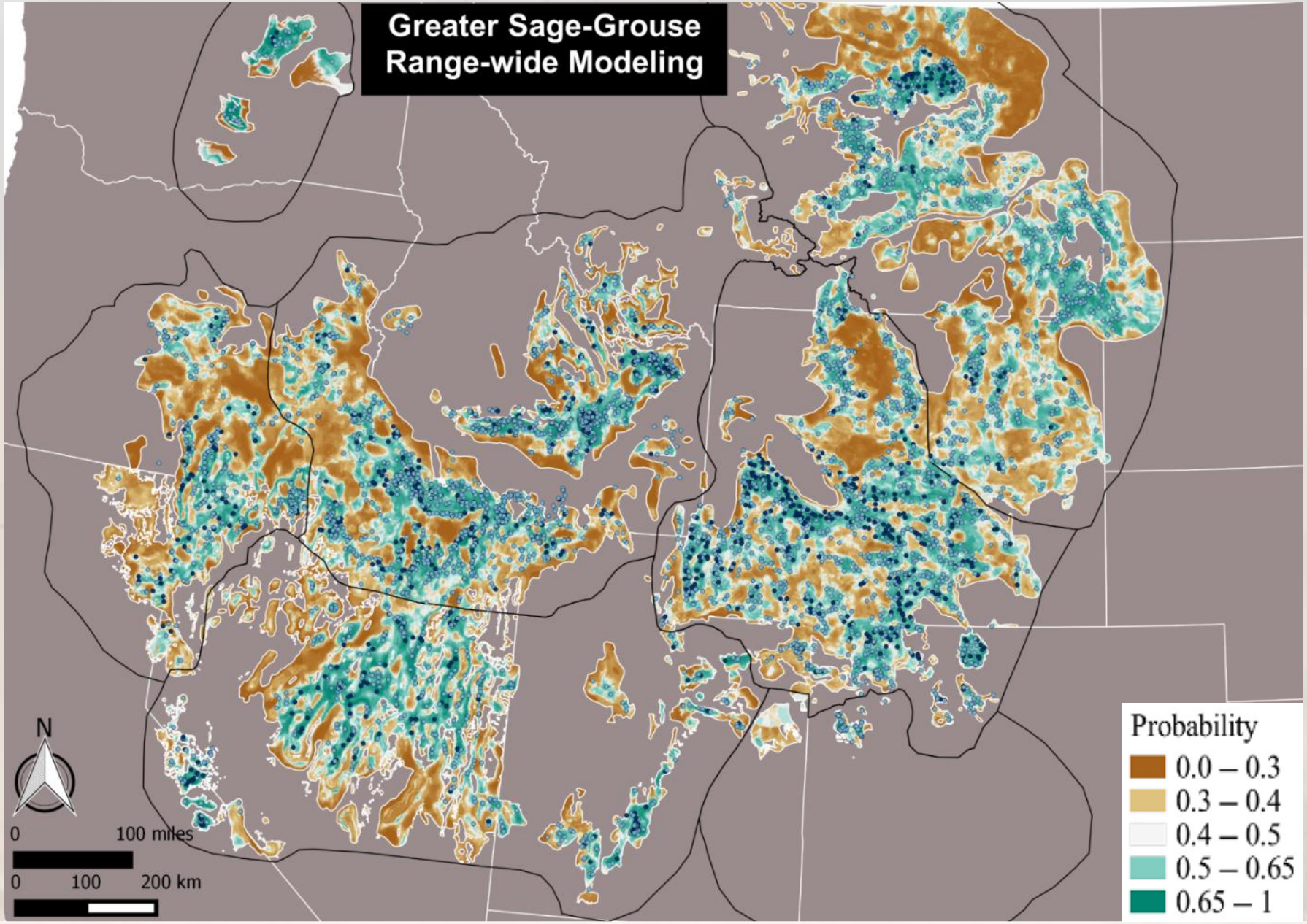
Model Fit :
Mean = 82.0%
Range = 75.4% – 88.0%)

Cross-validations
Mean = 80.9%
Range = 75.1% – 85.8%

Active leks located on probabilities
> 0.65

Doherty et al. 2016

Lek-based Breeding Habitat Model



Doherty et al. 2016

Variation in Functional Responses among MZs

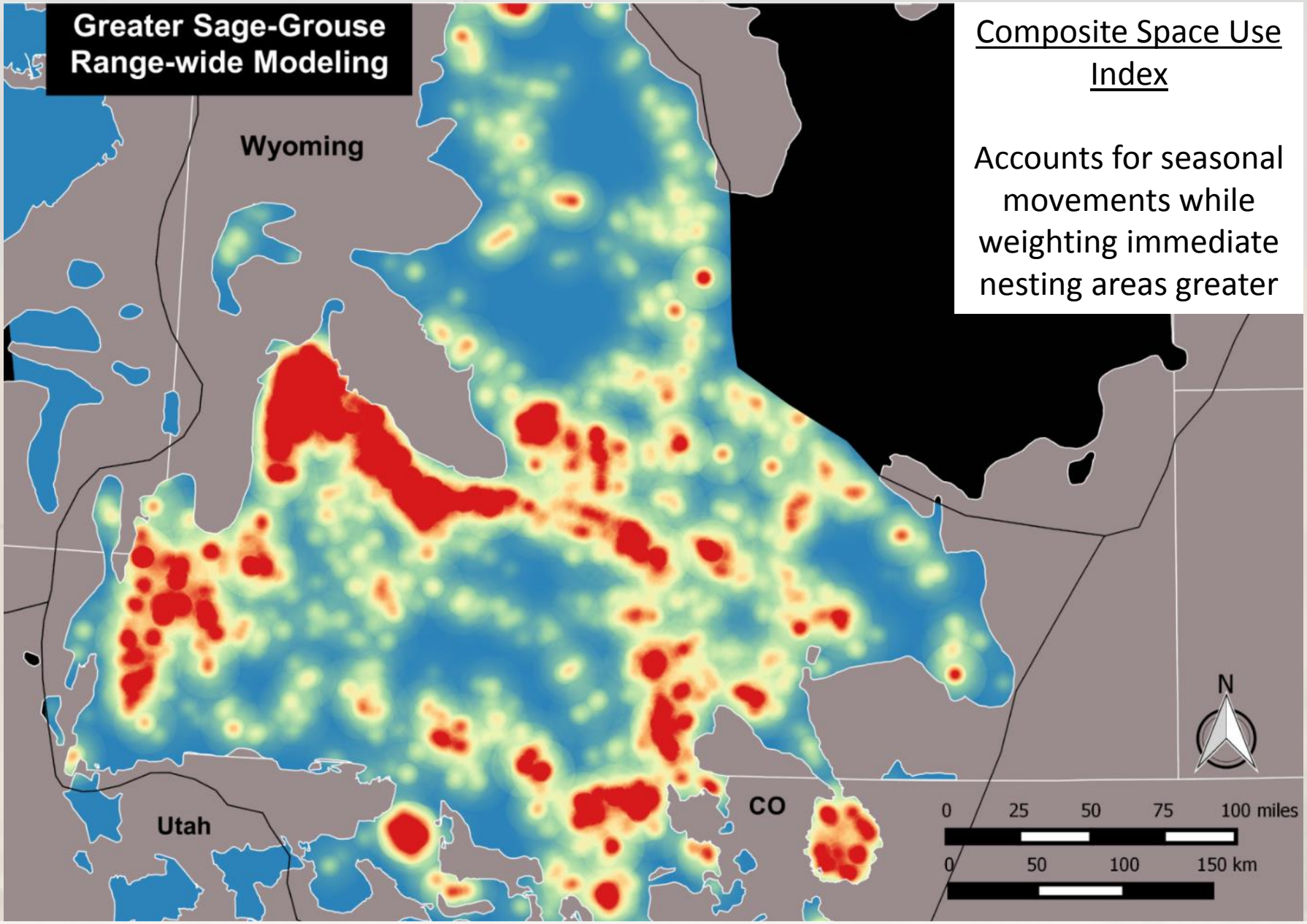
Management zone	Variable				
	1st	2nd	3rd	4th	5th
Northern Great Plains	Conifer cover (-)	All sagebrush	Roughness (-)	Topo wetness index	Primary production
Wyoming Basin	All sagebrush	Conifer cover (-)	Drought index (-)	Days > 5°C	Mean annual precipitation
Southern Great Basin	All sagebrush	Days > 5°C	Elevation	Drought index (-)	Conifer cover (-)
Snake River Plain	Conifer cover (-)	Drought index (-)	All sagebrush	Days > 5°C	Primary production
Northern Great Basin	All sagebrush	Drought index (-)	Low sagebrush	Annual precipitation	Days > 5°
Columbia Basin	Elevation	Days > 5°C	Grassland/herb	Drought index (-)	All sagebrush
Colorado Plateau	All sagebrush	Low sagebrush	Human Dist. (-)	Oil and gas wells (-)	

Variation in functional habitat selection relationships across range

- **In general, sage-grouse avoided conifer and selected contiguous tracts of sagebrush but strength of avoidance and selection varied across range**
- **Conifer avoidance most important in NGP and SRP and less important in SGB**
- **Human disturbance and oil and gas wells important in CP**

Doherty et al. 2016

Accounting for Abundance (Example Area)

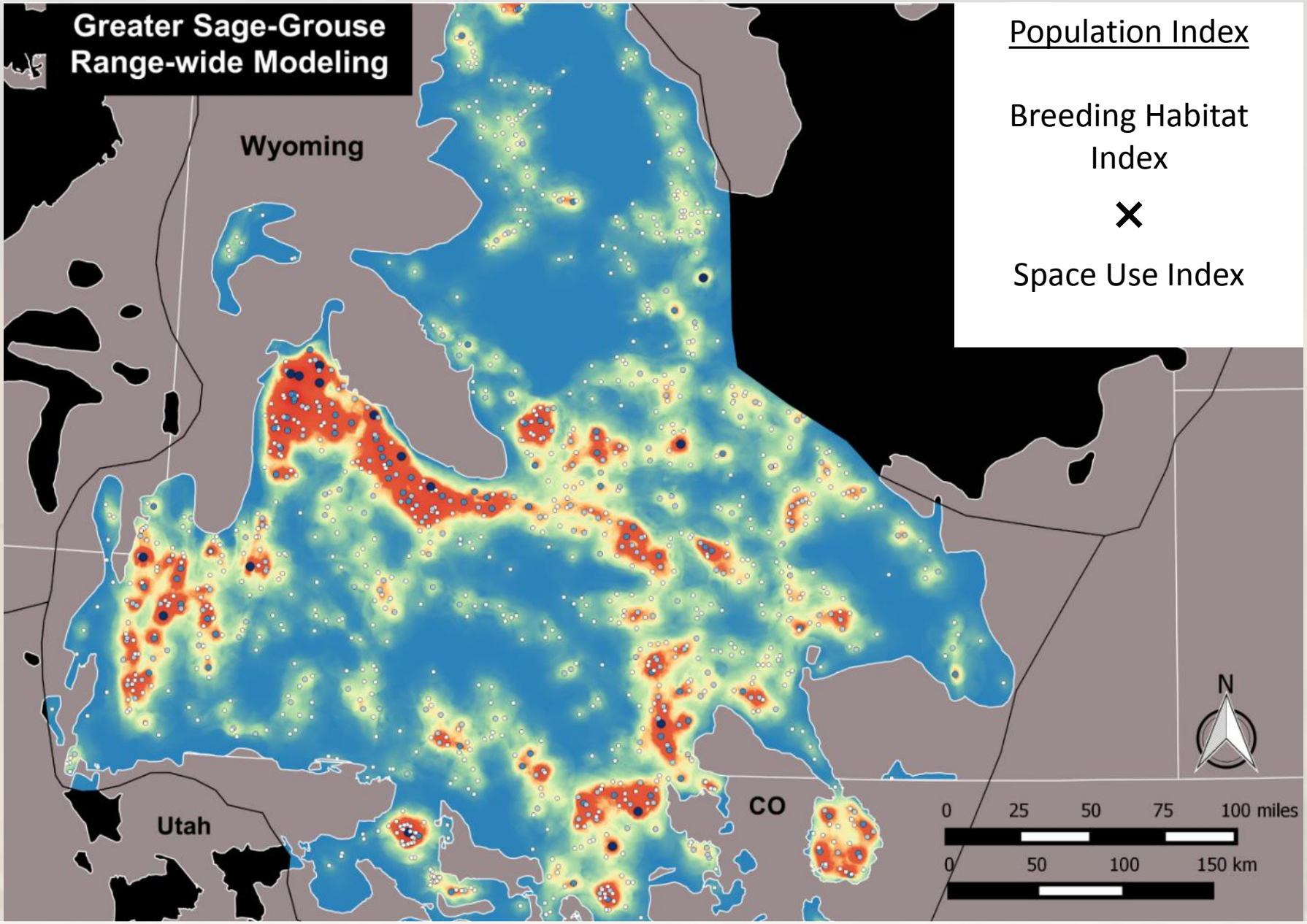


Composite Space Use Index

Accounts for seasonal movements while weighting immediate nesting areas greater

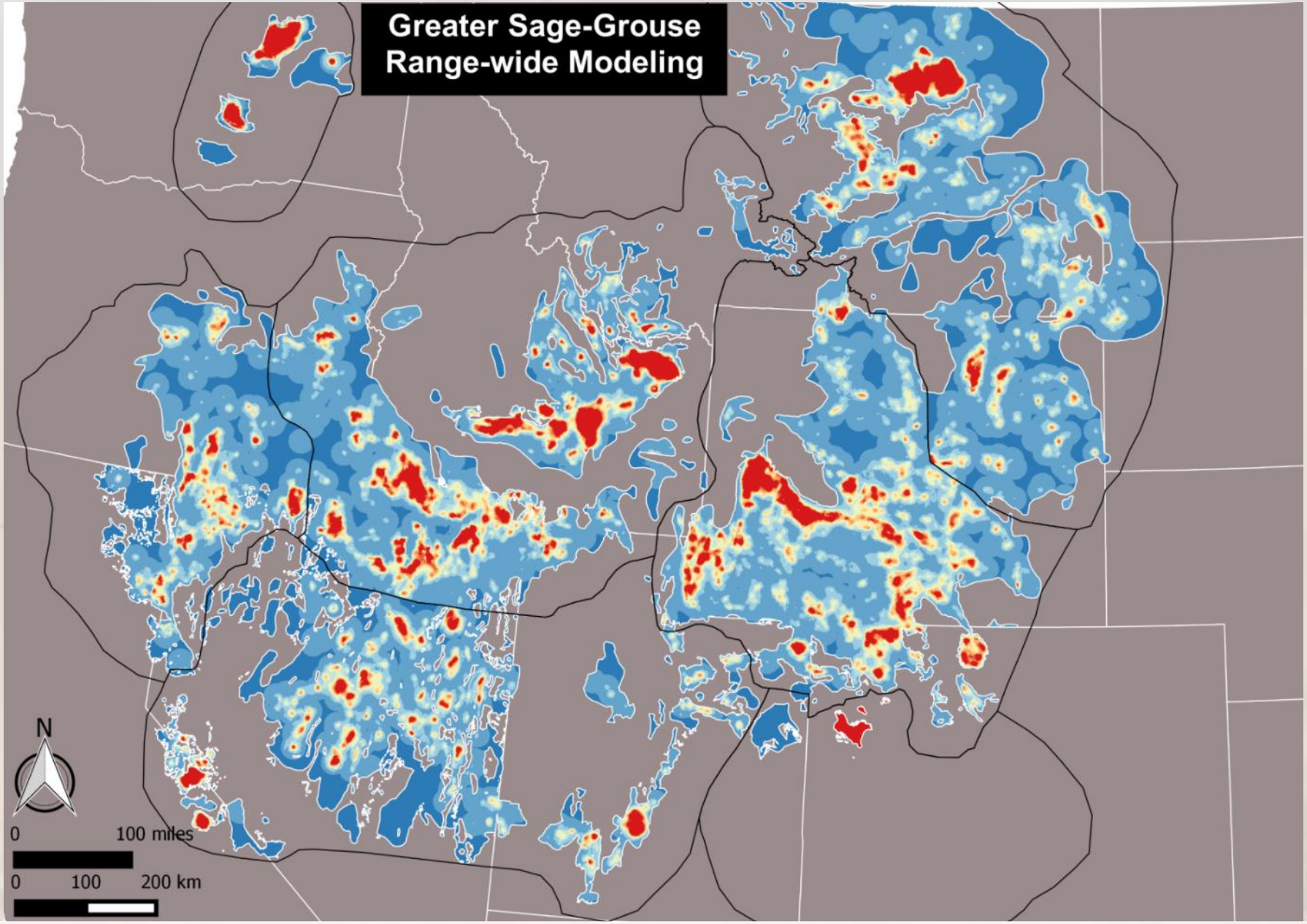
Doherty et al. 2016

GRSG Population Model (Example Area)



Doherty et al. 2016

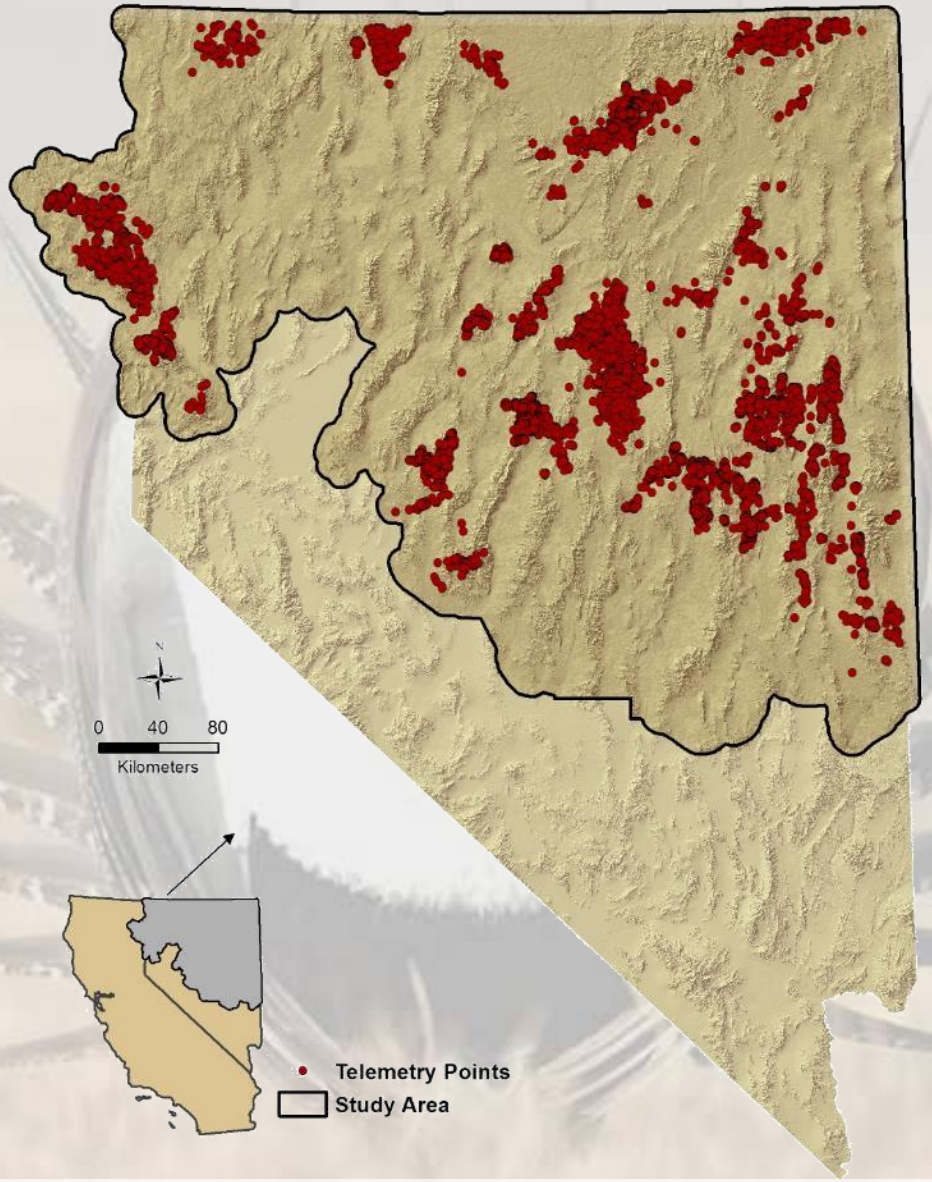
Lek-Based GRSG Population Model (2nd Order Habitat)



Doherty et al. 2016

Individual-Based Sage-Grouse Data (e.g., telemetry)

(Seasonal and Annual at Regional Scales)



> 47,000 locations

> 1,800 grouse

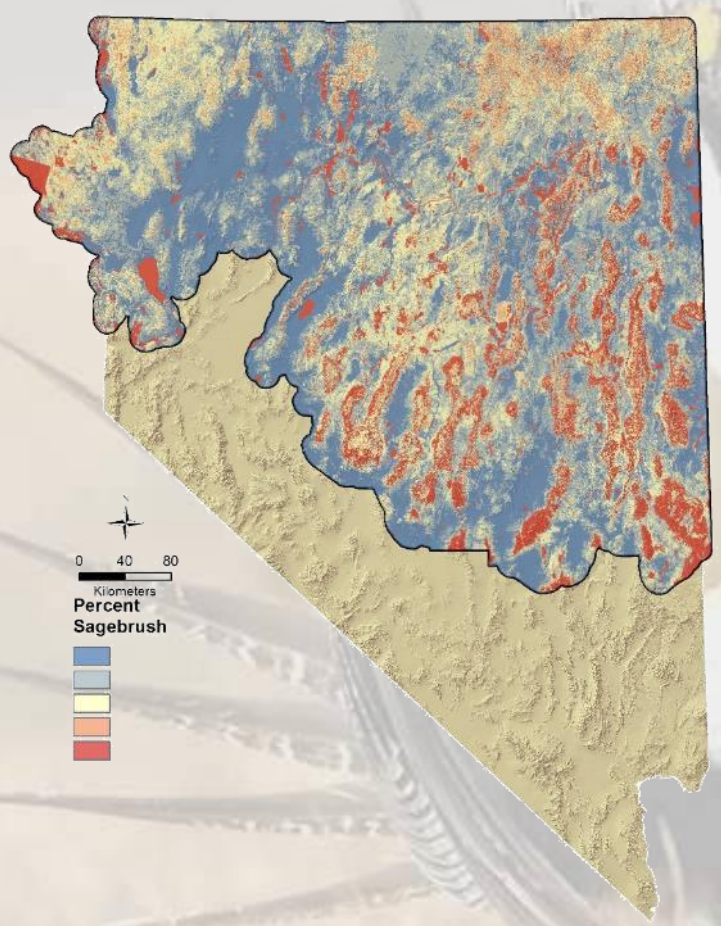
> 16 years

Multiple research effort

Coates et al. 2014, 2016

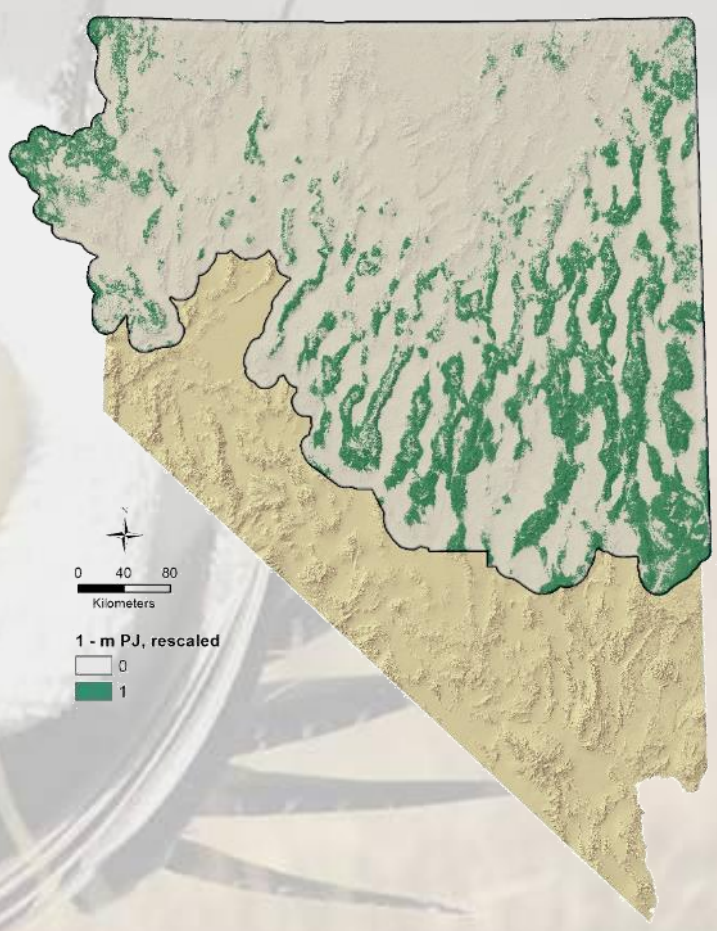
Higher Spatial Resolution Land Cover Data

Shubland Components (e.g., sagebrush)



Ground – Hyper – Multispectral

Conifers



1 – m resolution (Object Recognition)

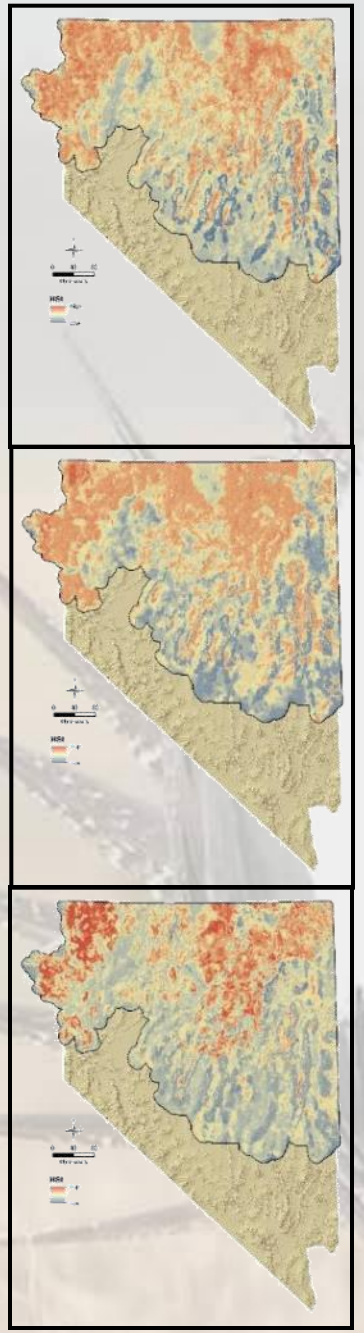
Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)

Annual HSI
(Product of seasonal probabilities)

Spring

Summer

Winter



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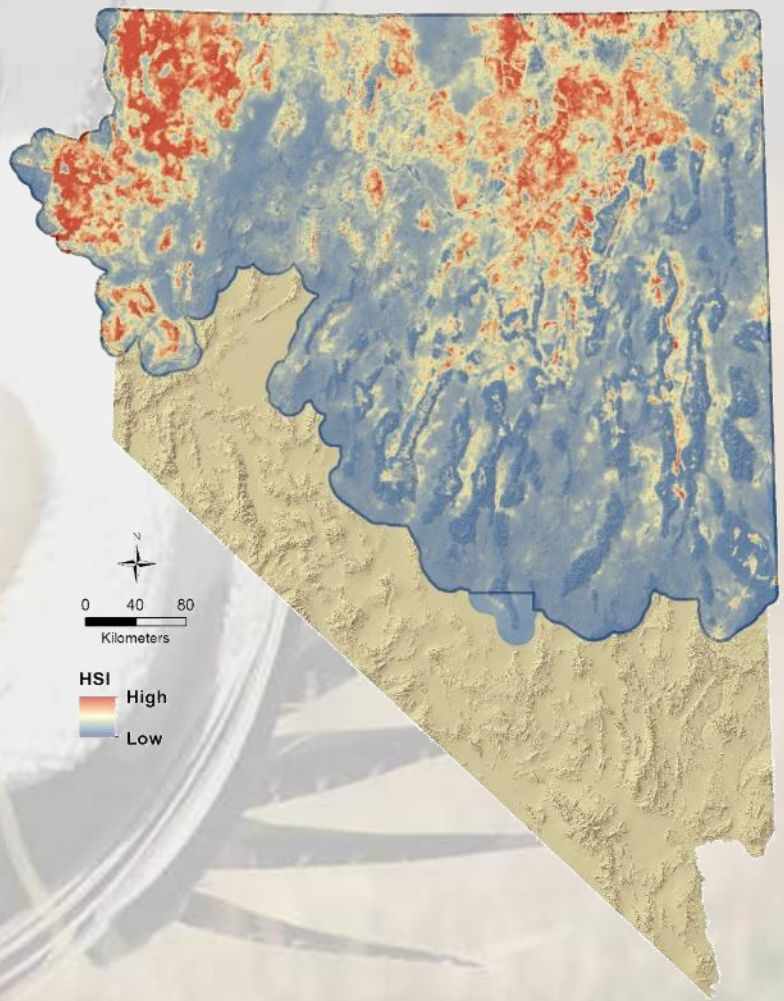
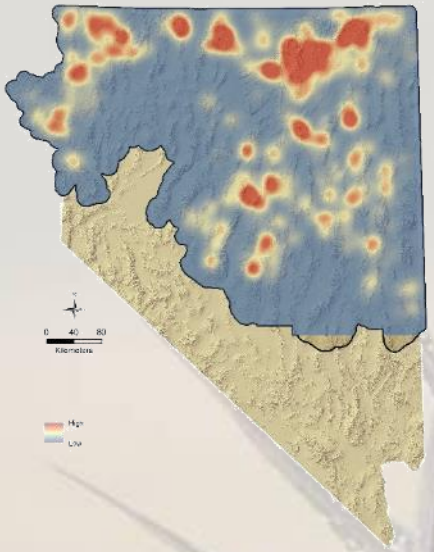
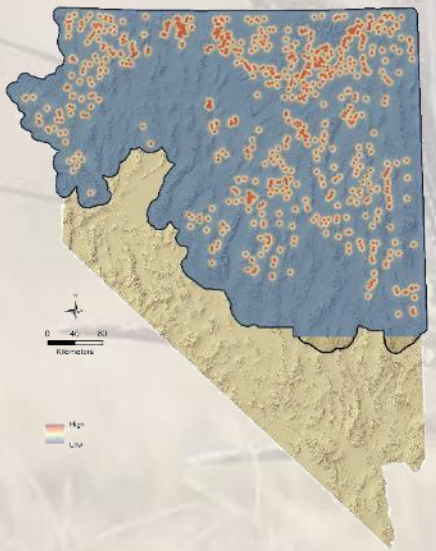


Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)

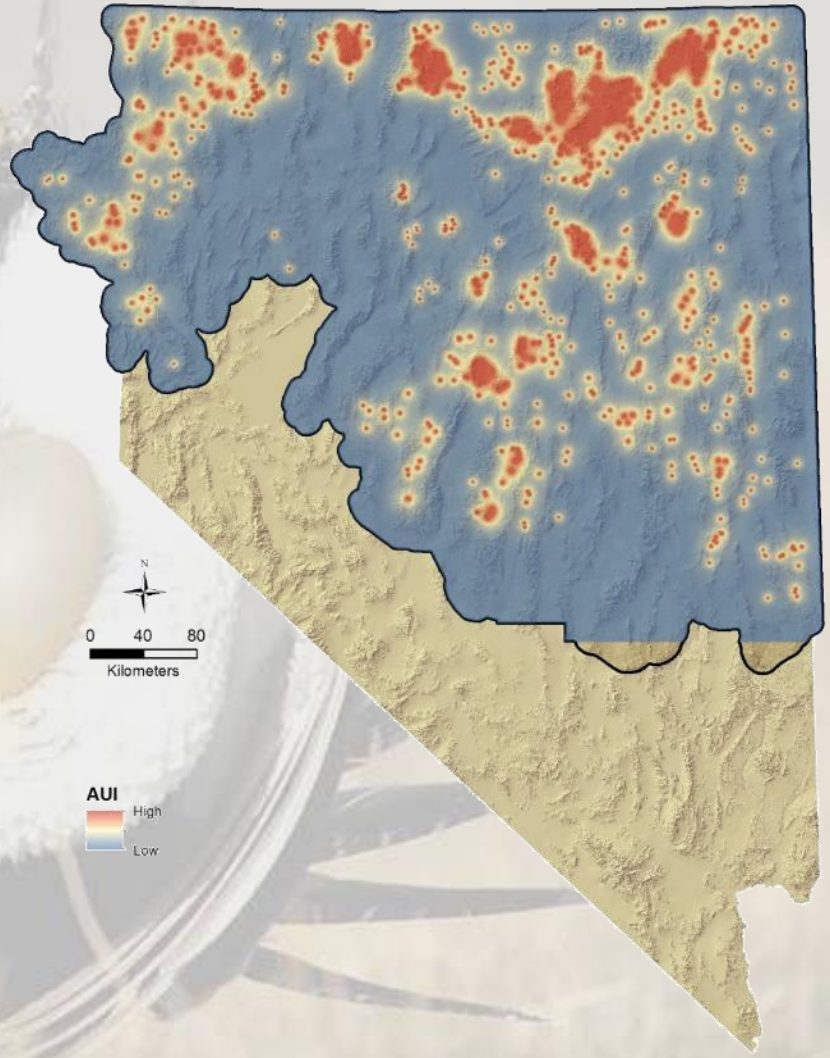
Lek Density Index



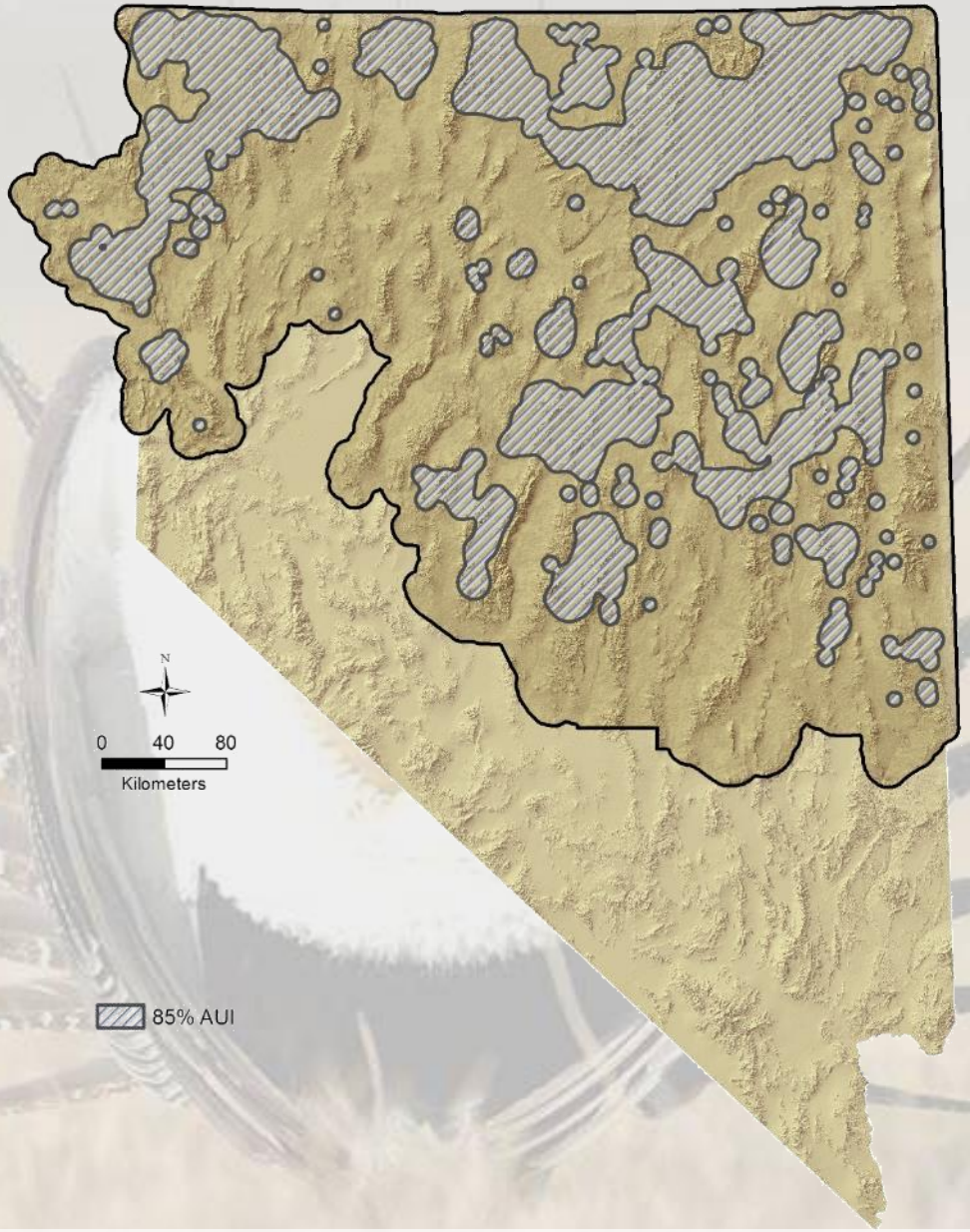
Lek Distance Index



Abundance & Space Use Index



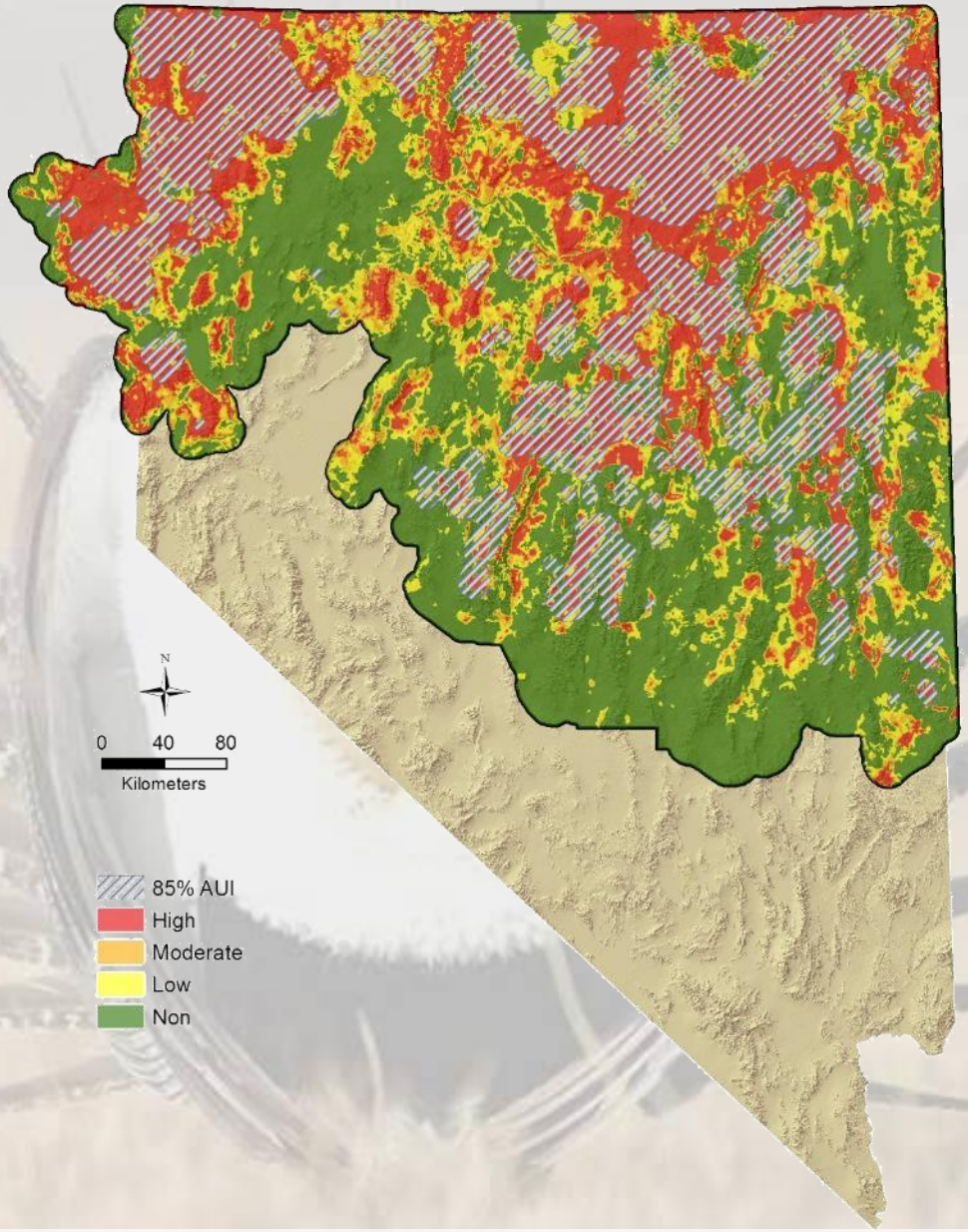
Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)



≥85 percentile of SUI Surface

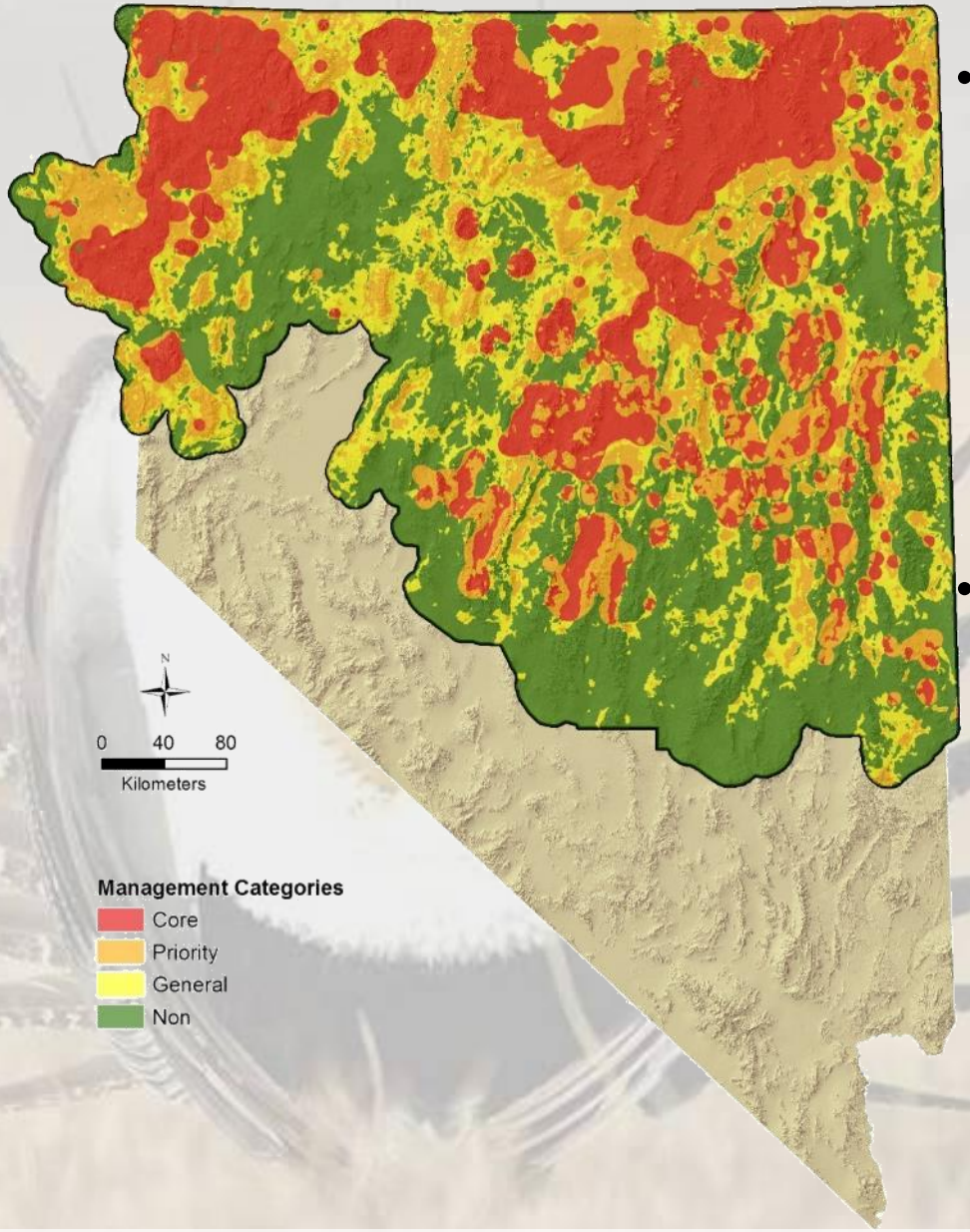
Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)

Intersecting Indices (Habitat and Space Use)



Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)

Regional Model (Improved Data)

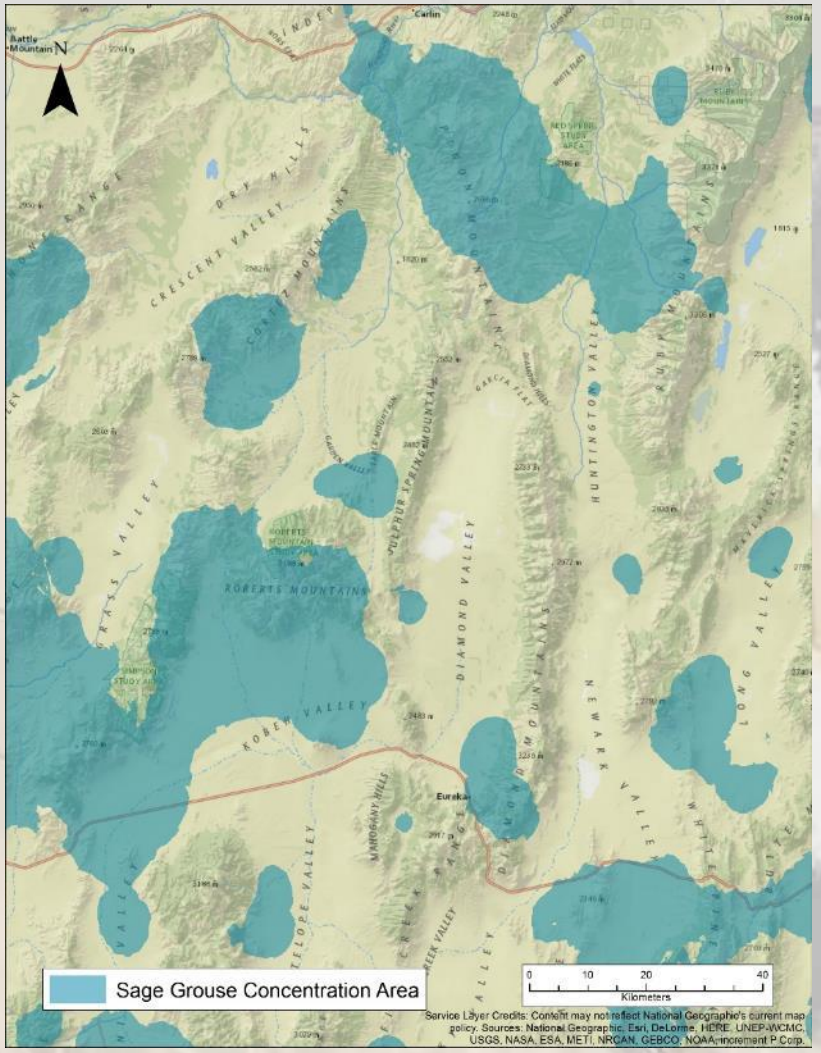


- **Highest 'value' for areas of suitable habitat and high probability of abundant sage-grouse**
- **2nd Order Habitat Selection Example**

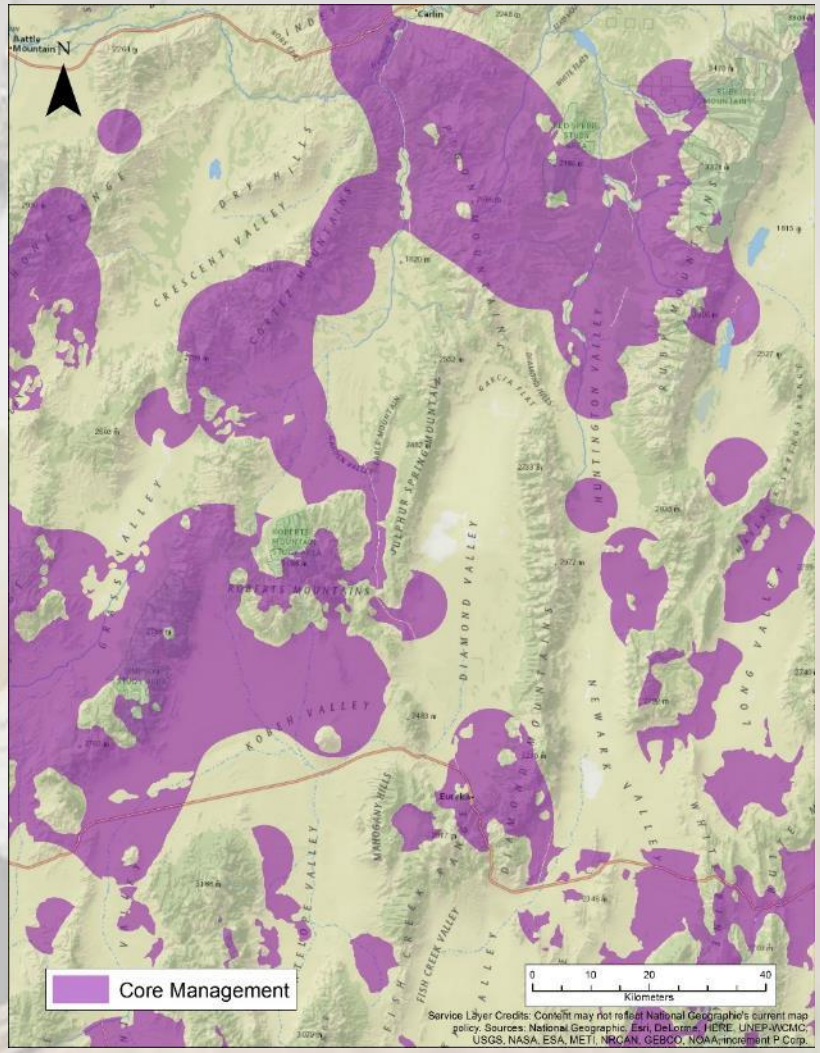
Coates et al. 2016 (USGS Open-File-Report; http://dx.doi.org/10.3133/ofr20161080)

Regional/Site Example (Improved Data)

Habitat based on lek model

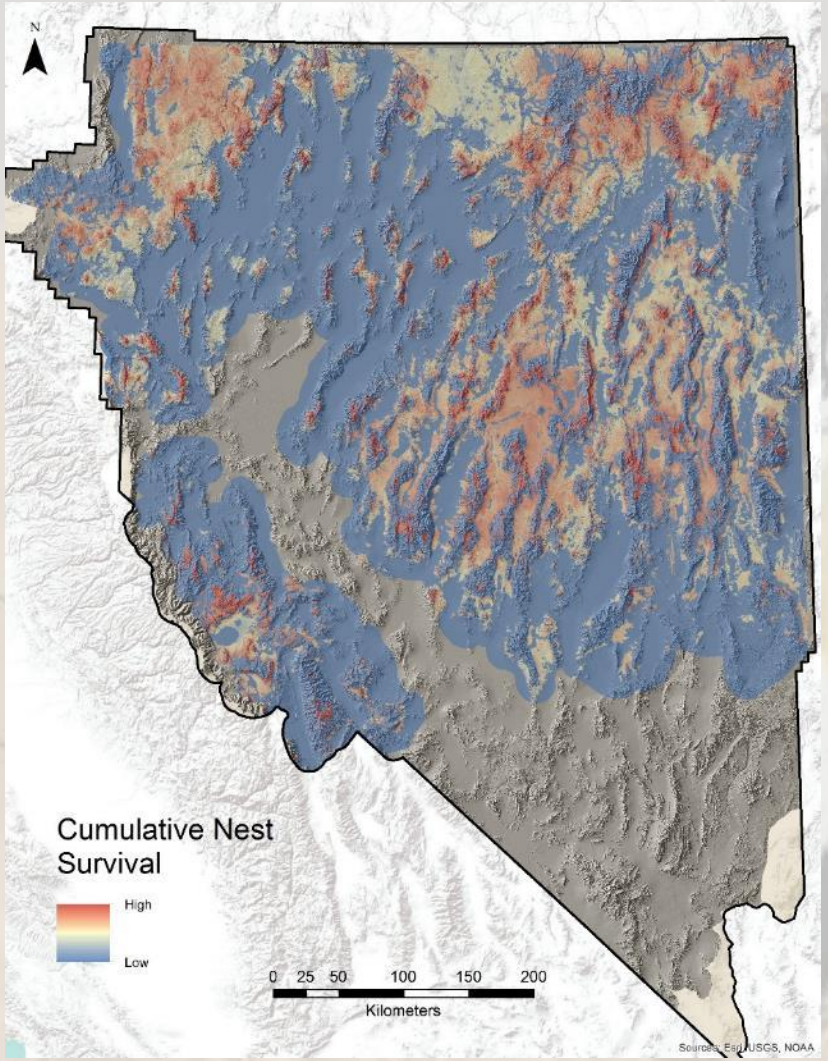


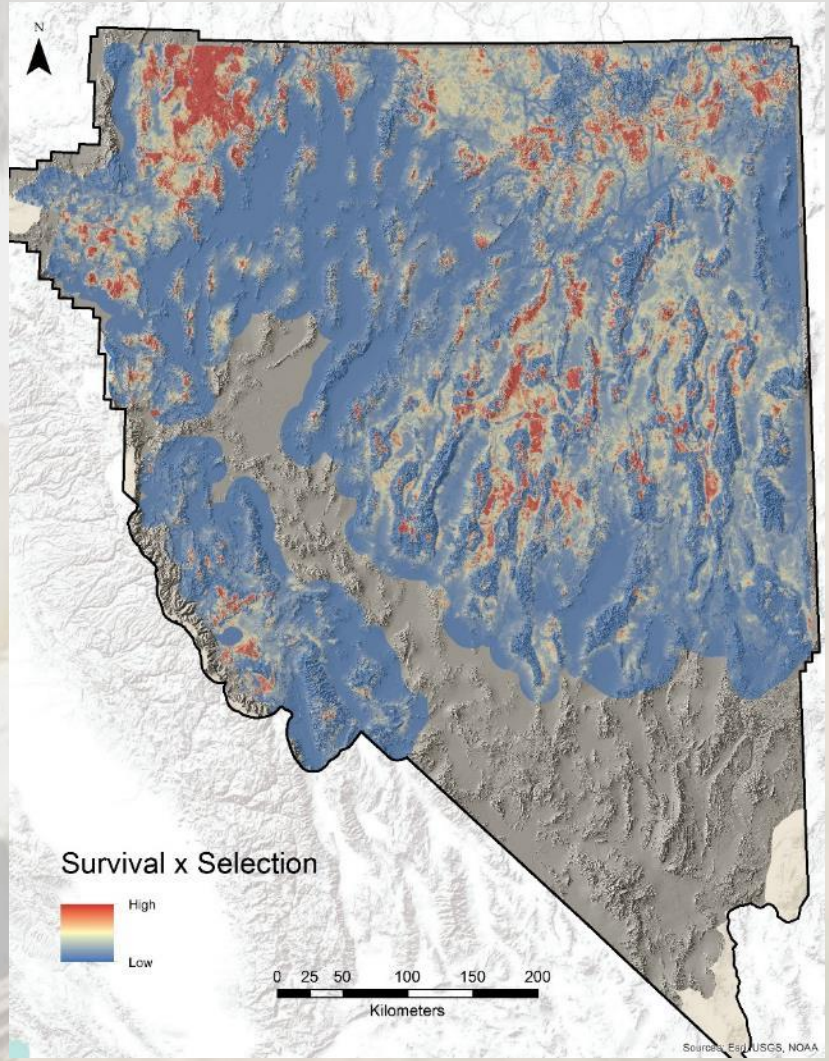
Habitat based on telemetry model



Doherty et al. 2016, Coates et al. 2016, 2017

Refining Regional Model: Nest Selection and Survival (3rd Order Selection; Fine Scale HAF)

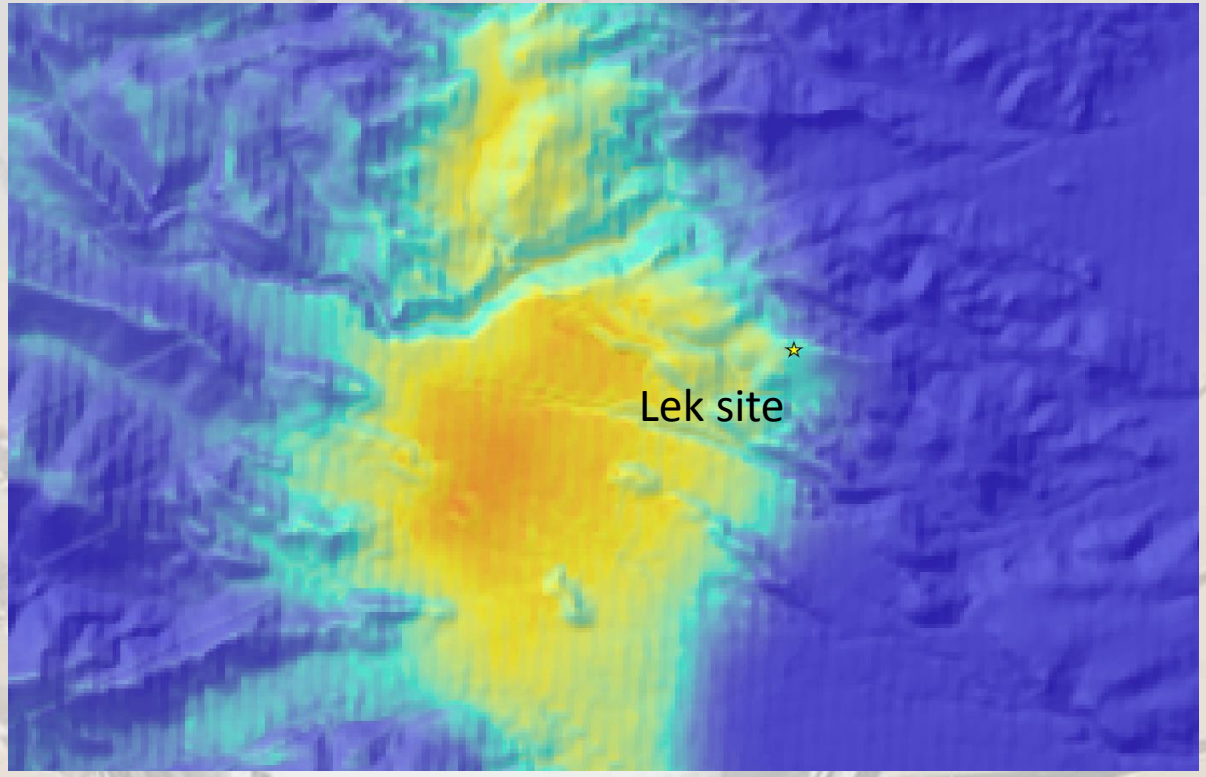




Preliminary Information—Subject to Revision. Not for Citation or Distribution

3rd Order Habitat Selection Example (Fine Scale HAF)

Seasonal maps within a region

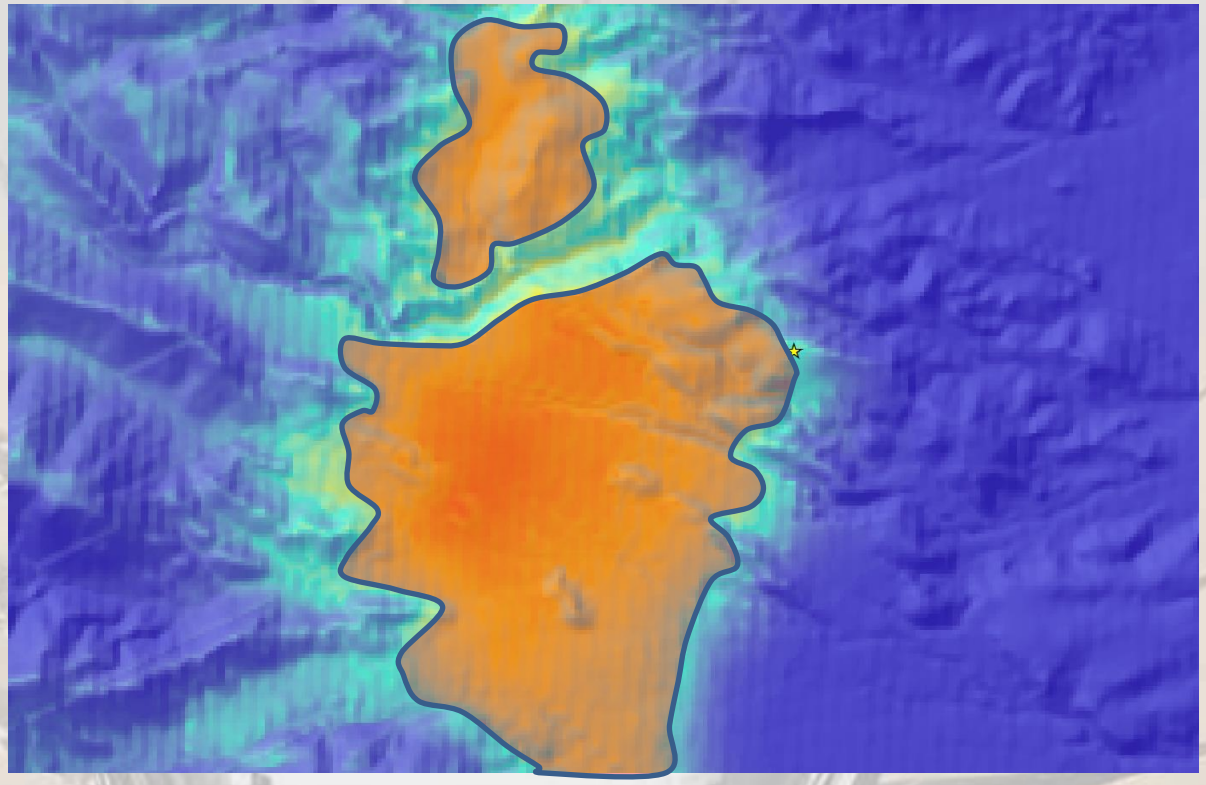


- Landscape level features are identified at relatively large spatial scales (e.g., tracts of contiguous sagebrush with few trees)
- Conditions are conducive to nesting at large spatial scale
- Assessment conducted based on GIS products from imagery

**Area still may not represent suitable habitat at smaller scales (microhabitat)*

3rd Order Habitat Selection Example (Fine Scale HAF)

Seasonal maps within a region



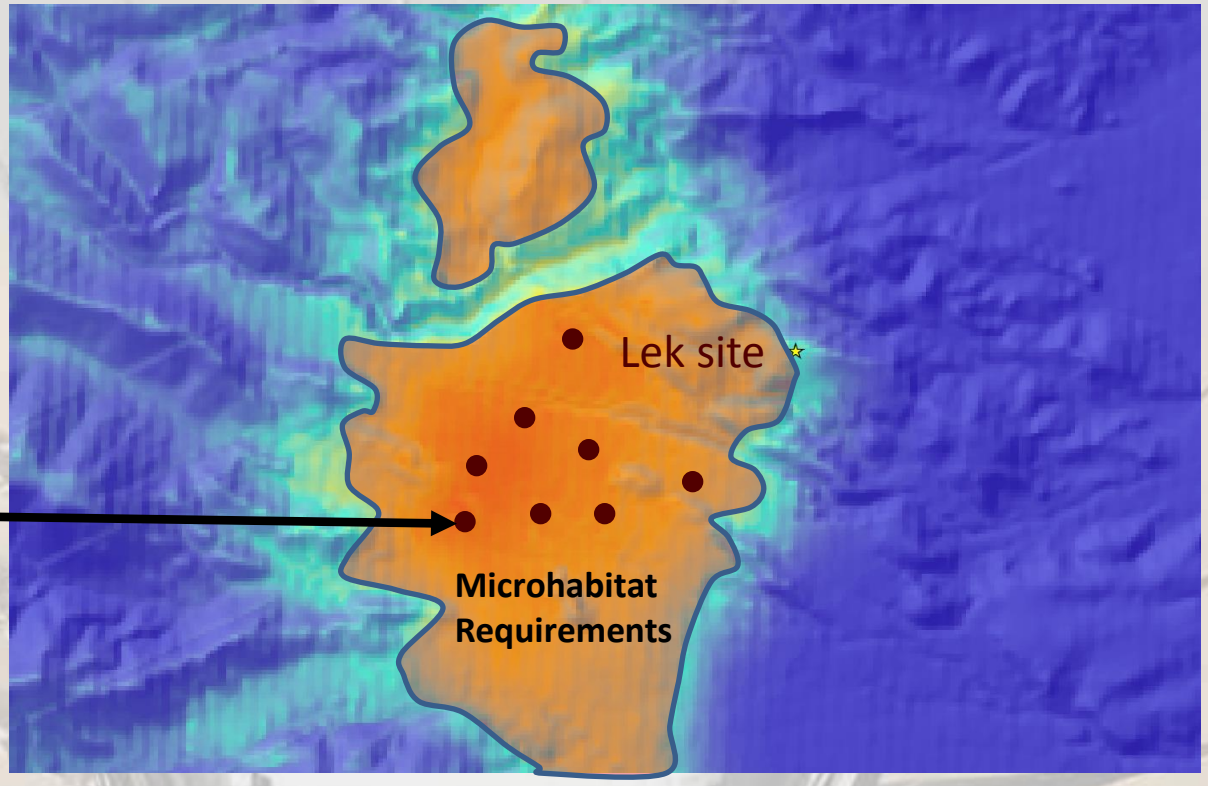
- Polygon is established based on threshold of habitat model
- Help guide management area and assessment for smaller spatial scale requirements

*Area still may not represent suitable habitat at smaller scales (microhabitat)

3rd Order Habitat Selection Example (Fine Scale HAF)

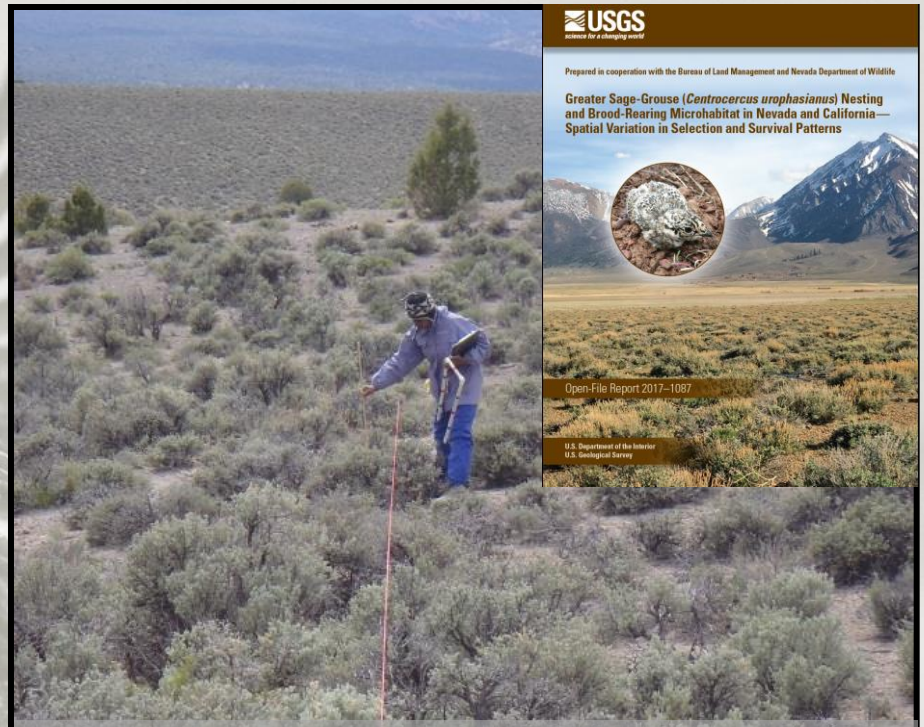
Seasonal maps within a region

4th order habitat assessment (site scale)



- Specific microsite components needed by sage-grouse (e.g., shrub cover and herbaceous cover, height and width of vegetation components, overall horizontal and vertical cover)

Microhabitat Sampling



- > 15 sites in CA and NV, 2009 - 2016
- 703 nest sites (& paired random sites)
- 270 late- brood rearing sites (&paired random sites)
  - Mesic and xeric sites
  - Accounted for phenology changes.
  - Coates et al. (2017, USGS OFR)

Nesting Microhabitat Standards - LUPA

Table 2-2
Habitat Objectives for GRSG

Attribute	Indicators	Desired Condition (Habitat Objectives)	Reference
GENERAL/LANDSCAPE-LEVEL[1]			
NESTING (Seasonal Use Period: April 1 to June 30)[1]			
Cover	Sagebrush cover	≥20%	Kolada et al. 2009a, 2009b
	Residual and live perennial grass cover (such as native bunchgrasses)	≥10% if shrub cover is <25%[5]	Coates et al. 2013 Coates and Delehanty 2010 Kolada et al. 2009a, 2009b
	Annual grass cover	<5%	Lockyer et al. (in press)
	Total shrub cover	≥30%	Coates and Delehanty 2010 Kolada et al. 2009a Lockyer et al. (in press)
	Perennial grass height (includes residual grasses)	Provide overhead and lateral concealment from predators	Connelly et al. 2000, 2003 Hagen et al. 2007; Stiver et. al. 2015 (in press) HAF

https://eplanning.blm.gov/epl-front-office/projects/lup/21152/63235/68484/NVCA_Approved_RMP_Amendment.pdf

Example Microhabitat Standards Table for Nesting Habitat Based on Results of Selection and Survival Analyses

Variable	Habitat type	Unsuitable	Marginal	Suitable
Horizontal cover (%)	Xeric*	<79.9	79.9–82.3	>82.3
	Mesic*	<81.1	81.1–83.8	>83.8
Vertical cover (%)	Xeric	<56.0	56.0–72.7	>72.7
	Mesic	<60.0	60.0–74.4	>74.4
Maximum height (cm)	Xeric	<53.0	53.0–72.8	>72.8
	Mesic	<52.8	52.8–73.0	>73.0
Average height (cm)	Xeric	<33.4	33.4–43.7	>43.7
	Mesic	<32.4	32.4–50.5	>50.5
Perpendicular width (cm)	Xeric*	<86.4	86.4–92.5	>92.5
	Mesic	<68.0	68.0–96.3	>96.3
Sagebrush height (cm)	Xeric	<30.0	30.0–43.2	>43.2
	Mesic	<40.0	40.0–59.1	>59.1
Non-sagebrush height (cm)	Xeric	<6.5	6.5–20.8	>20.8
	Mesic*	<31.7	31.7–37.0	>37.0
Perennial grass height (cm)[1]	Xeric*	<10.6 4.2in	10.6–12.1	>12.1 4.8 in
	Mesic	<9.9 3.9in	9.9–17.8	>17.8 7 in
Perennial forb height (cm)[1]	Xeric	0	0.0–5.5	>5.5
	Mesic	<1.4	1.4–7.6	>7.6
Residual grass height (cm)	Xeric	<3.4	3.4–7.5	>7.5
	Mesic	<6.3	6.3–12.5	>12.5
Perennial grass cover (%)	Xeric	<2.5	2.5–6.8	>6.8
	Mesic	<5.2	5.2–12.8	>12.8
Annual grass cover (%)	Xeric	>4.8	2.5–4.8	<2.5
	Mesic	>5.2	2.5–5.2	<2.5
Perennial forb cover (%)[1]	Xeric*	<4.6	4.6–4.9	>4.9
	Mesic	<2.5	2.5–8.6	>8.6
Annual forb cover (%)	Xeric	>3.5	2.5–3.5	<2.5
	Mesic	>5.7	5.3–5.7	<5.3
Tall sagebrush cover (%)	Xeric	0	0.0–14.9	>14.9
	Mesic*	<9.9	9.9–12.0	>12.0
Dwarf sagebrush cover (%)	Xeric	0	0.0–8.2	>8.2
	Mesic	0	0.0–7.5	>7.5
Total sagebrush cover (%)	Xeric	<14.1	14.1–20.4	>20.4
	Mesic*	<17.7	17.7–19.6	>19.6
Non-sagebrush shrub cover (%)	Xeric	0	0.0–5.3	>5.3
	Mesic*	<4.3	4.3–5.2	>5.2
Total shrub cover (%)	Xeric	<18.7	18.7–27.8	>27.8
	Mesic*	<23.0	23.0–25.8	>25.8

[1] *Corrected based on estimated hatch date*

* *Selection influenced survival*

- Suitable based on mean of selected used sites
- Unsuitable based on low end of selected used sites, or mean of failed sites if selection influenced survival

Coates et al. (2017) USGS Open File Report, https://doi.org/10.3133/ofr20171087

Moist Sites

Successful nesting sites

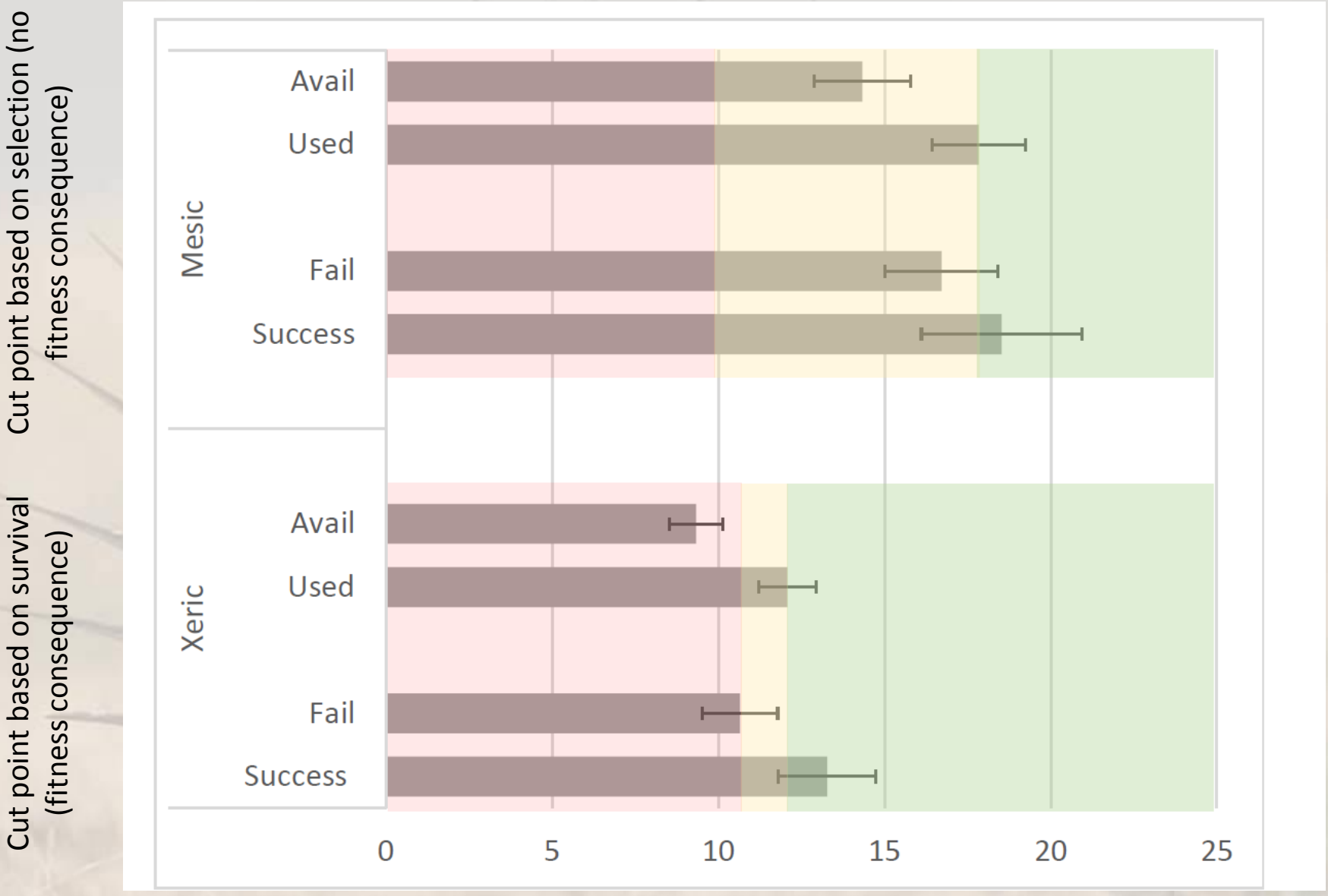
Failed nesting sites

Dry Sites

Successful nesting sites

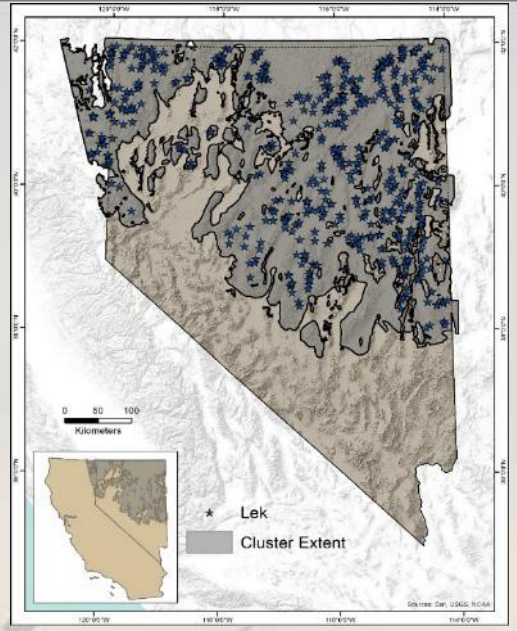
Failed nesting sites

Candidate Revised Nesting Standards: Grass Height



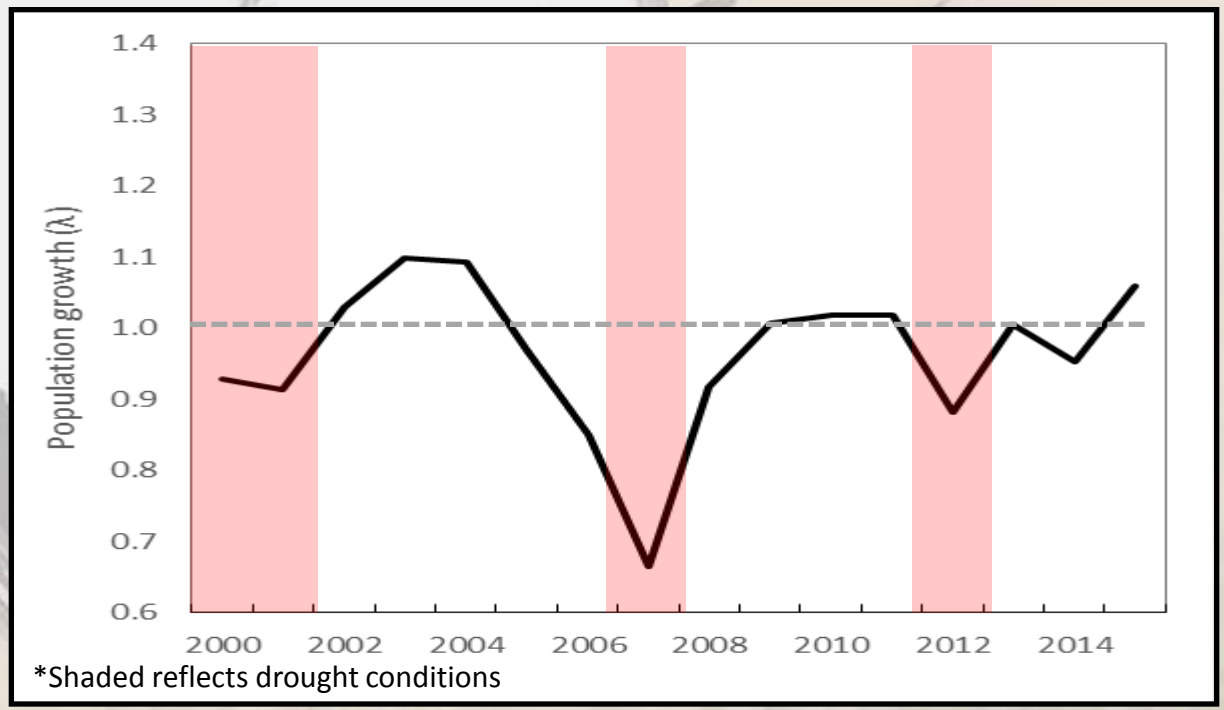
Derived from Coates et al. (2017 USGS Open File Report, https://doi.org/10.3133/ofr20171087)

Population Modeling Tools to Inform Adaptive Management



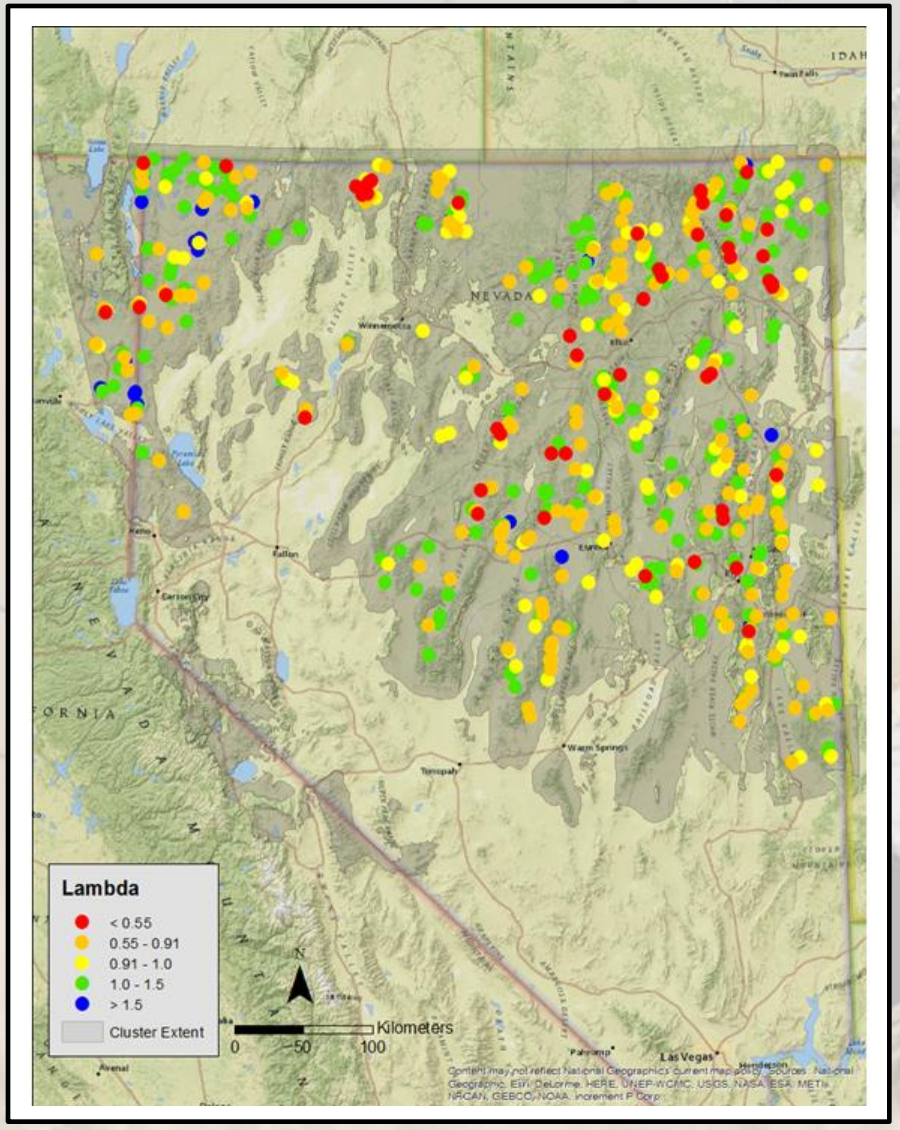
Region-wide decline

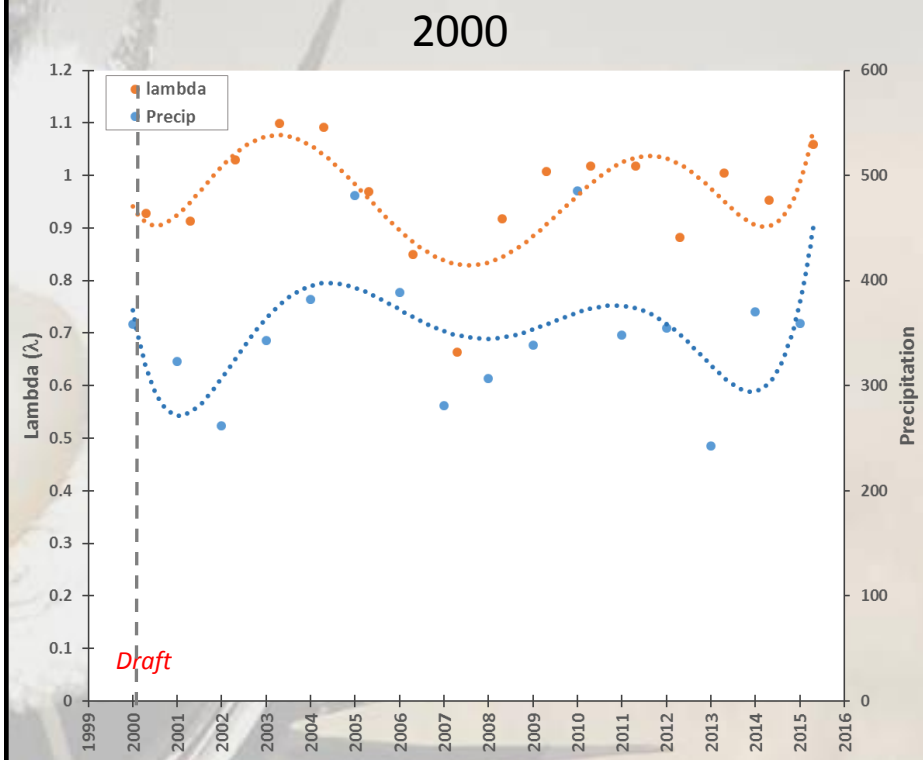
- 3.8% annual decline
- Generally related to drought conditions



Coates et al. 2017

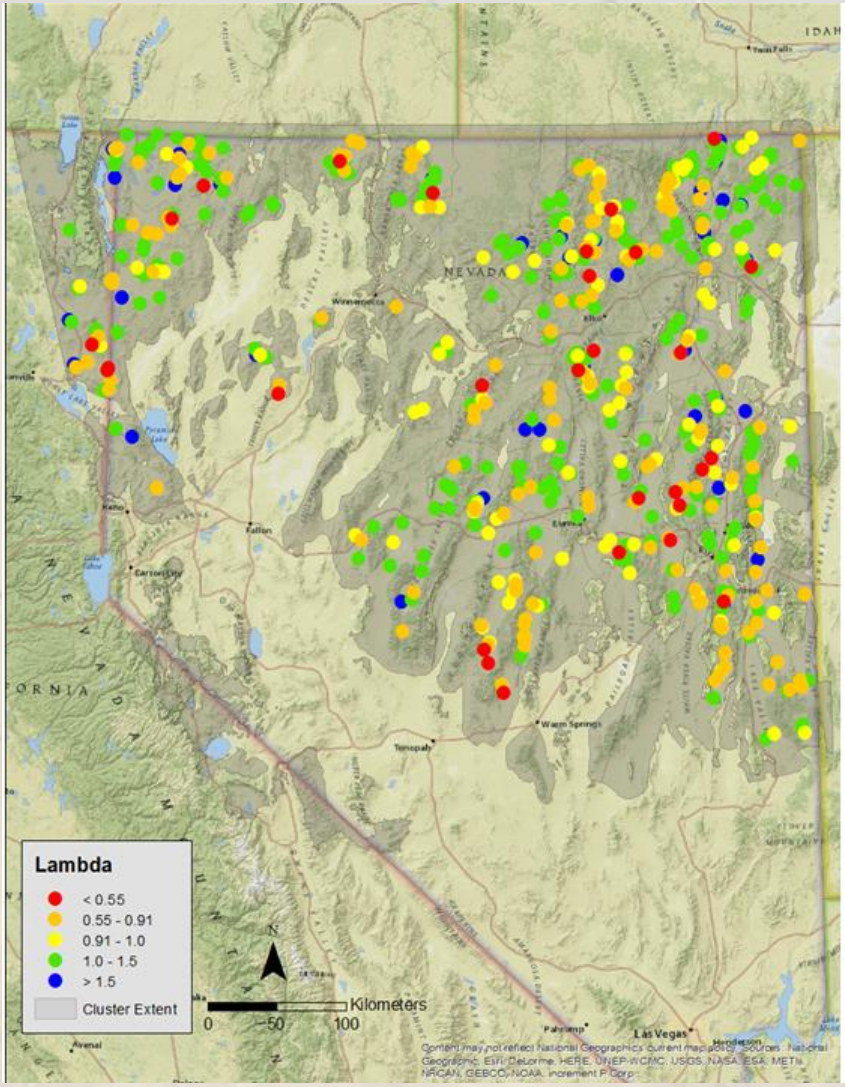
Lek-Level Variation in Population Trends

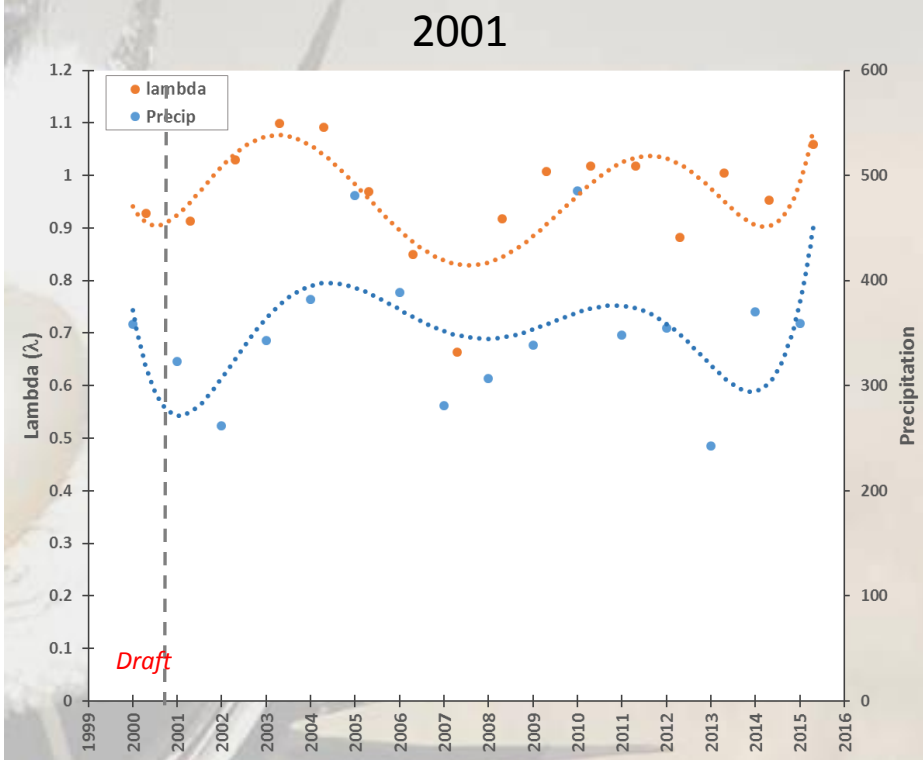




Derived from Coates et al. 2017

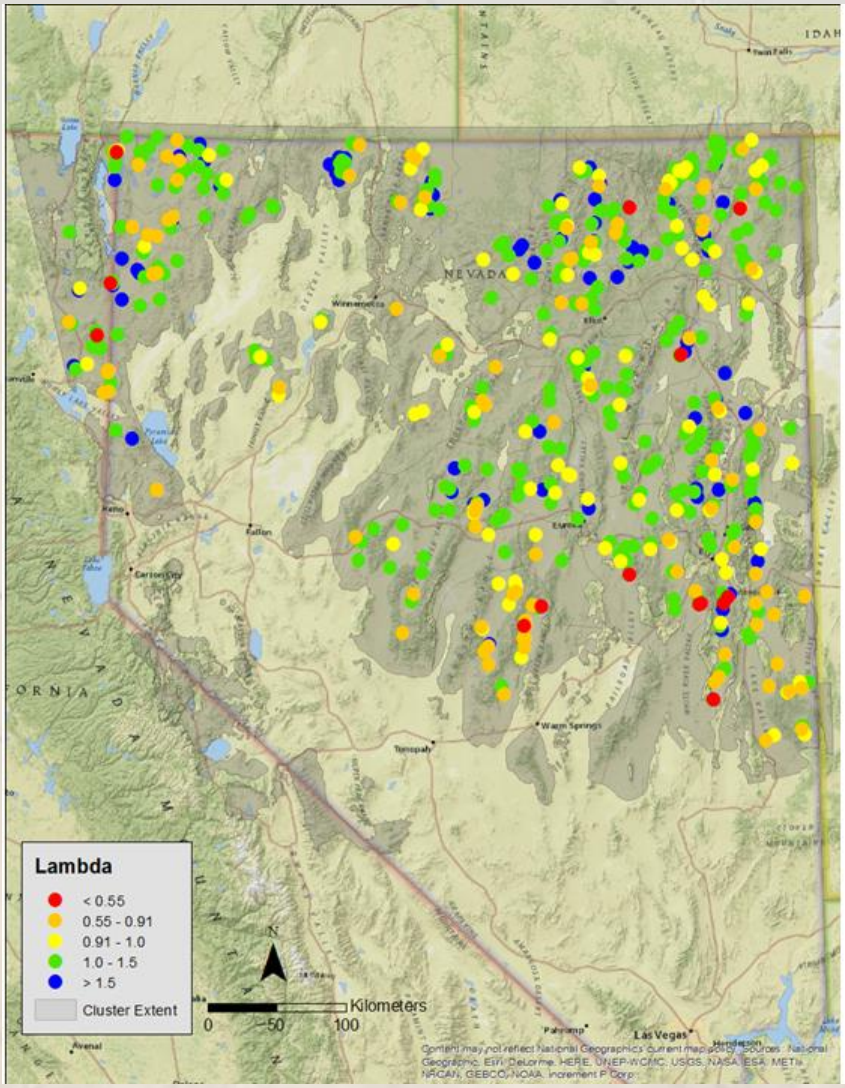
Lek-Level Variation in Population Trends

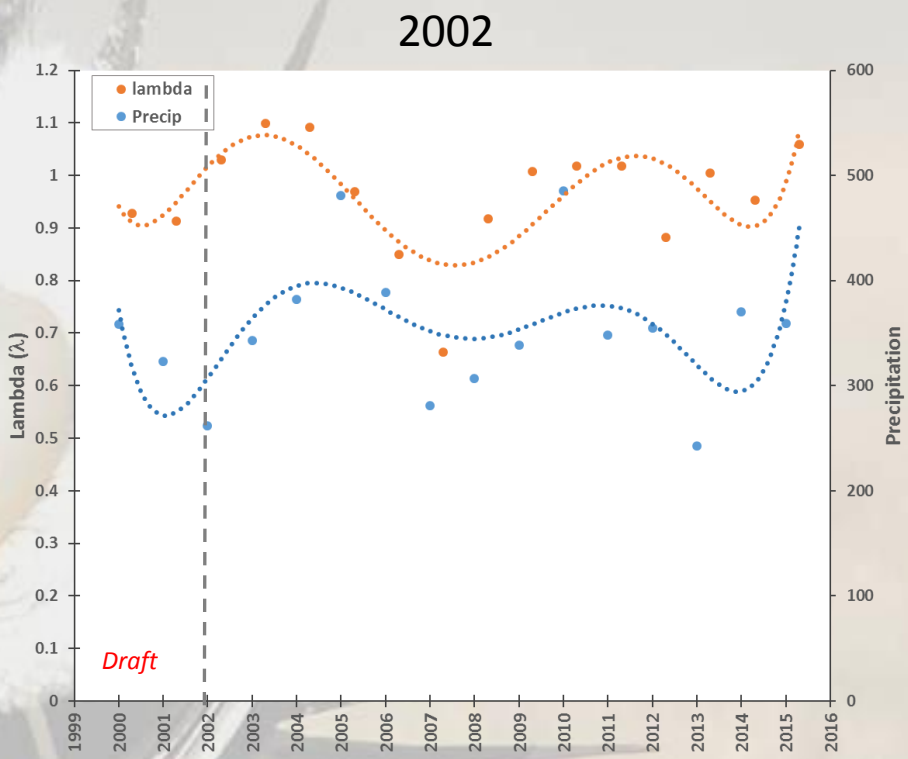




Derived from Coates et al. 2017

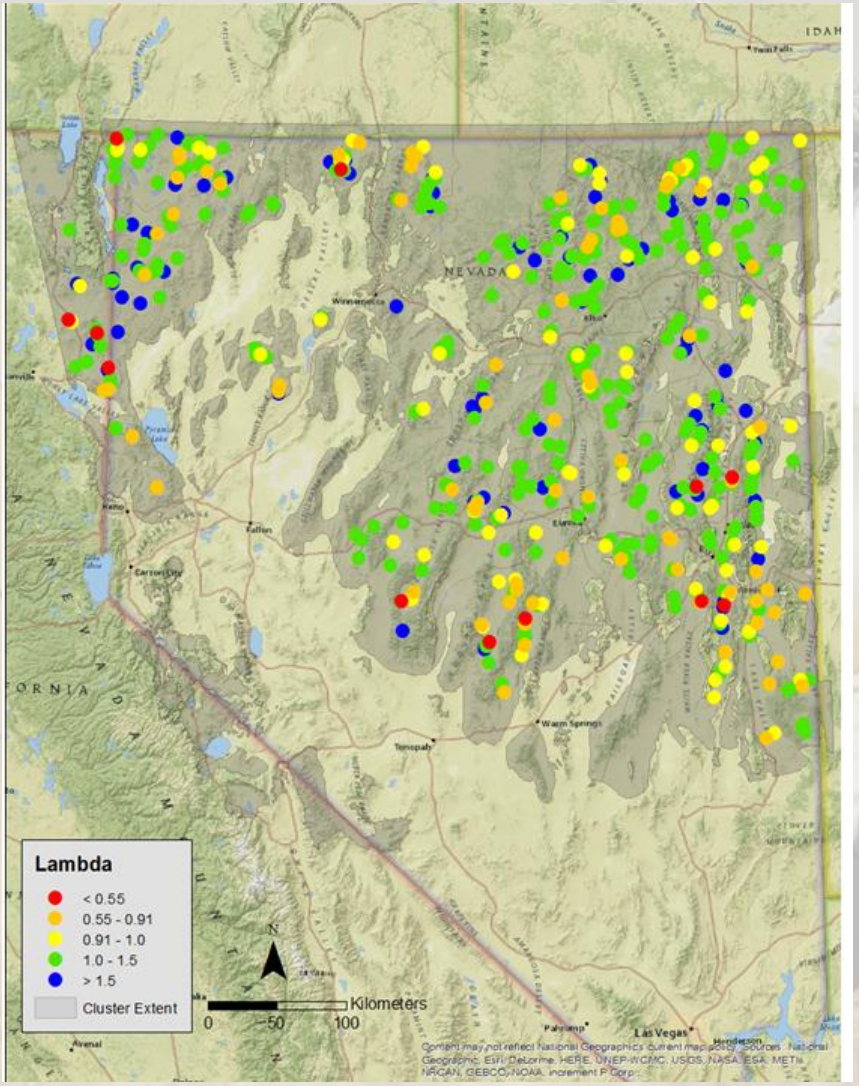
Lek-Level Variation in Population Trends

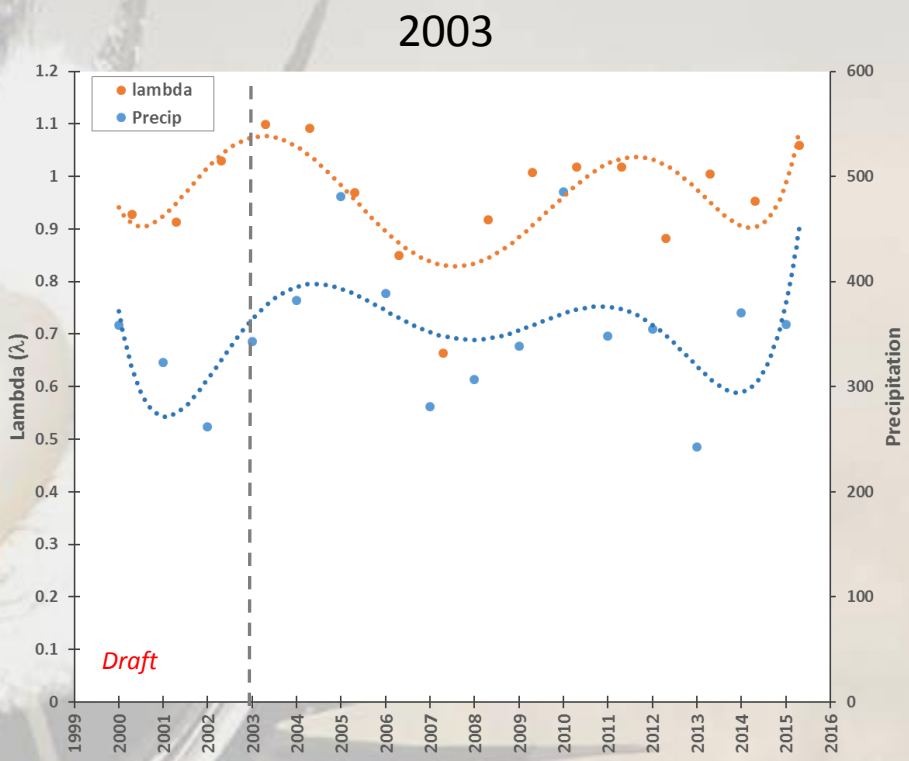




Derived from Coates et al. 2017

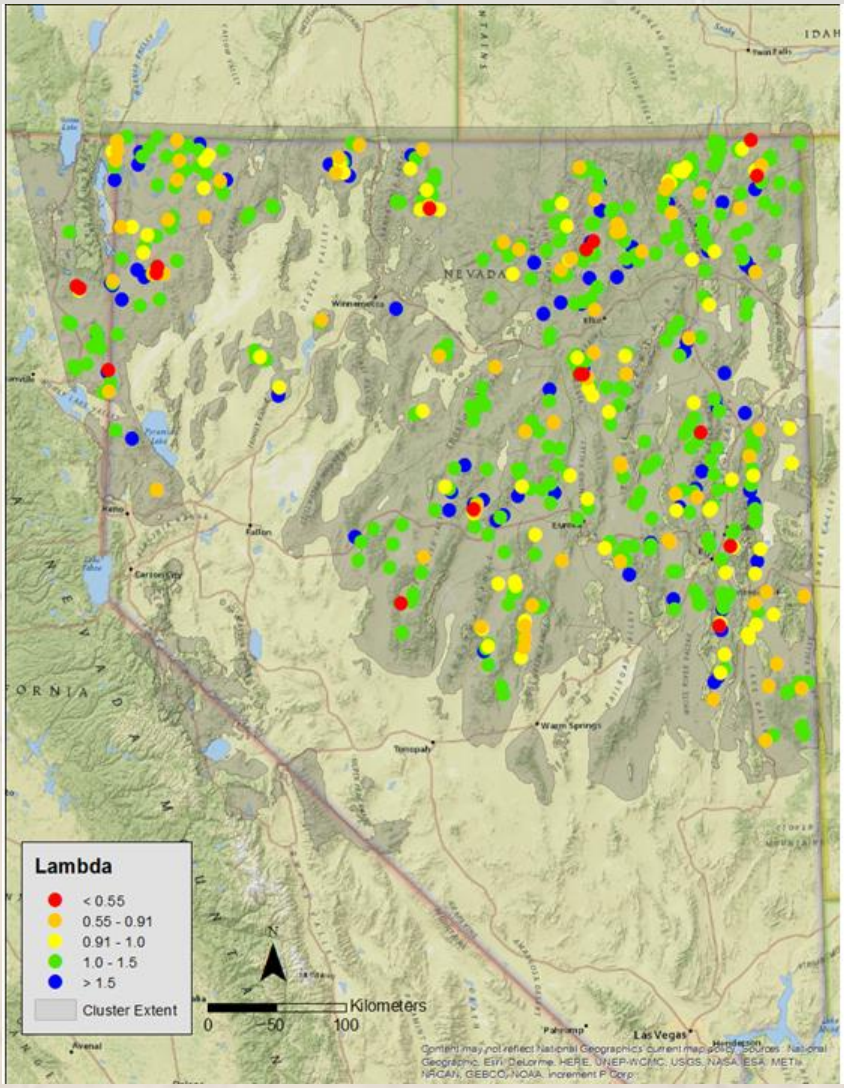
Lek-Level Variation in Population Trends

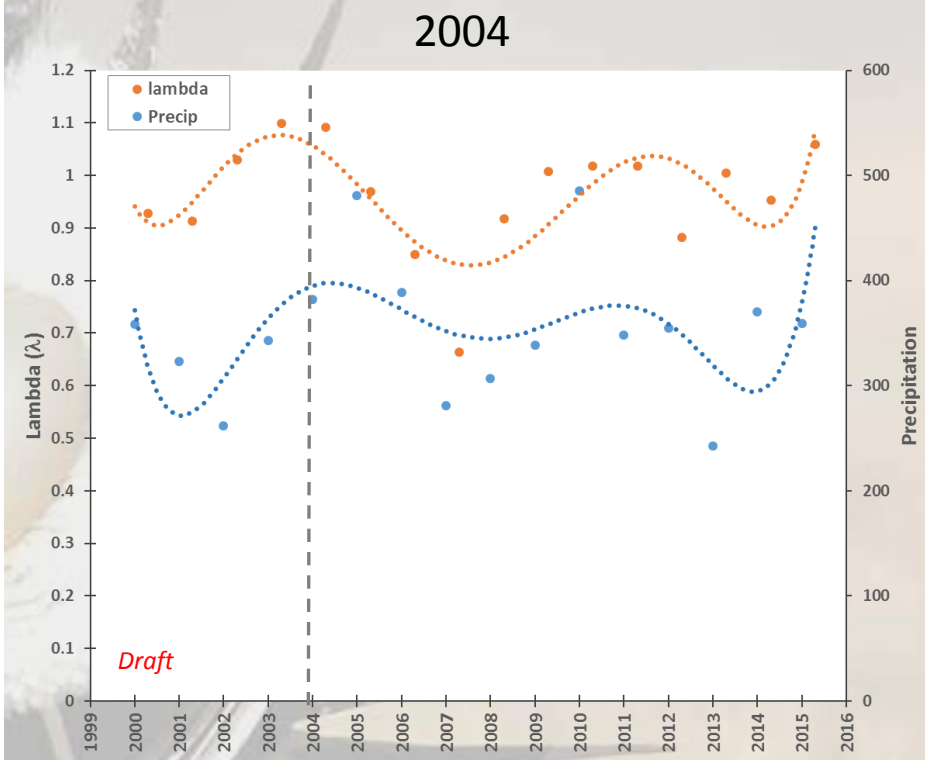




Derived from Coates et al. 2017

Lek-Level Variation in Population Trends





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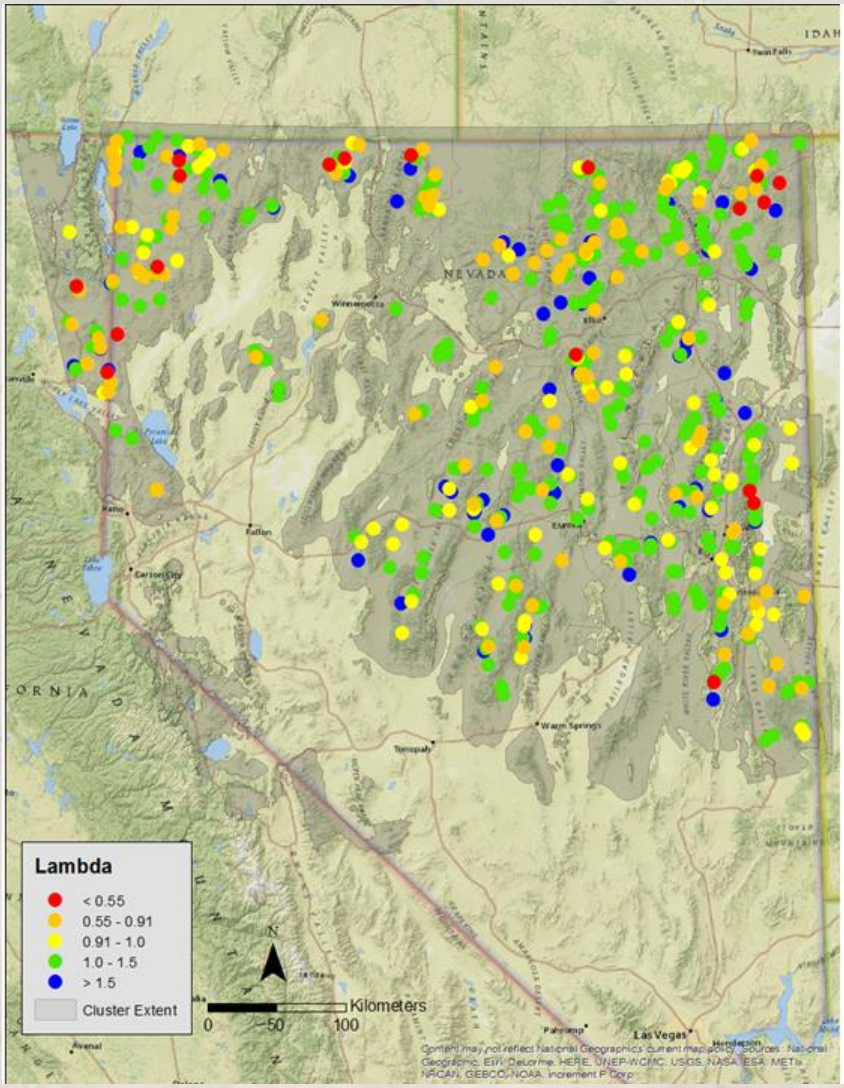
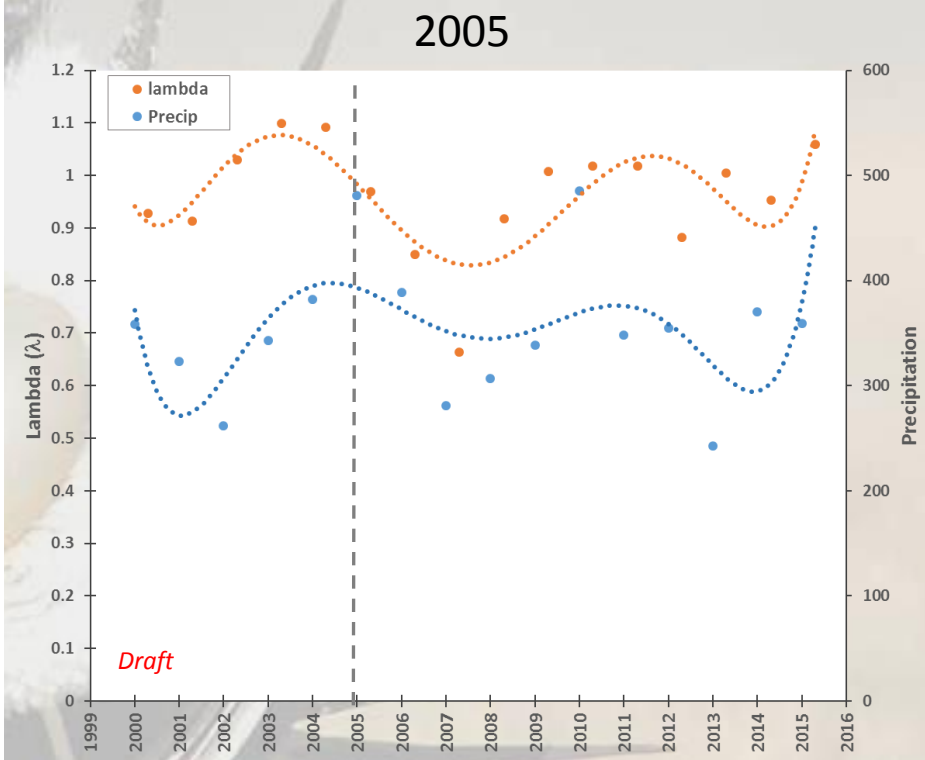
Lek-Level Variation in Population Trends





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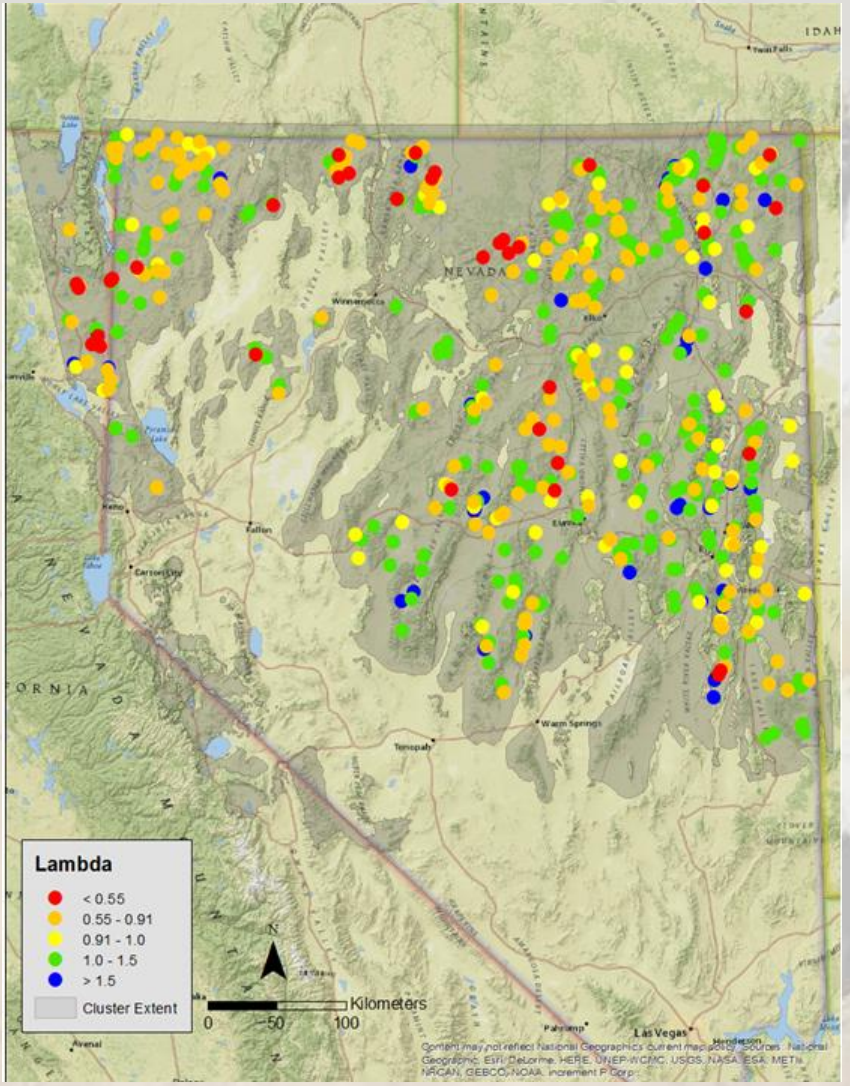
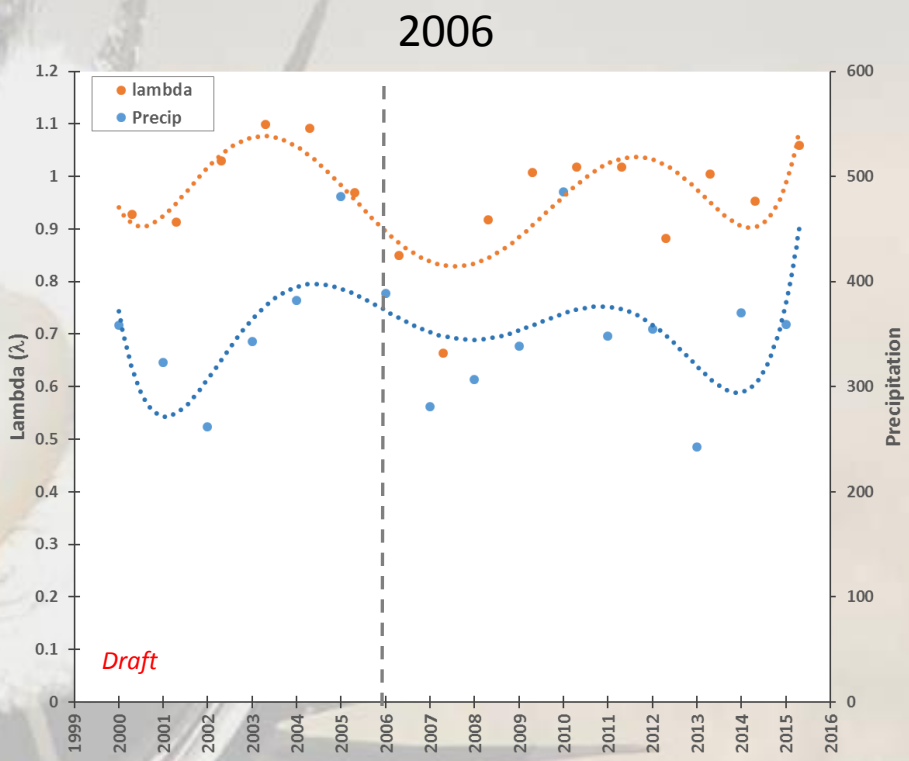
Lek-Level Variation in Population Trends





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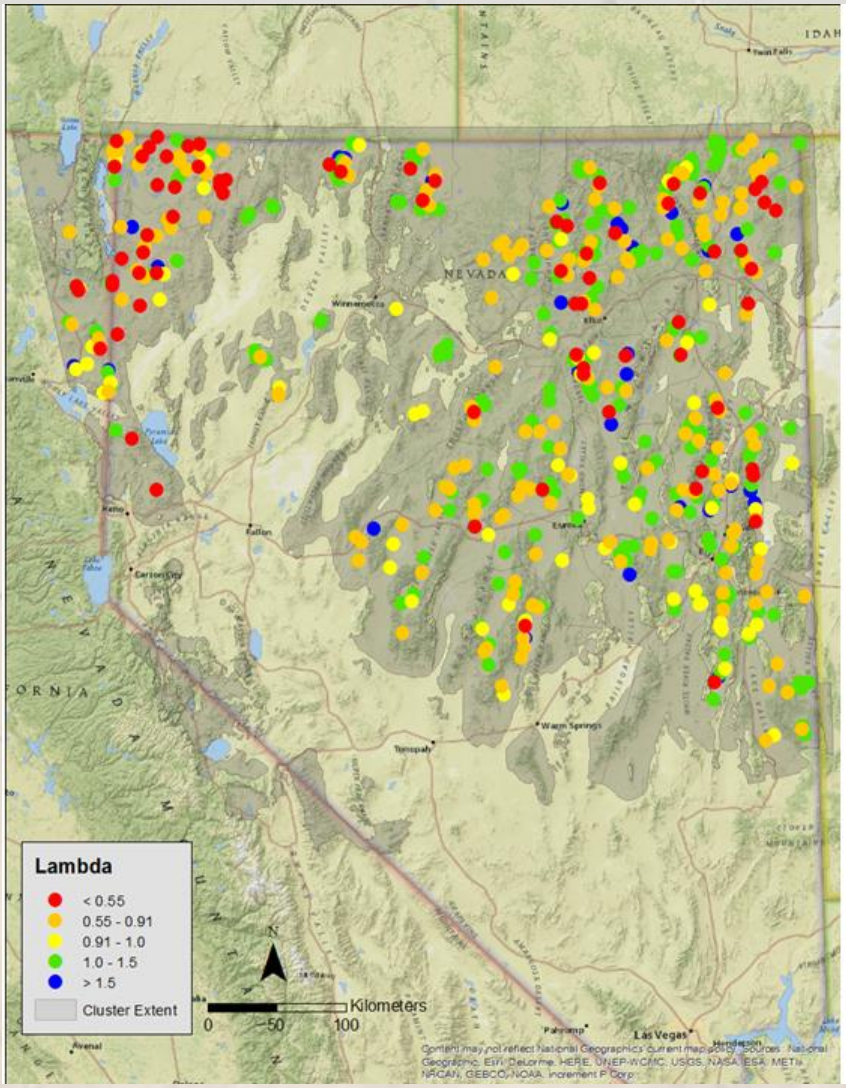
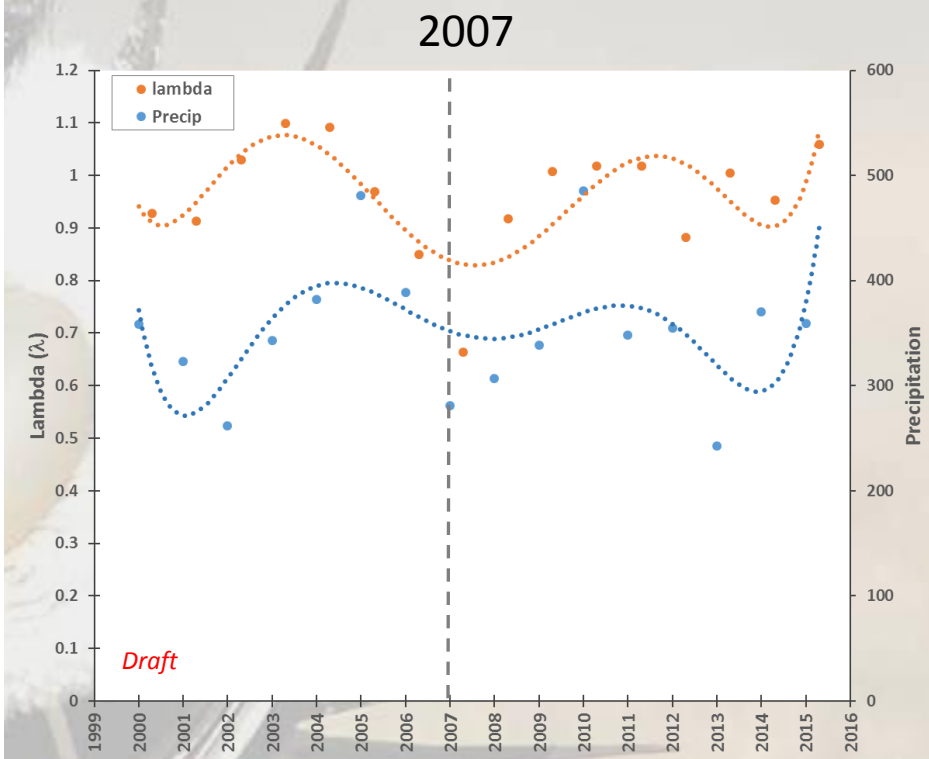
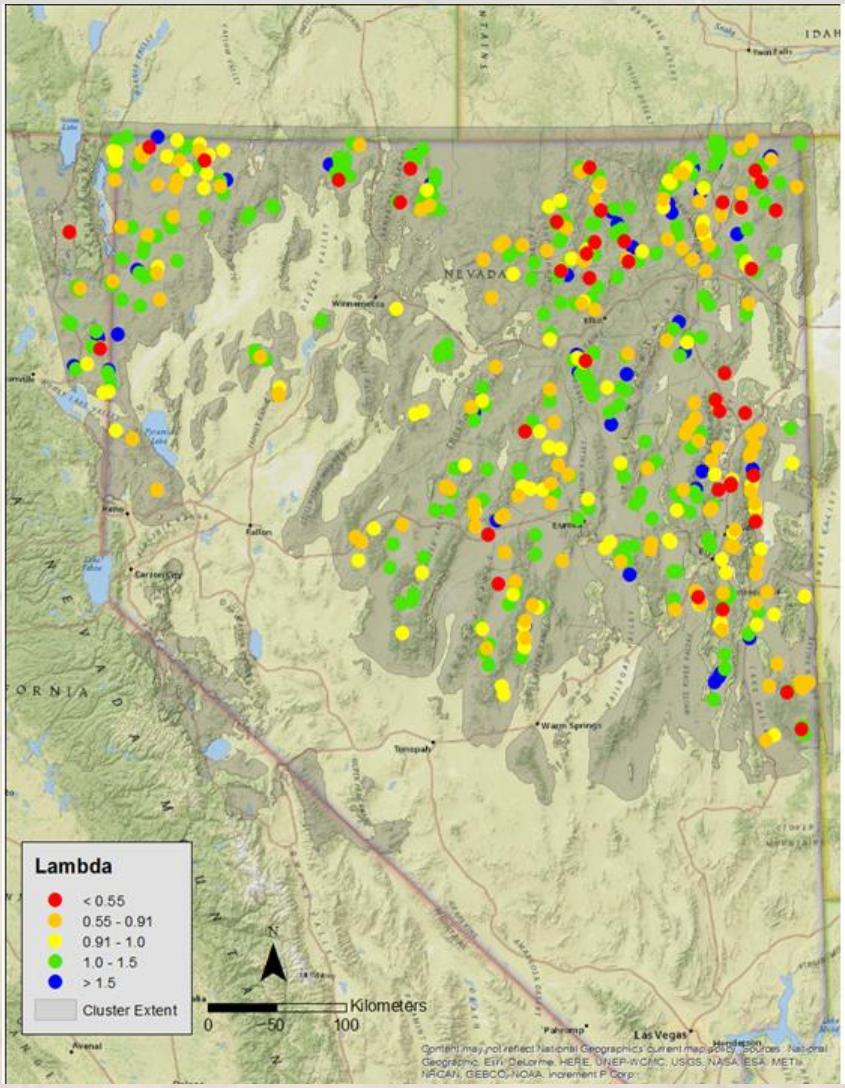
Lek-Level Variation in Population Trends

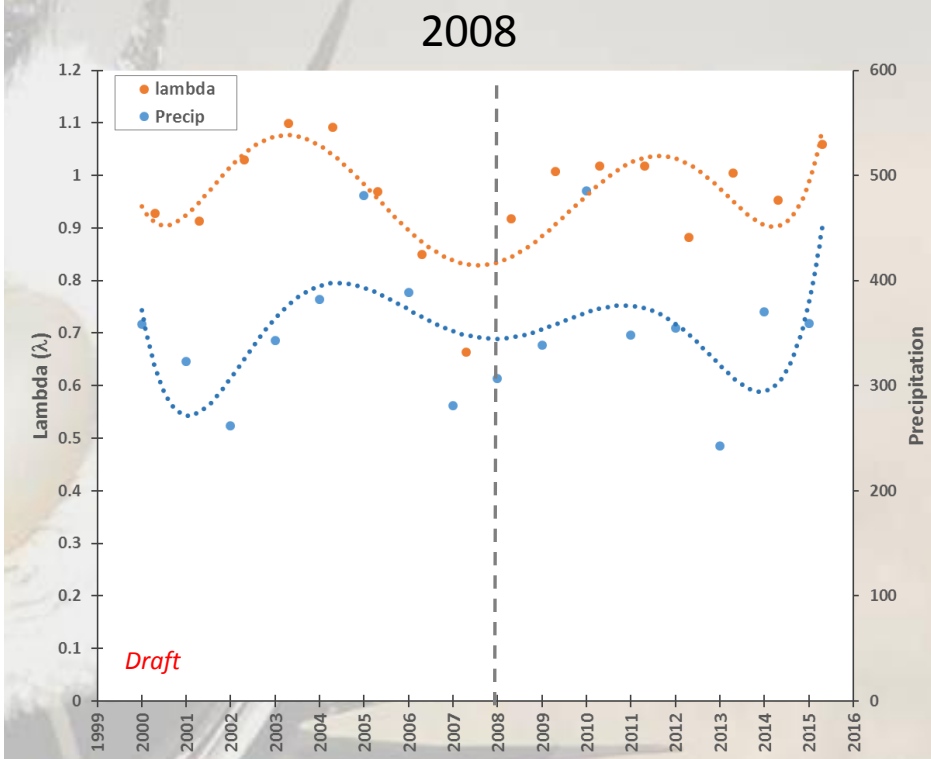




Derived from Coates et al. 2017

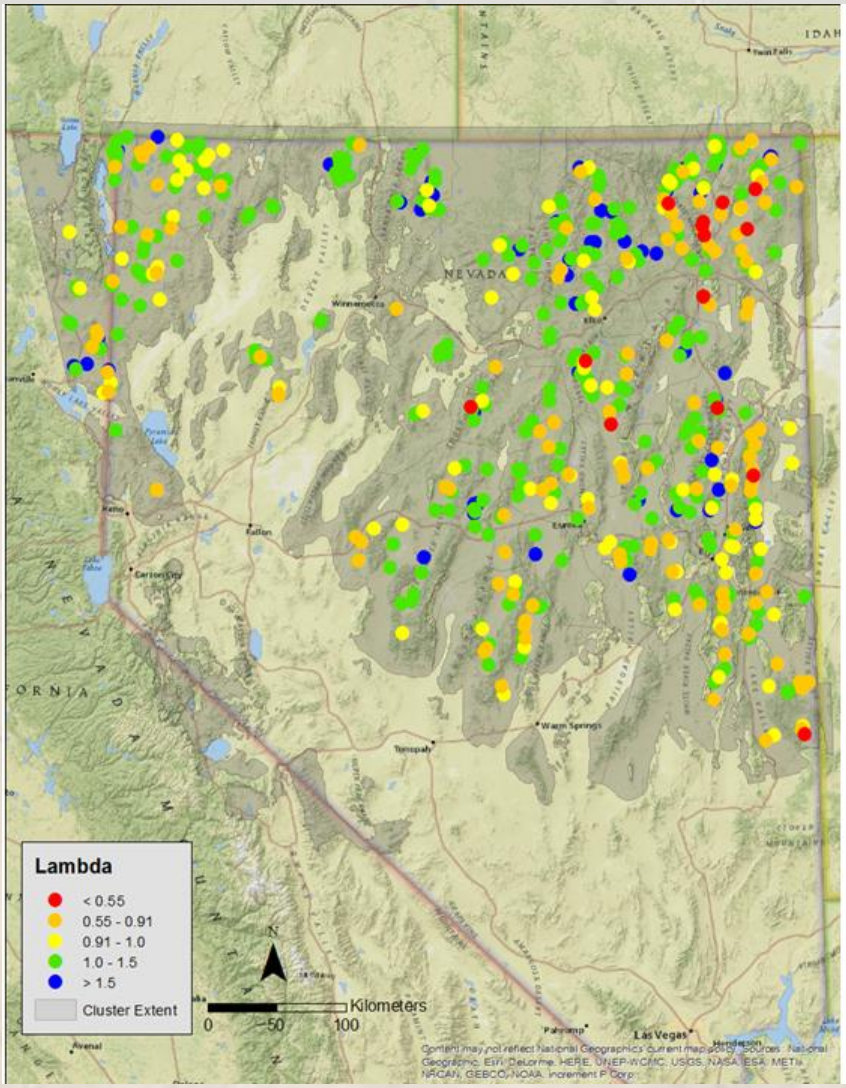
Lek-Level Variation in Population Trends

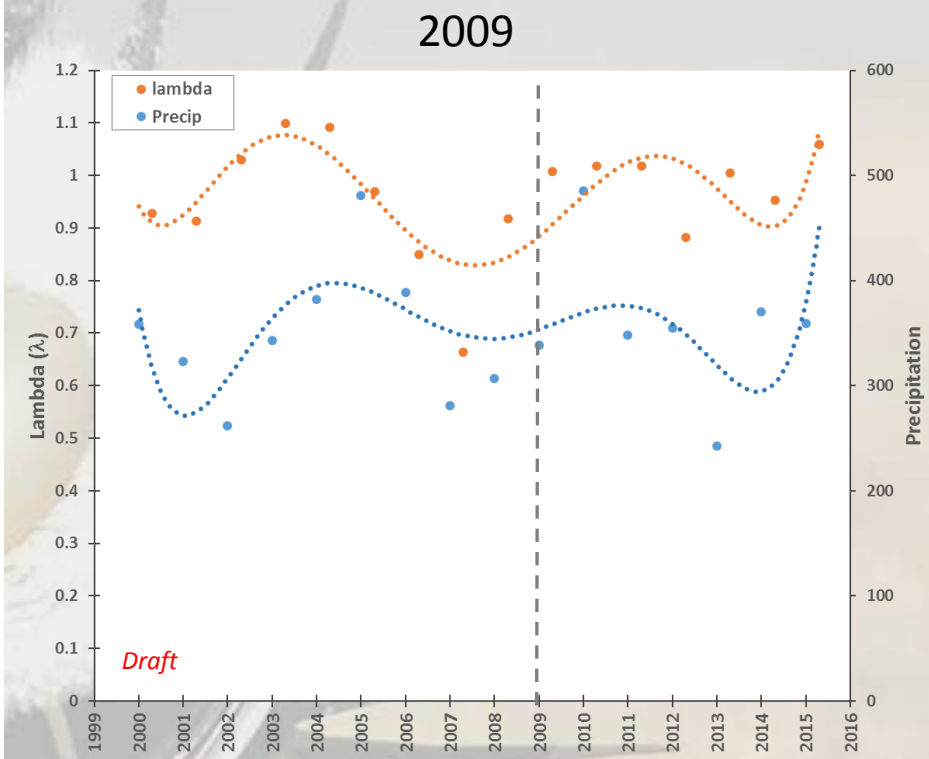




Derived from Coates et al. 2017

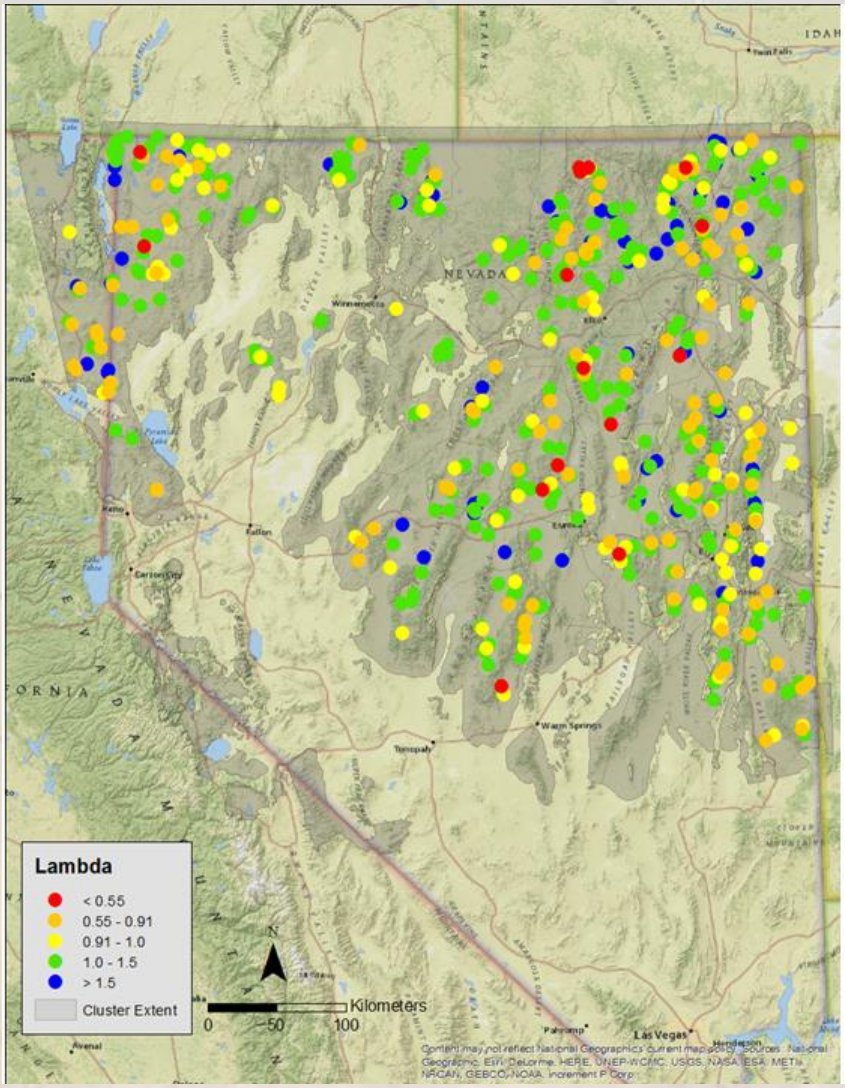
Lek-Level Variation in Population Trends

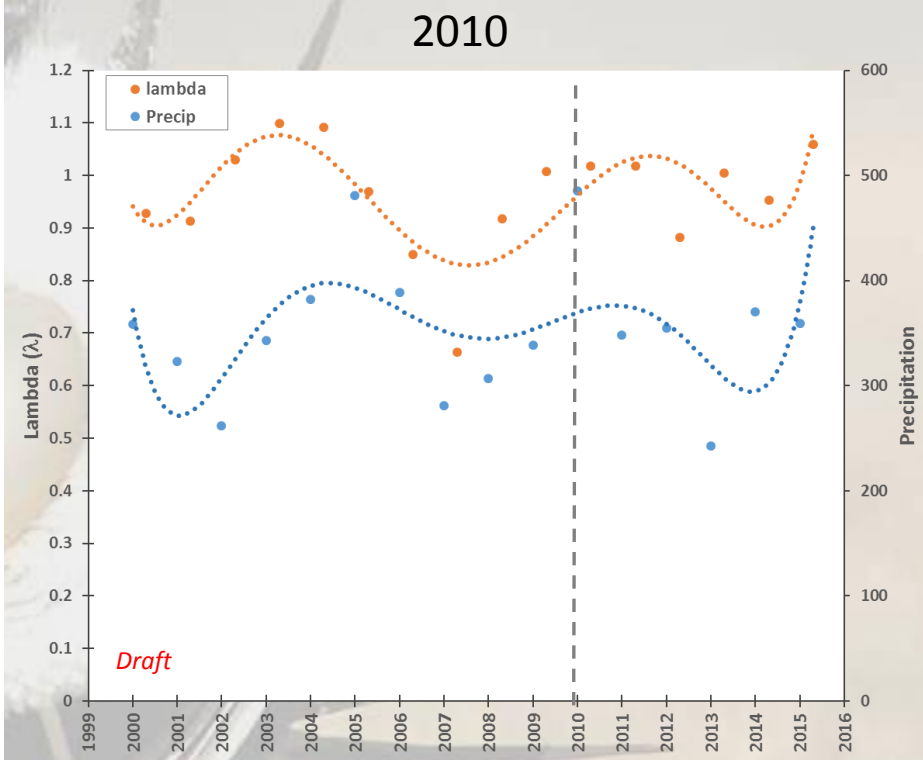




Derived from Coates et al. 2017

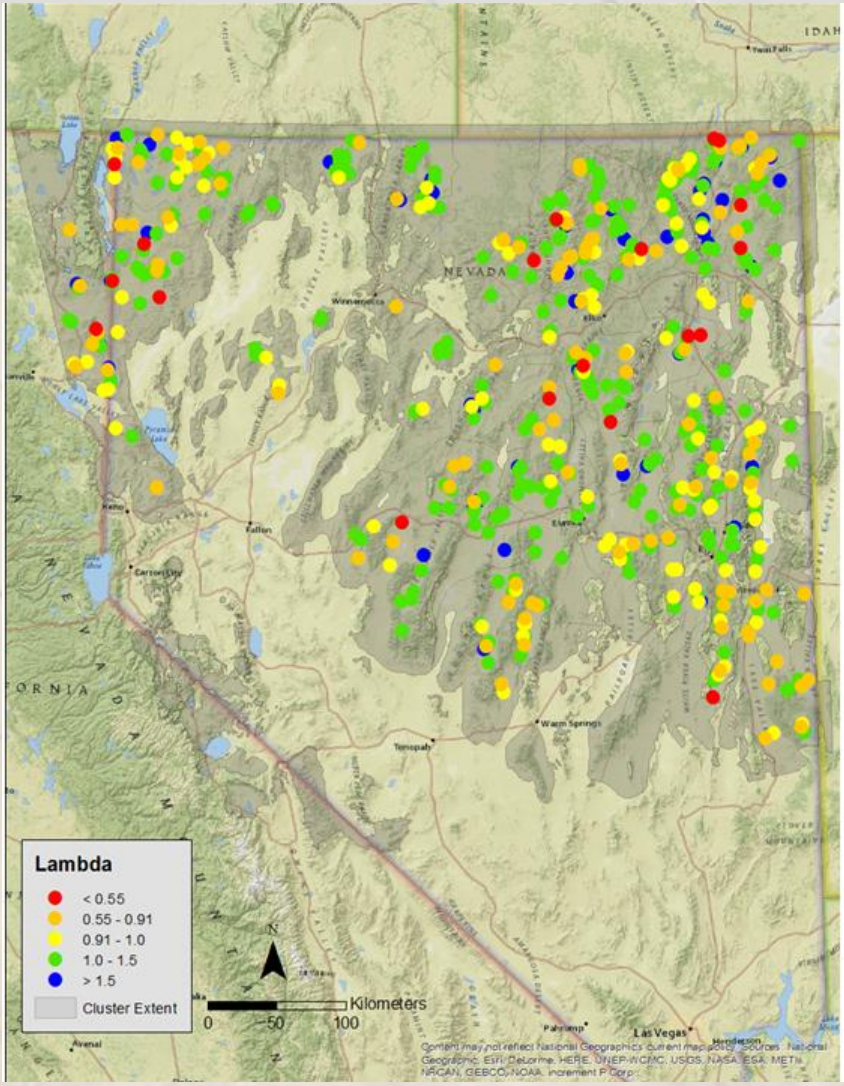
Lek-Level Variation in Population Trends

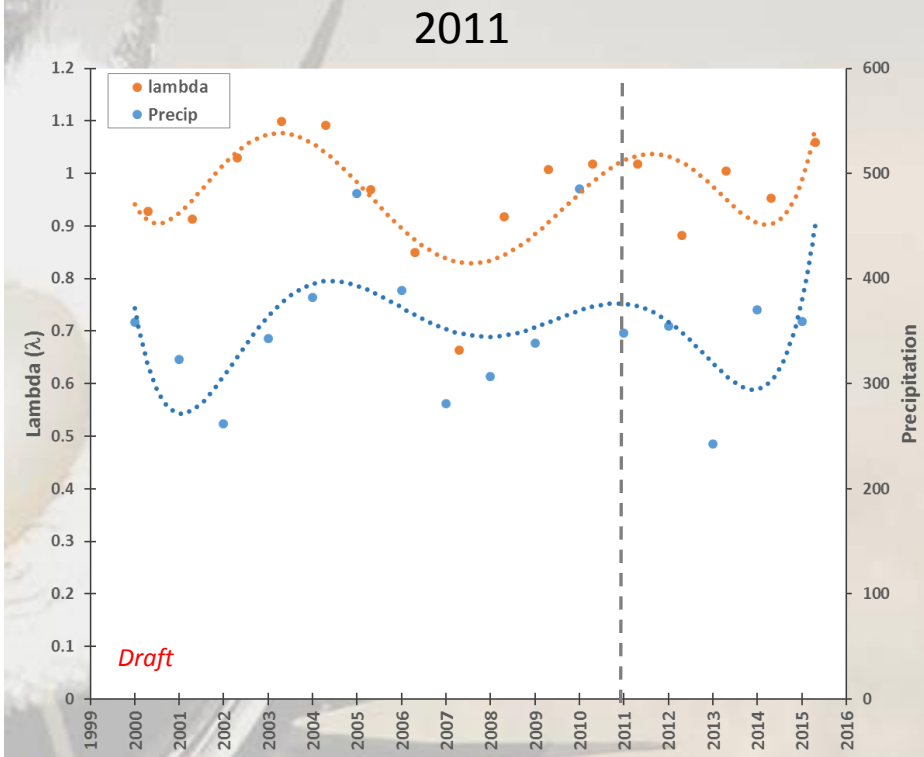




Derived from Coates et al. 2017

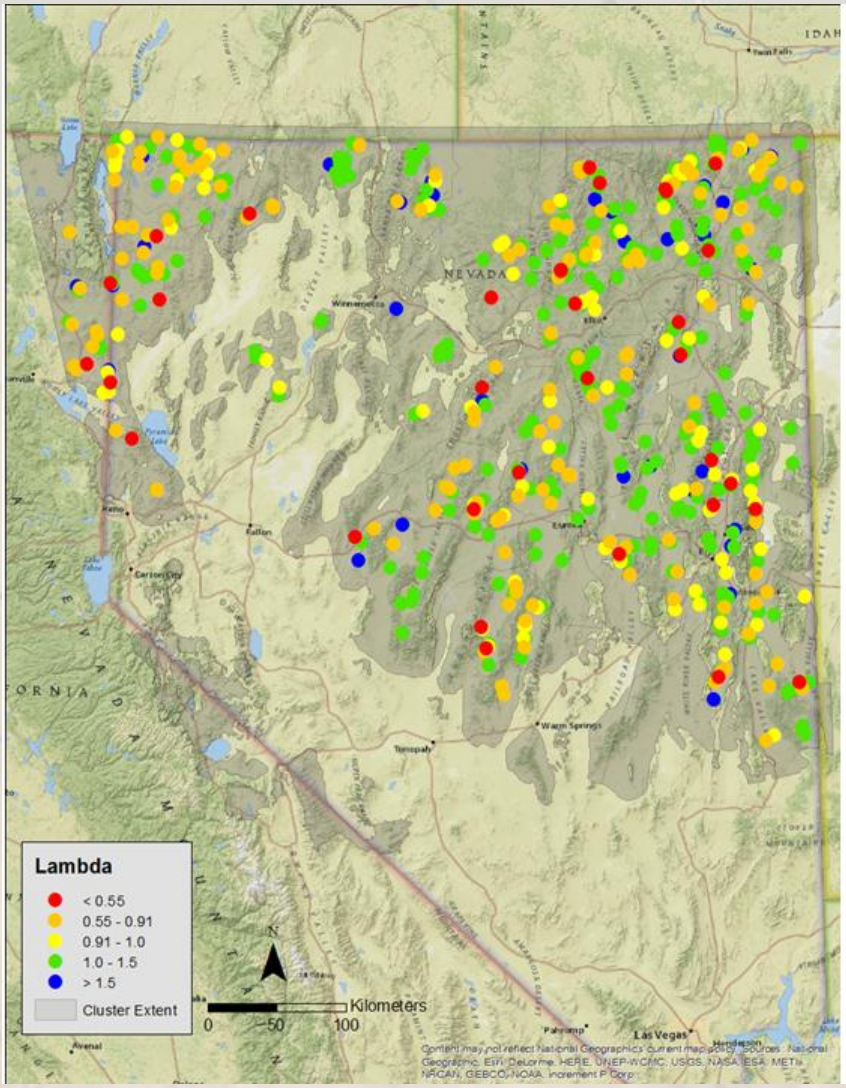
Lek-Level Variation in Population Trends

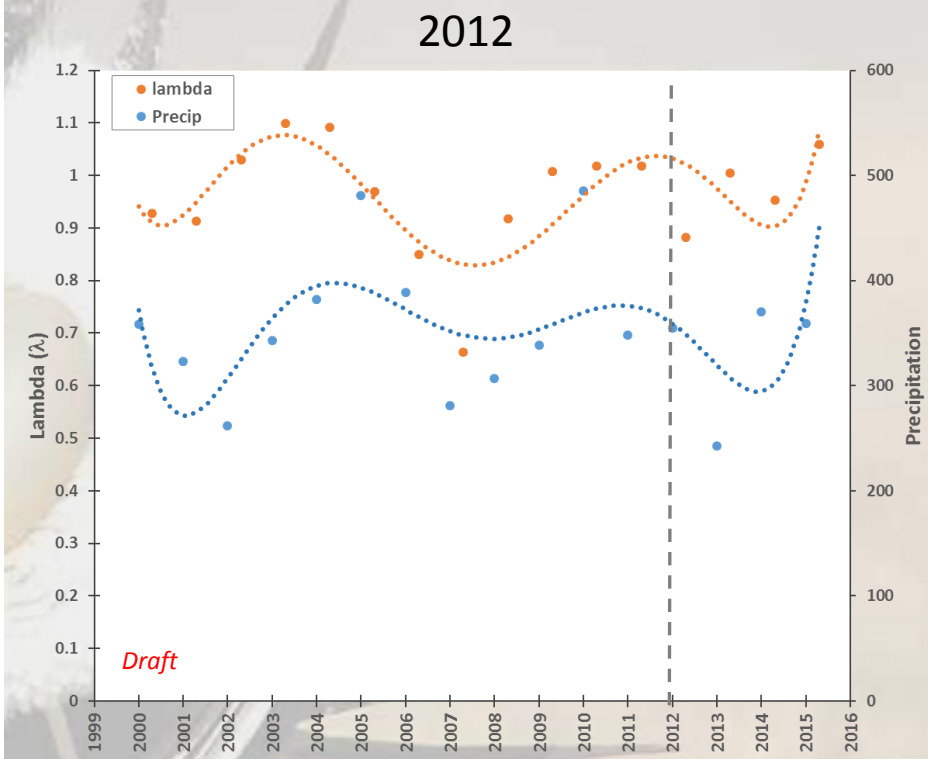




Derived from Coates et al. 2017

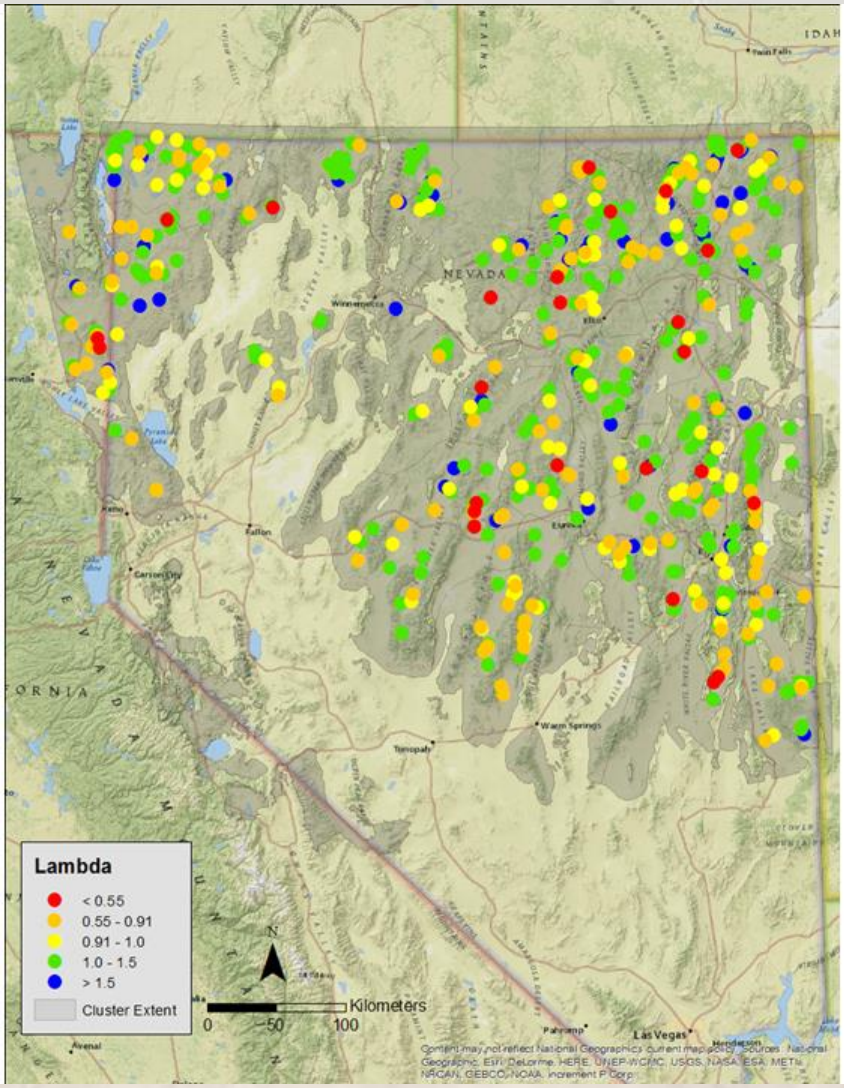
Lek-Level Variation in Population Trends

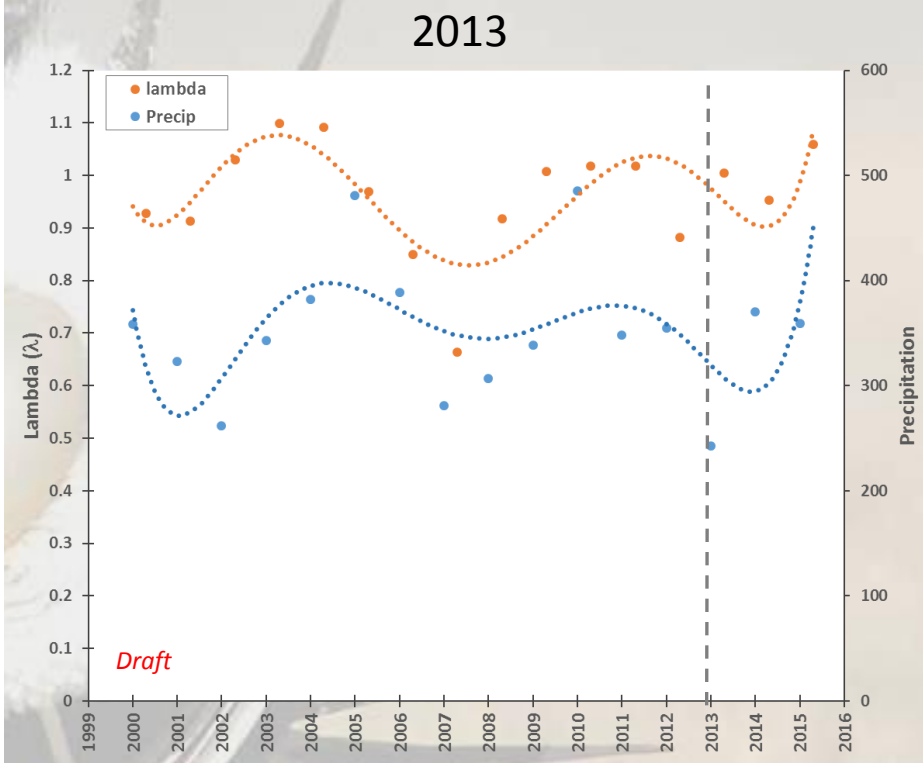




Derived from Coates et al. 2017

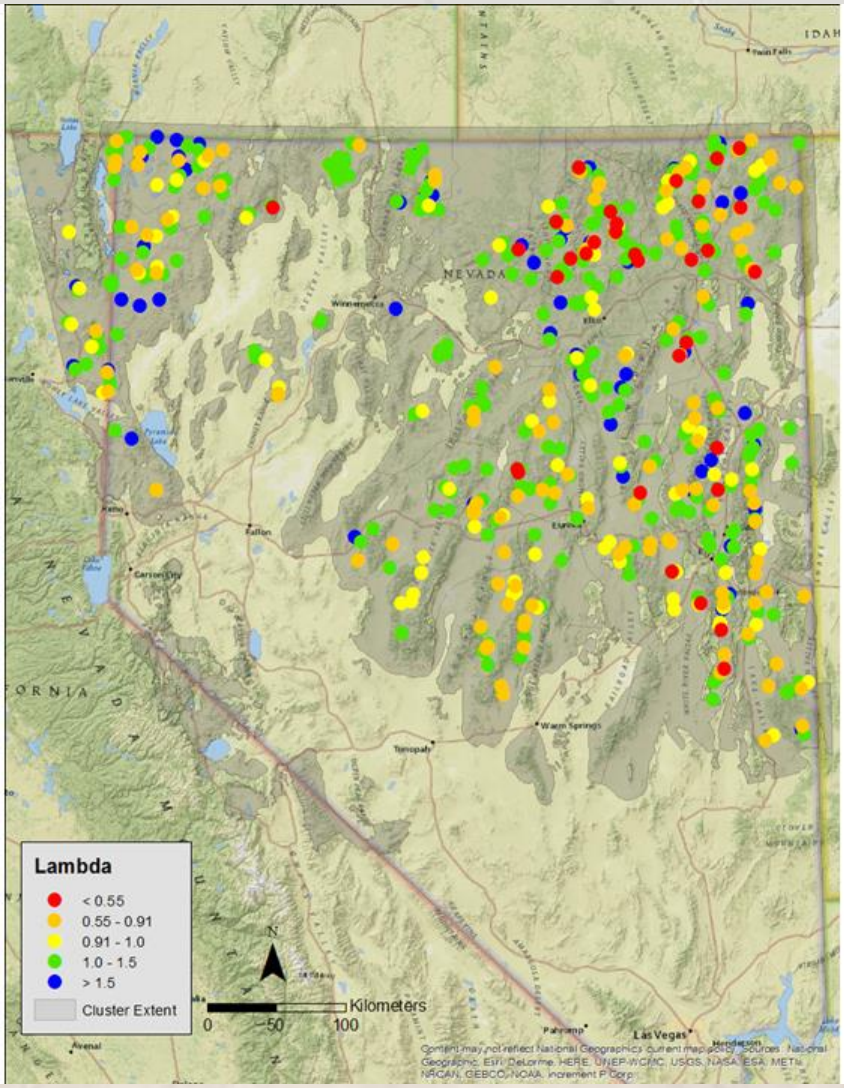
Lek-Level Variation in Population Trends

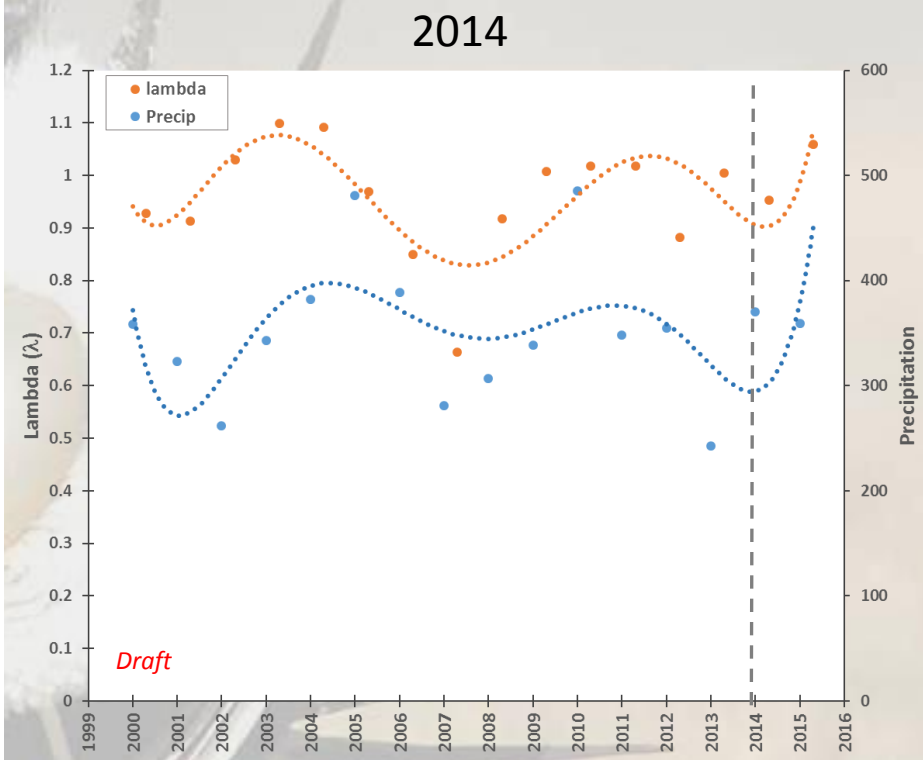




Derived from Coates et al. 2017

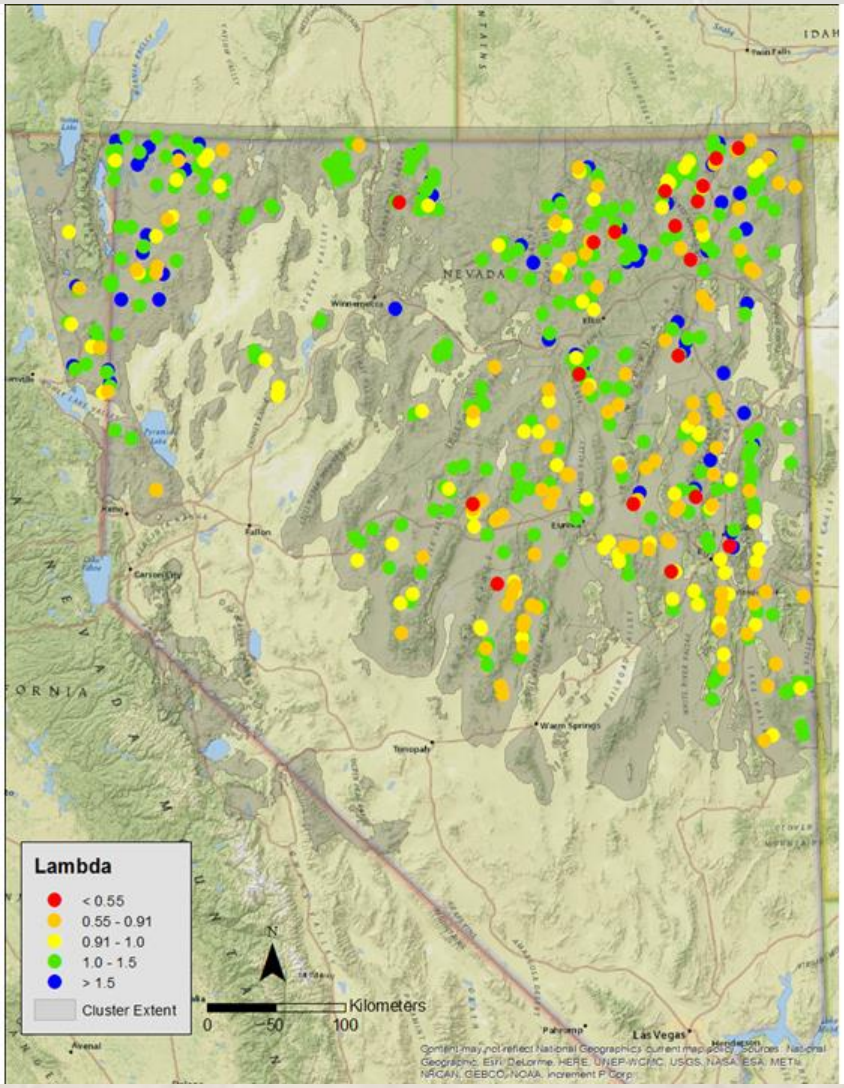
Lek-Level Variation in Population Trends

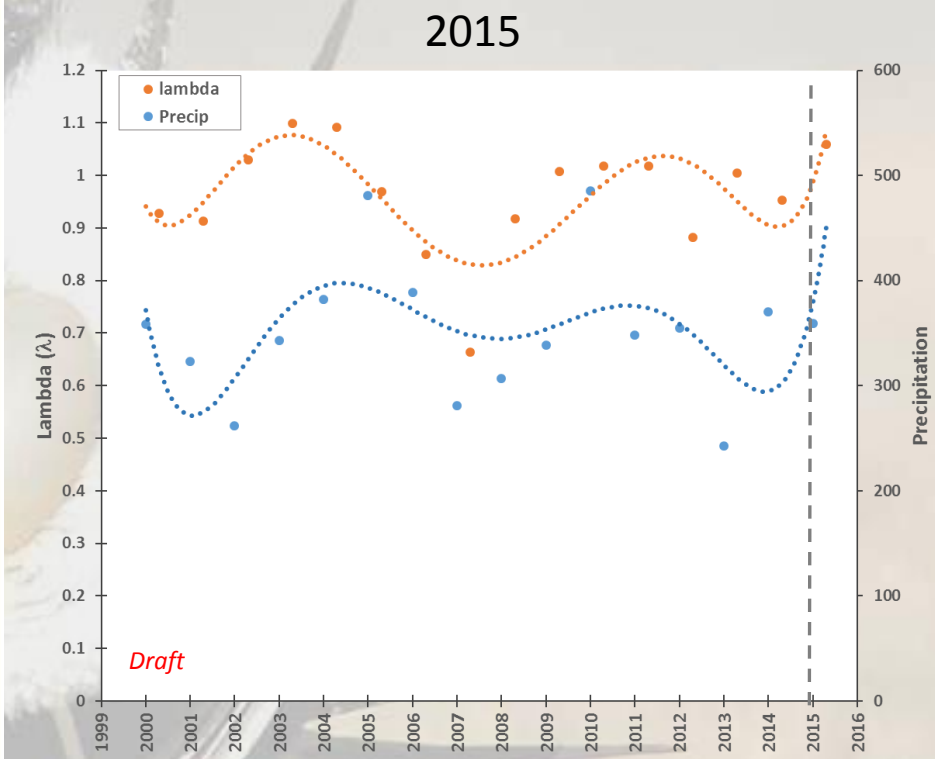




Derived from Coates et al. 2017

Lek-Level Variation in Population Trends





Derived from Coates et al. 2017

Integrated Population Model

State Process
Demographic Data

Estimated Pop. Size
(N_{t-1})

↓

Survival and Fecundity
Parameters

↓

Estimated Pop. Size
(N_t)

Observation Process
Lek Count Data

$$y_t = N_t + \varepsilon_t$$
$$\varepsilon_t \sim Normal(0, \sigma^2)$$

- Accounts for observation error
- Normally distributed

Demographic Components

Fecundity

Nest Propensity	Clutch Size	Nest Survival	Hatchability	Chick Survival	Juvenile Survival
Prior (Taylor et al. 2012)	Poisson model	Proportional Hazards model	Binomial model	Binomial model	Prior (Taylor et al. 2012)

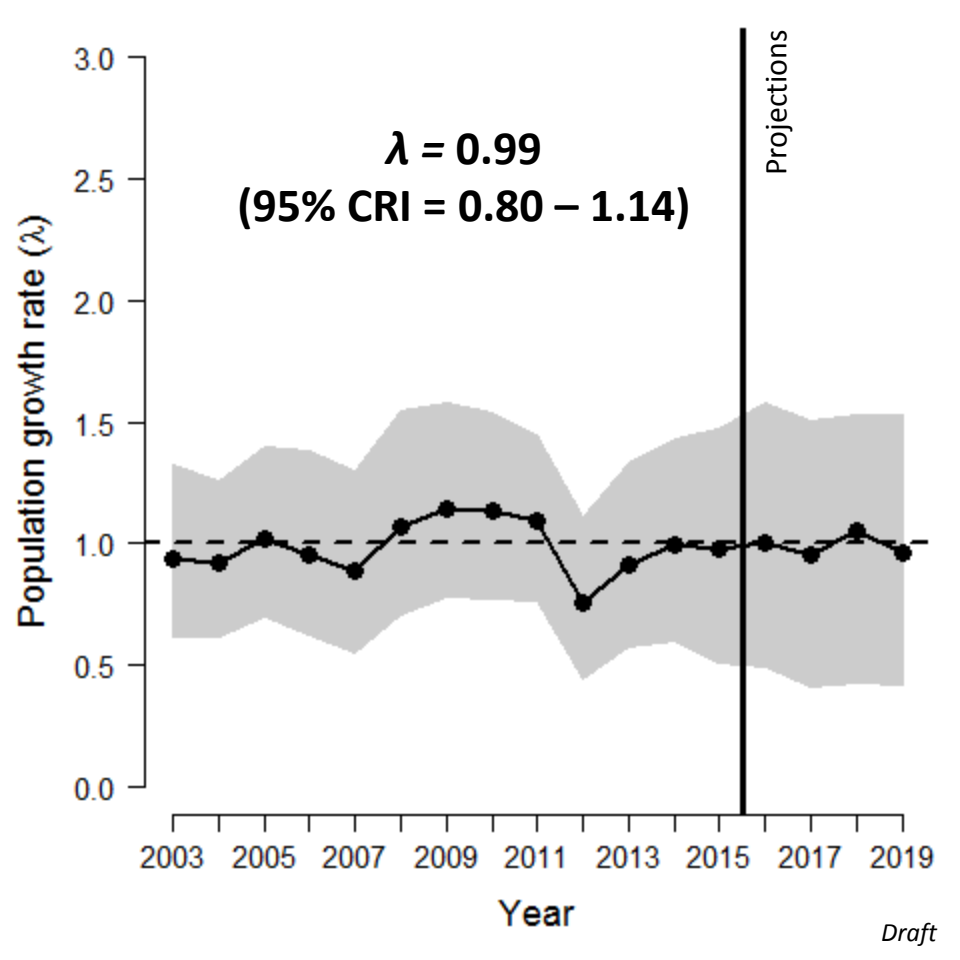
$$F_{ija} = (np1_a \times cl1_{ija} \times ns1_{ija} \times h_a \times cs_{ija} \times js_a) + \left((1 - ns1_{ija}) + np2_a \times cl2_{ija} \times ns2_{ija} \times h_a \times cs_{ija} \times js_a\right)$$

Second nest attempts

i = site; *j* = year; *a* = age class

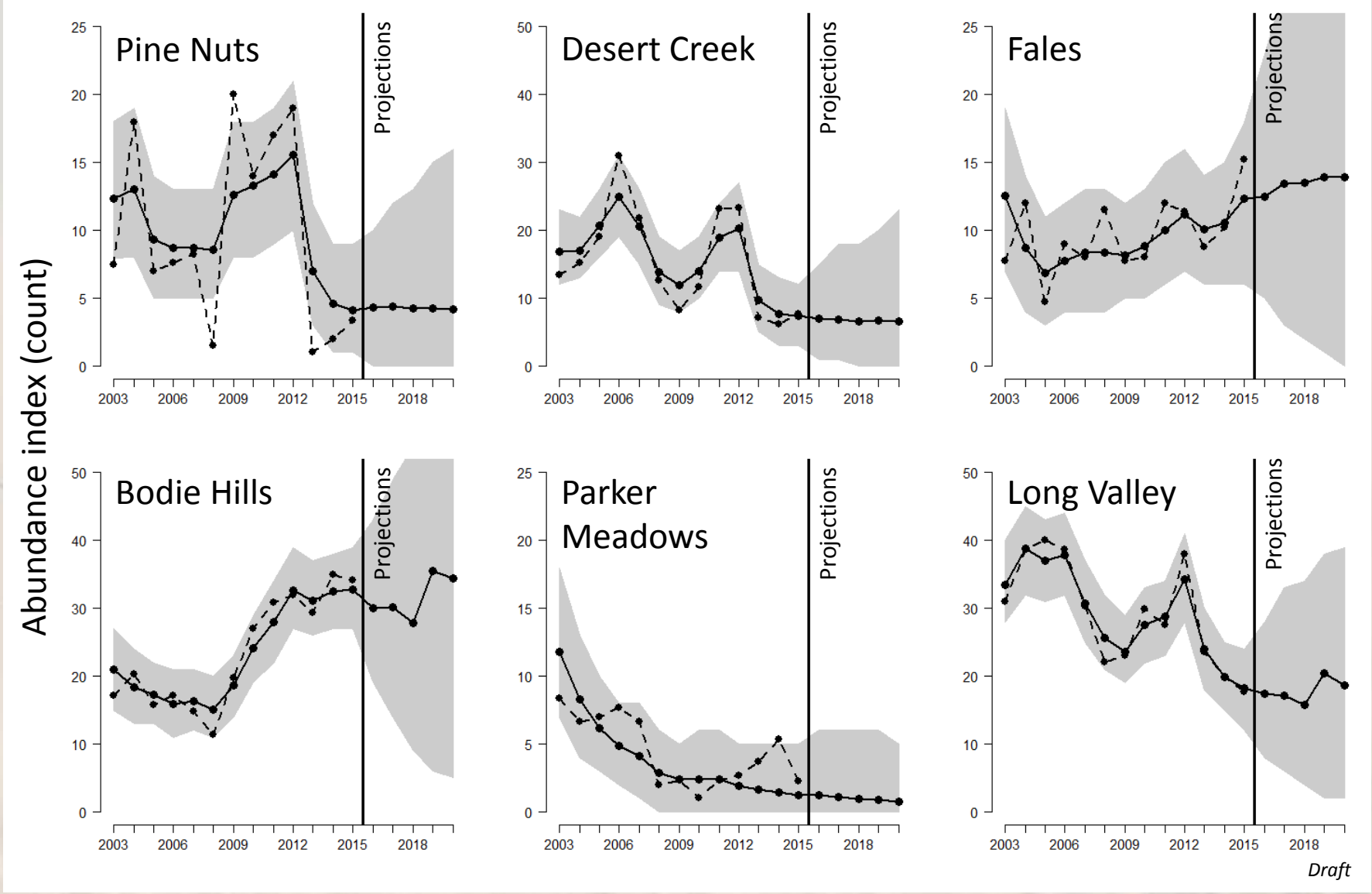
Adult and Yearling Survival (s)
Proportional Hazards model

Bi-State Wide Population Growth Rate Trend



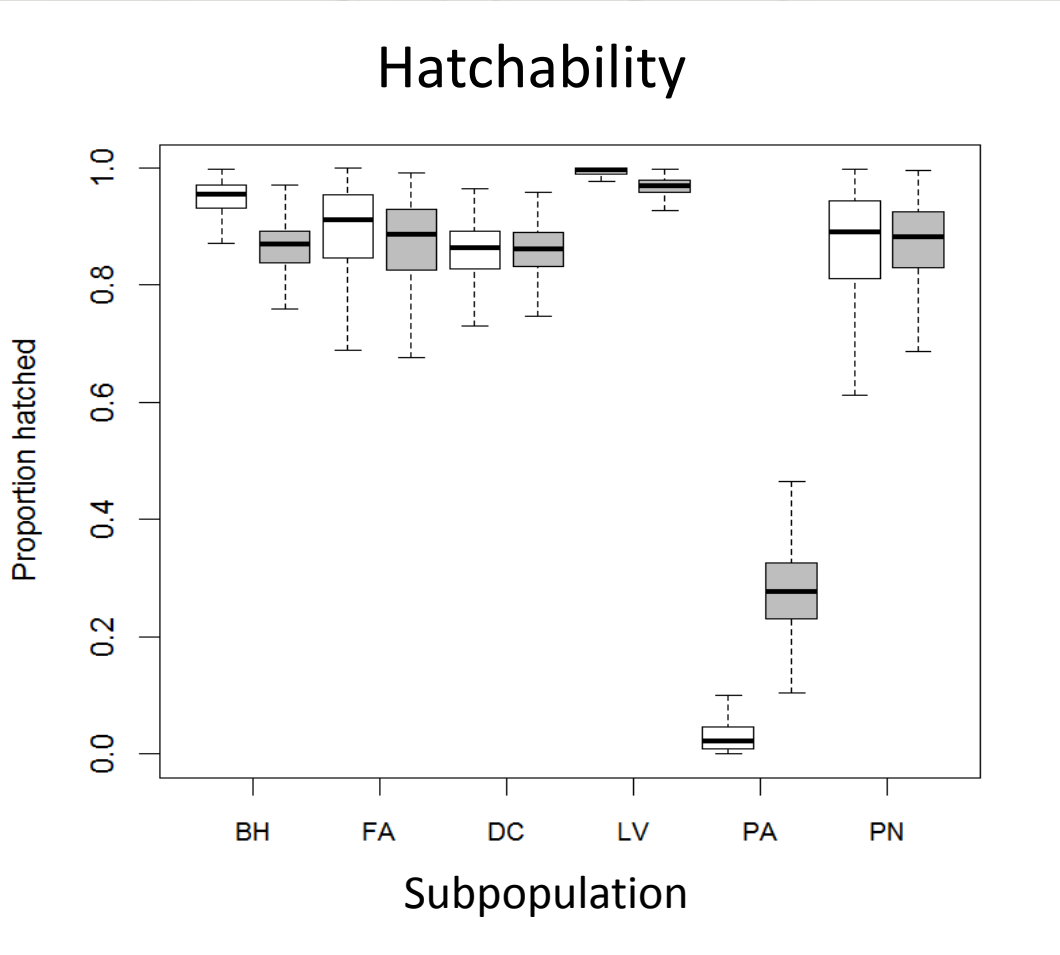
Coates et al. 2014; Coates et al. In Press, The Auk

Bi-State Subpopulation Abundance Estimates



Coates et al. 2014; Coates et al. In Press, The Auk

Limiting Vital Rate

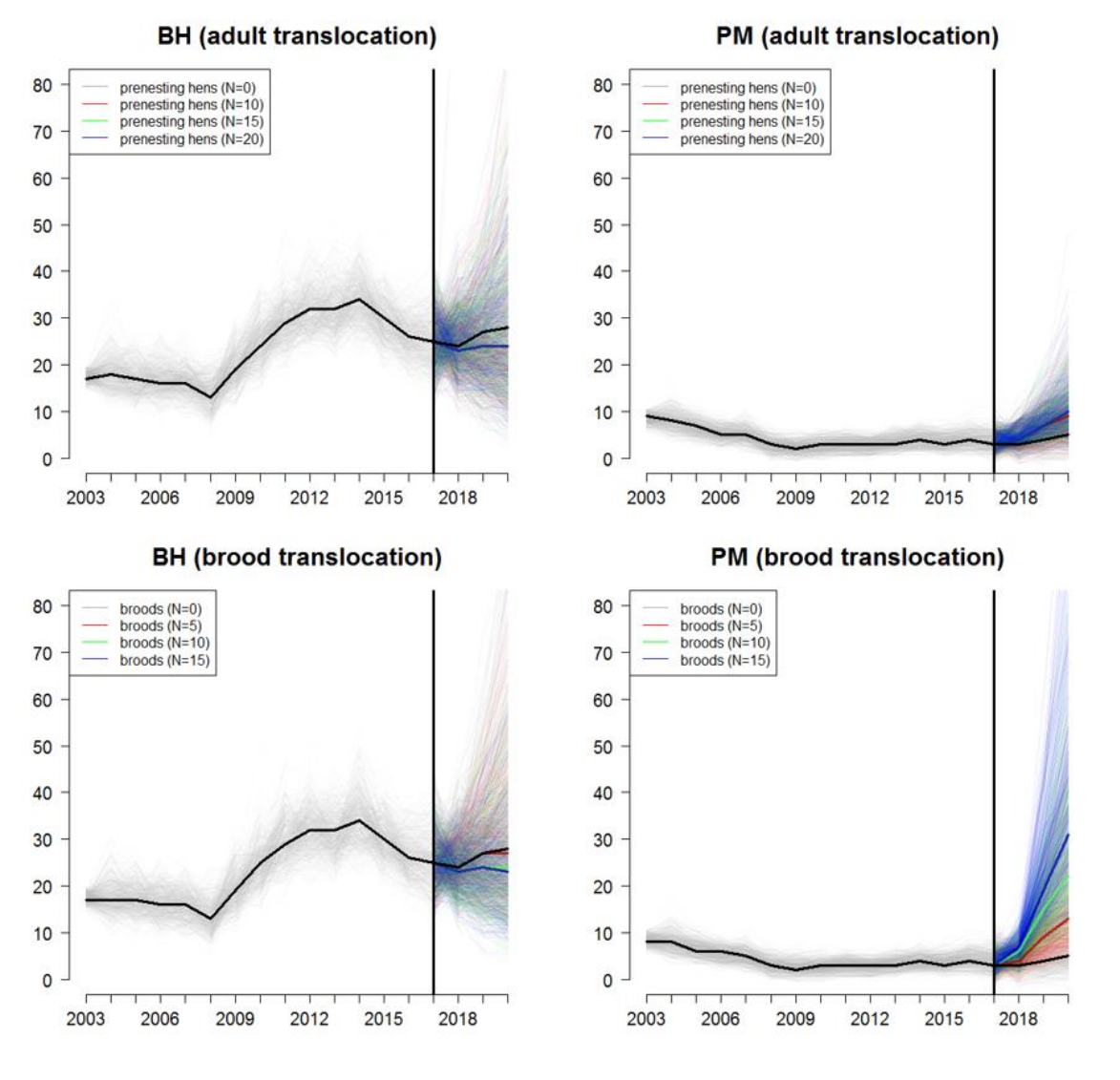


Hatchability was only limiting vital rate, likely result of low fertility rate

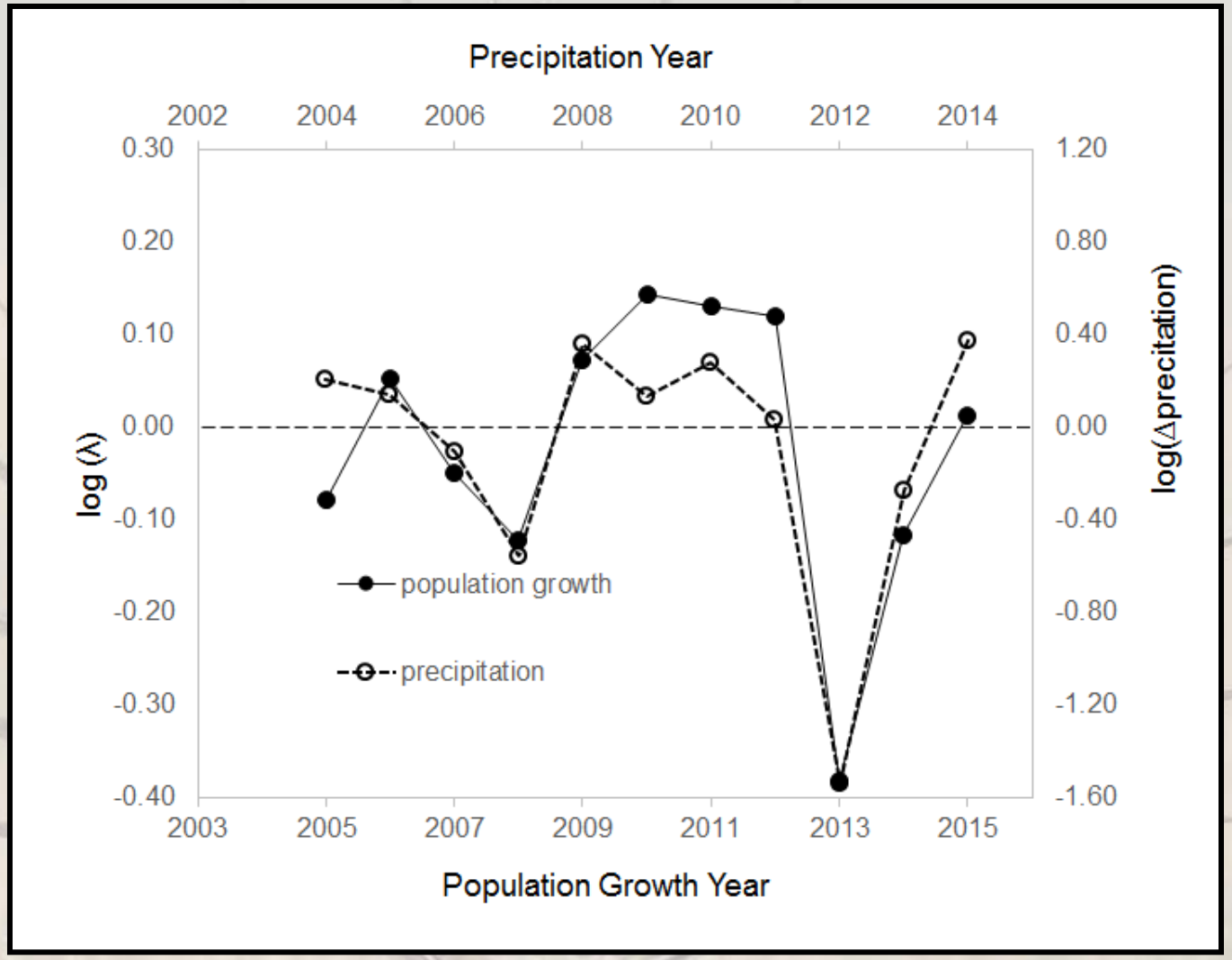
Coates et al. 2014; Coates et al. In Press, The Auk

Translocation Program to Save Parker Meadows

Using the IPM to Inform Translocation Strategies (Pre-Nesting Hens vs. Broods)

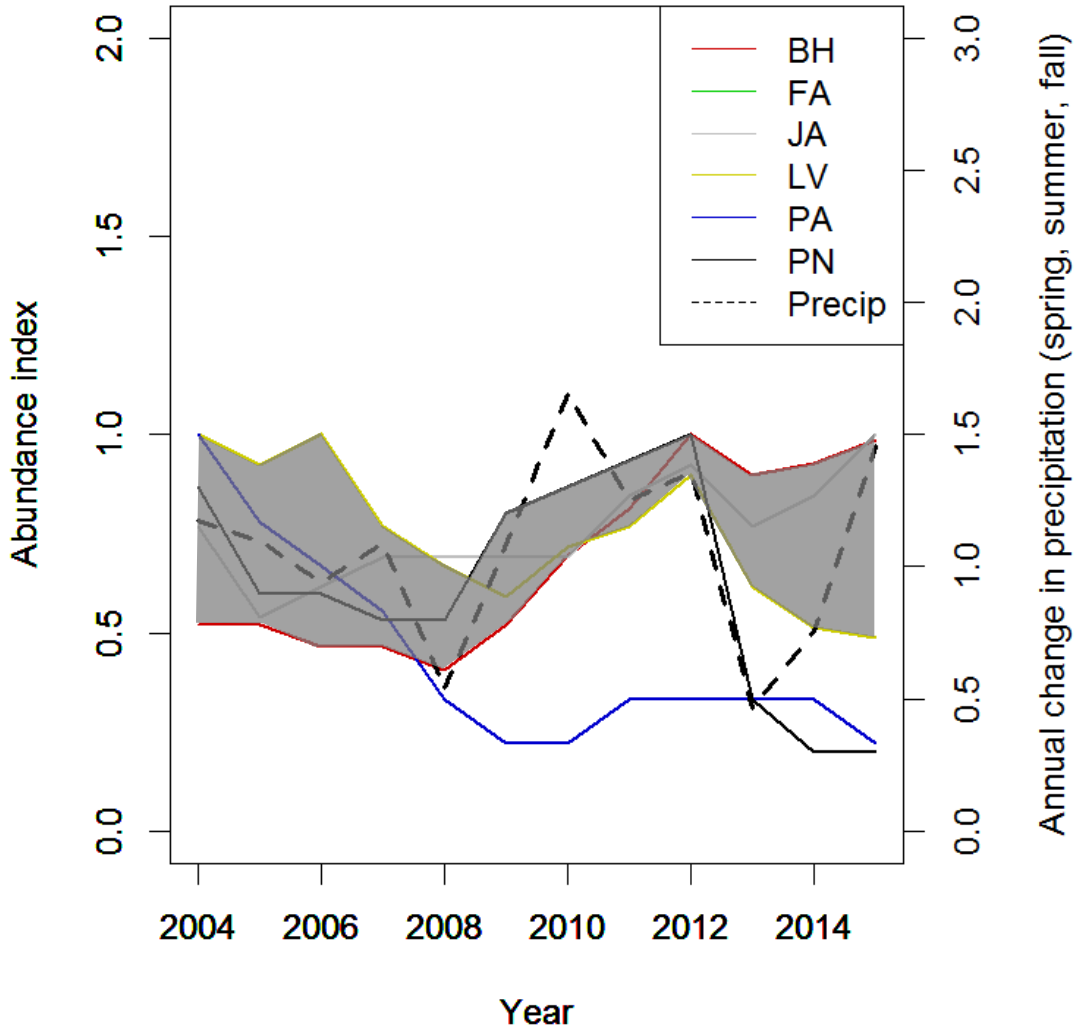


Influence of Climatic Factors



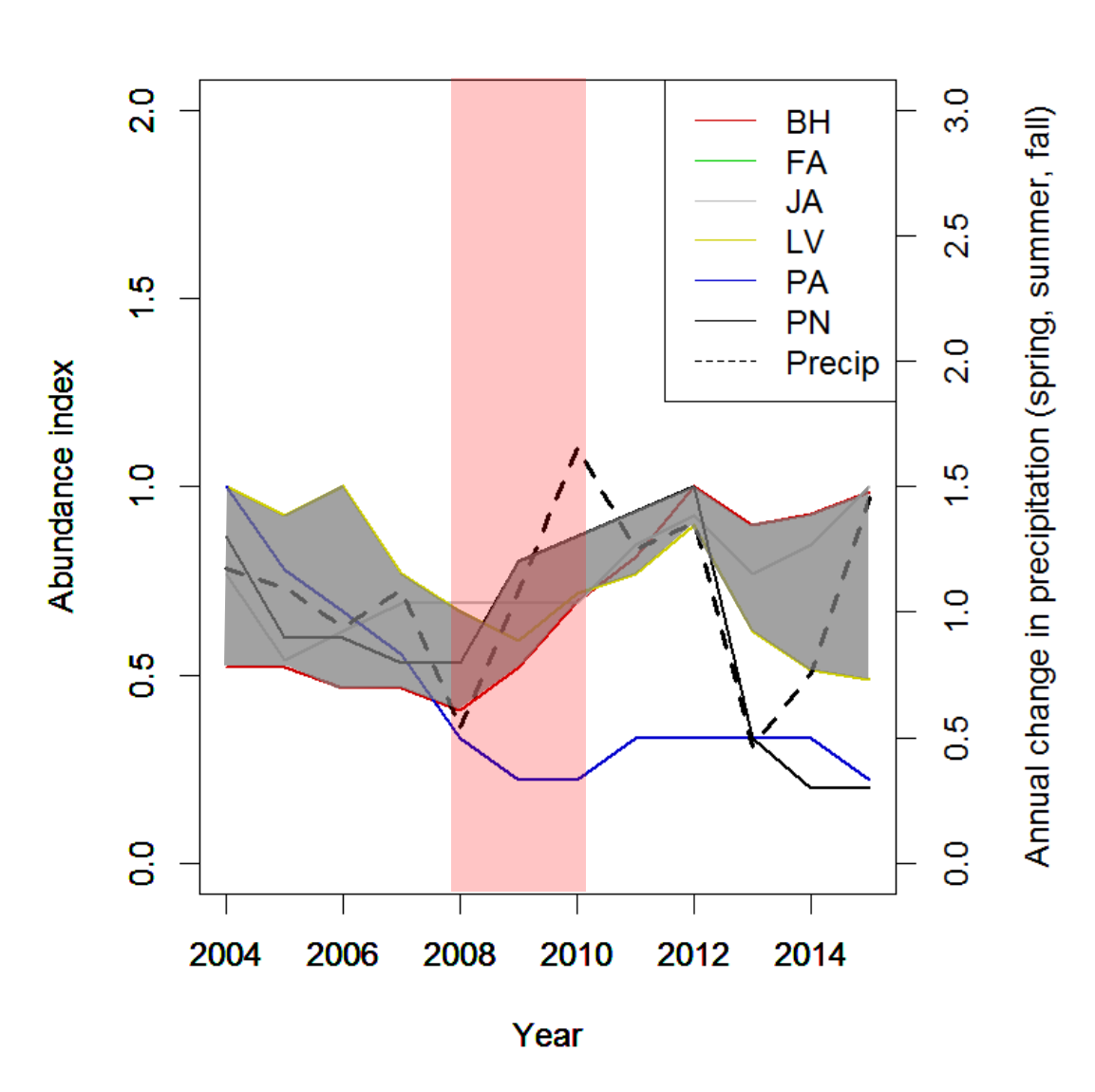
Coates et al. In Press, The Auk

Climate Covariates



Coates et al. In Press, The Auk

Climate Covariates



Coates et al. In Press, The Auk

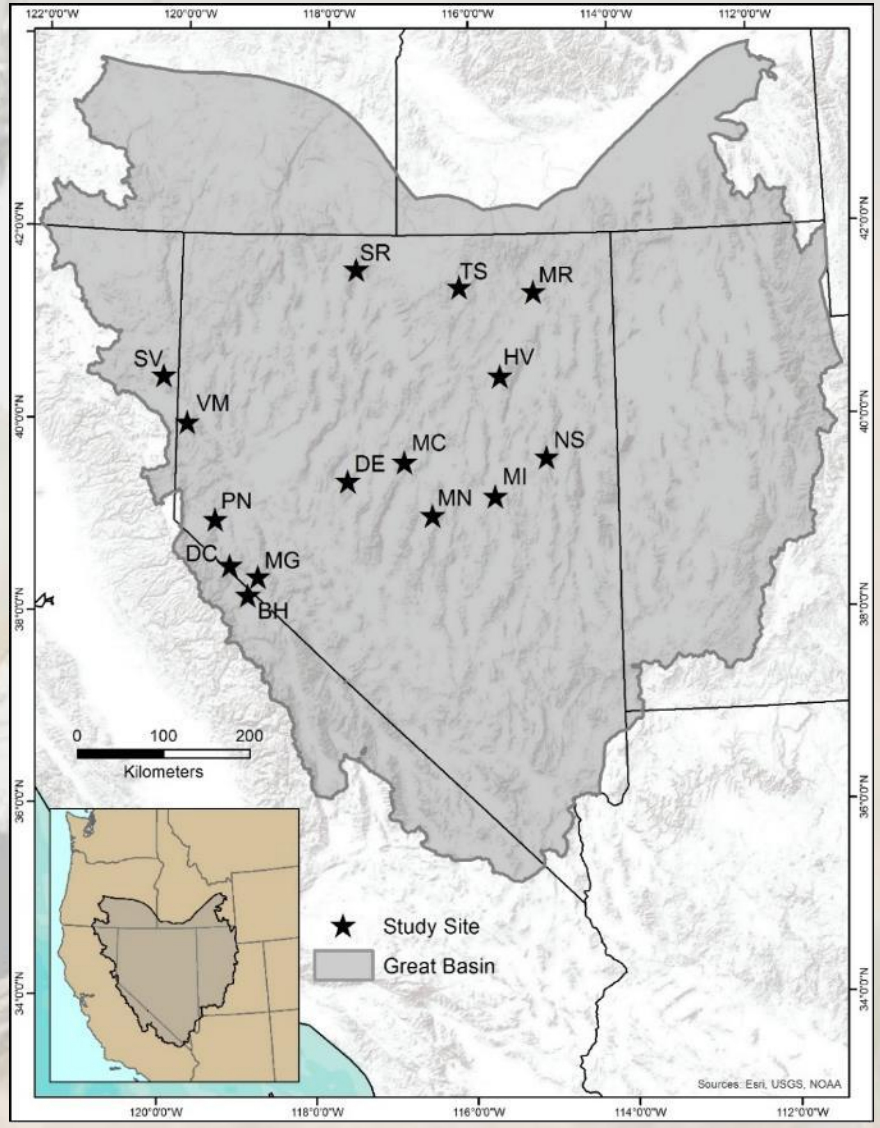
4b. Population Monitoring Tools

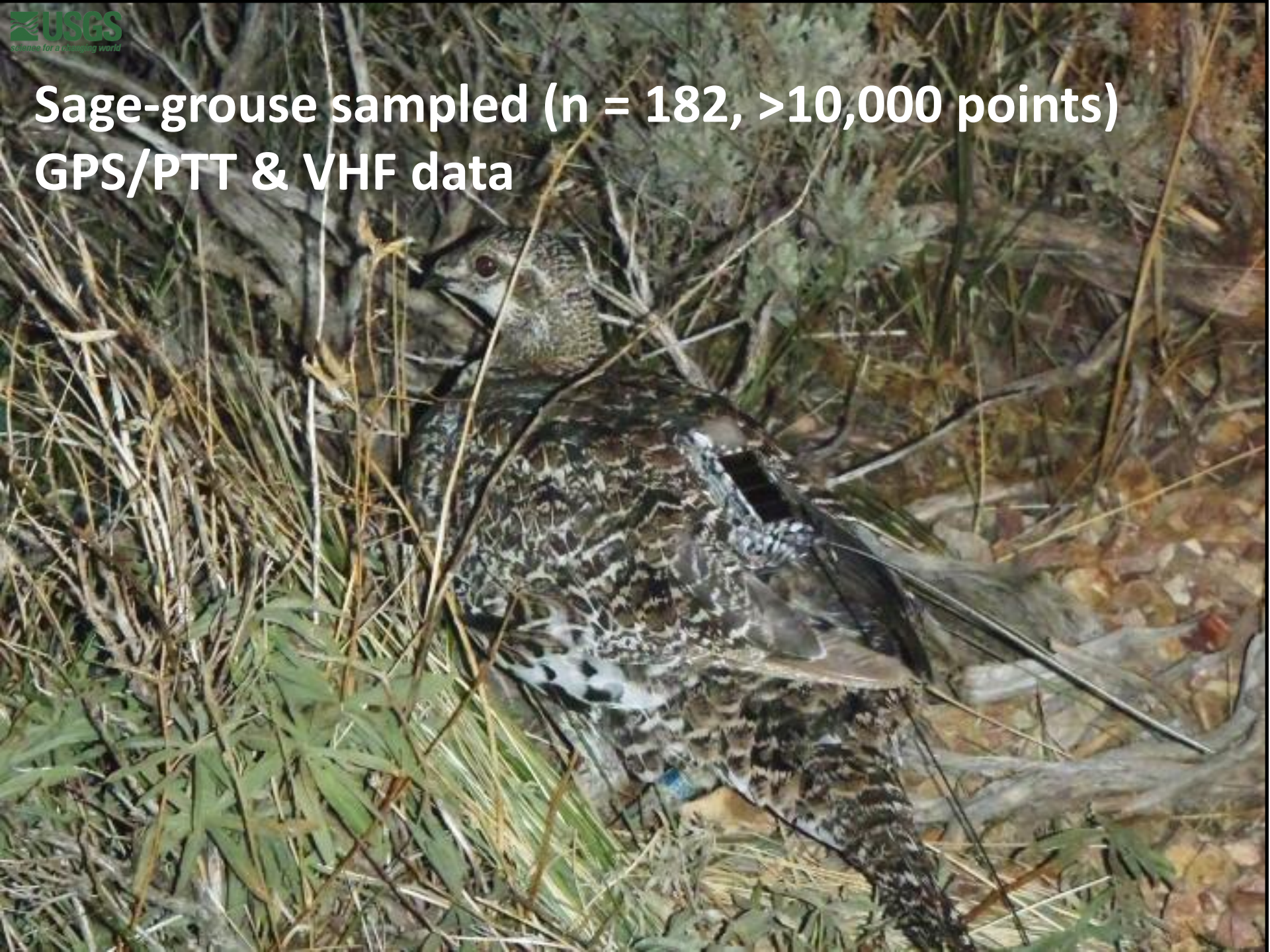
- Estimate trends across multiple spatial scales (lek count model; state-space, N-mix)
- Establish an early warning system for populations in decline based on scale-dependent comparisons
- Align scale of demographic response to management action

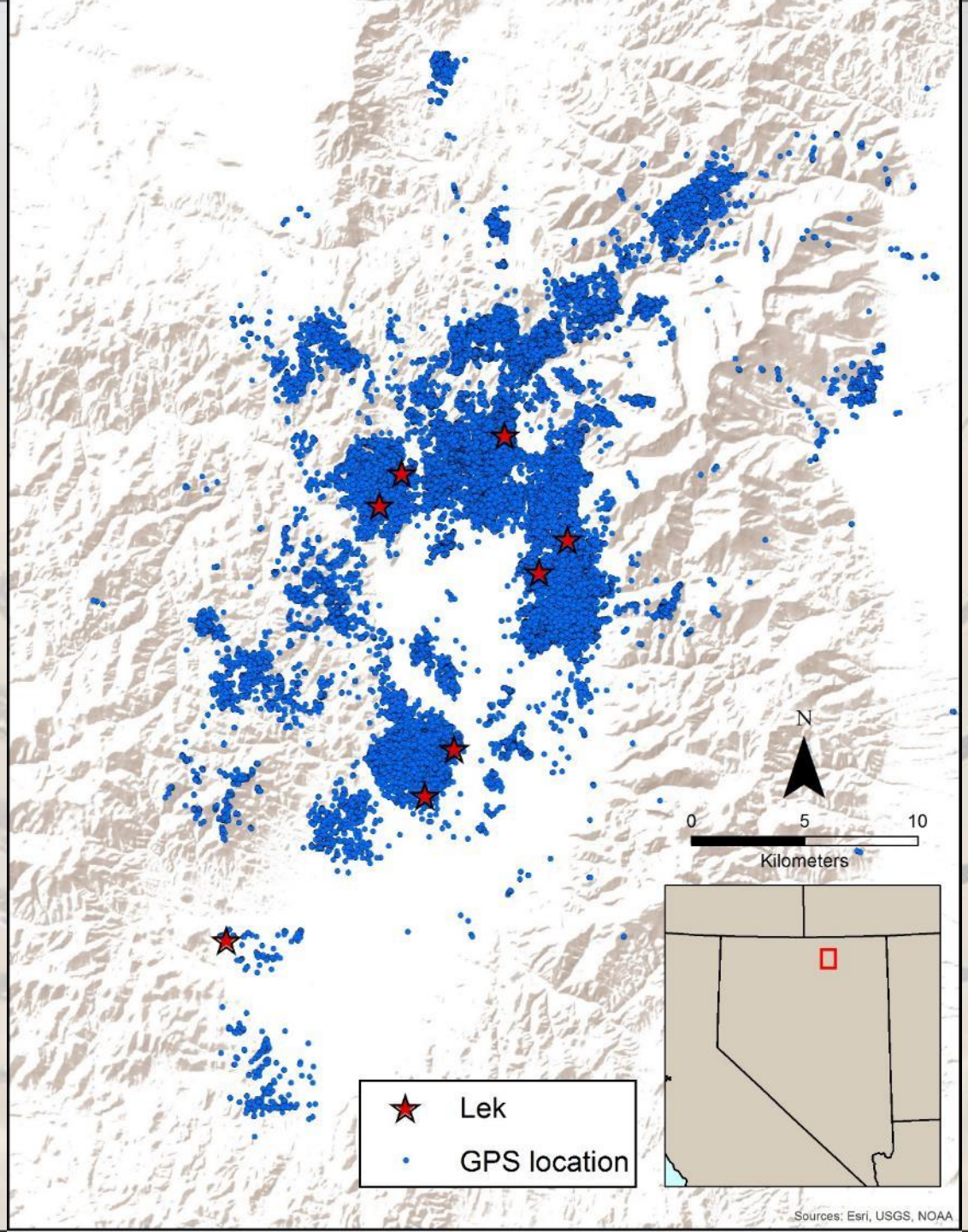
Advancements to Improve Population Estimates

Studies to inform detection probability and visitation rates

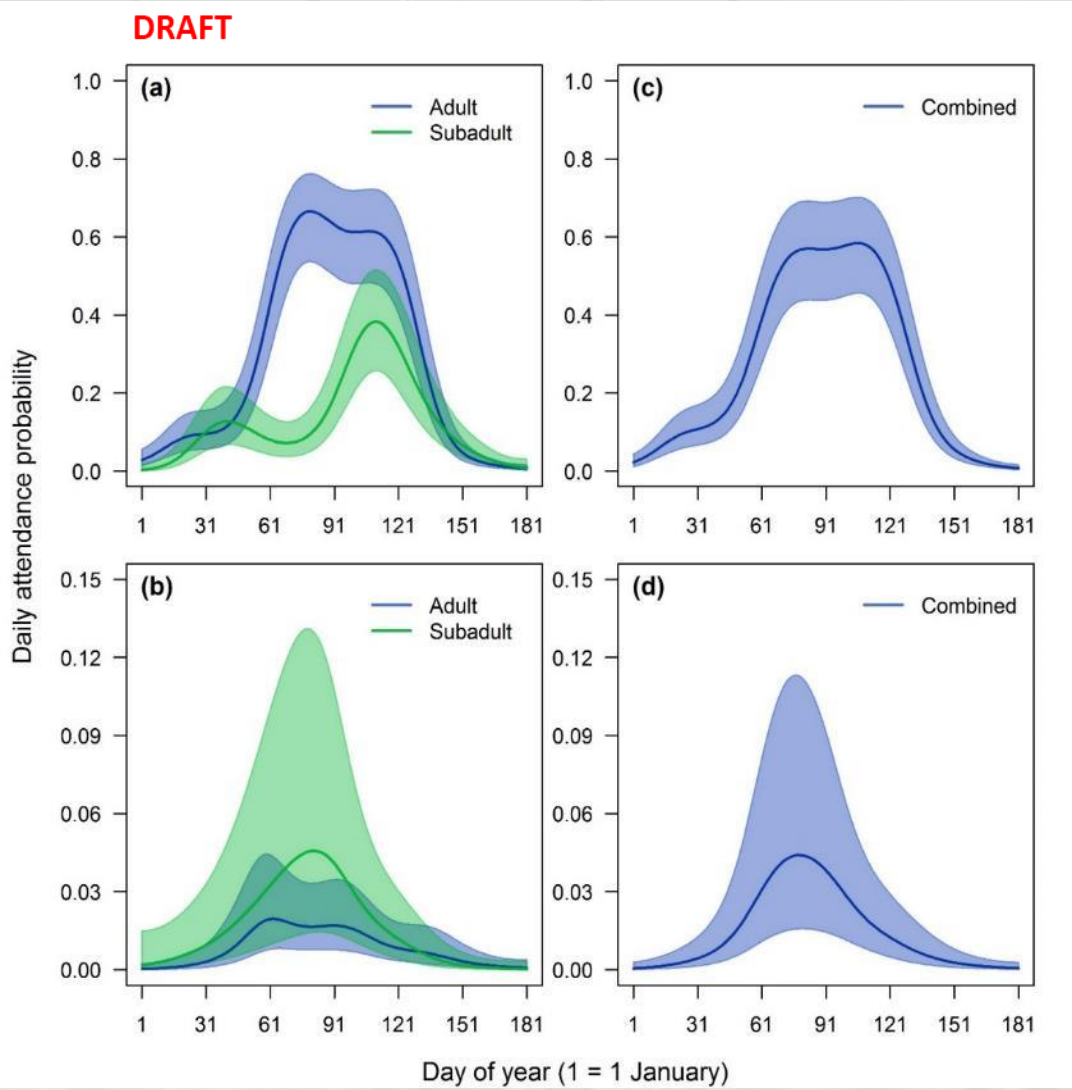
- Accounting for Attendance Rates and Detection Error (State-Space and N-mix Models)
- Lek Count Data
  - Repeated lek counts
  - 15 sites
  - 1,186 counts
- GPS Data (Attendance Rates)
  - 13 sites
  - >100 GPS marked malesmales



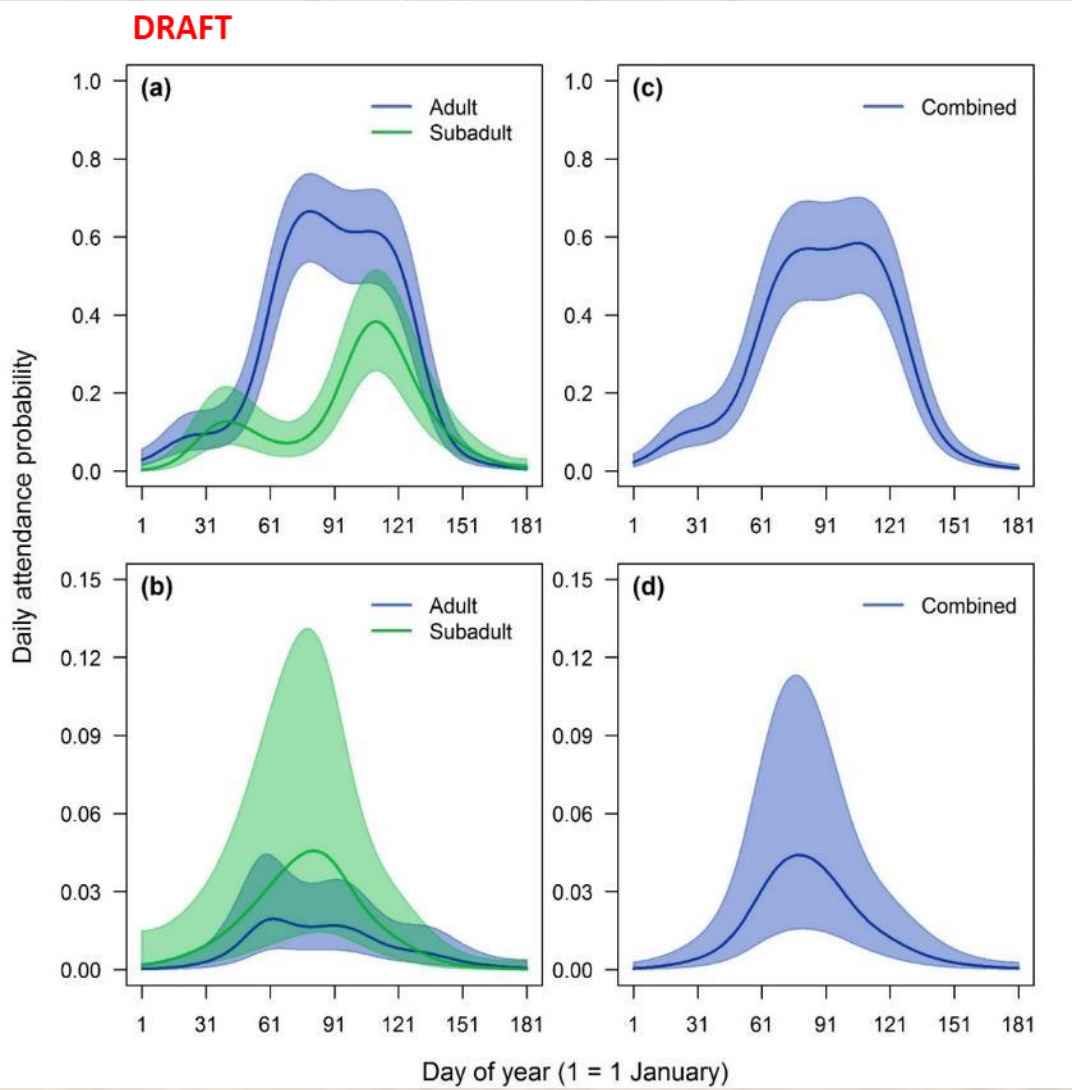

Sage-grouse sampled (n = 182, >10,000 points)
GPS/PTT & VHF data


N
0
5
10
Kilometers
Lek
GPS location
Sources: Esri, USGS, NOAA

Accounting for visitation rate

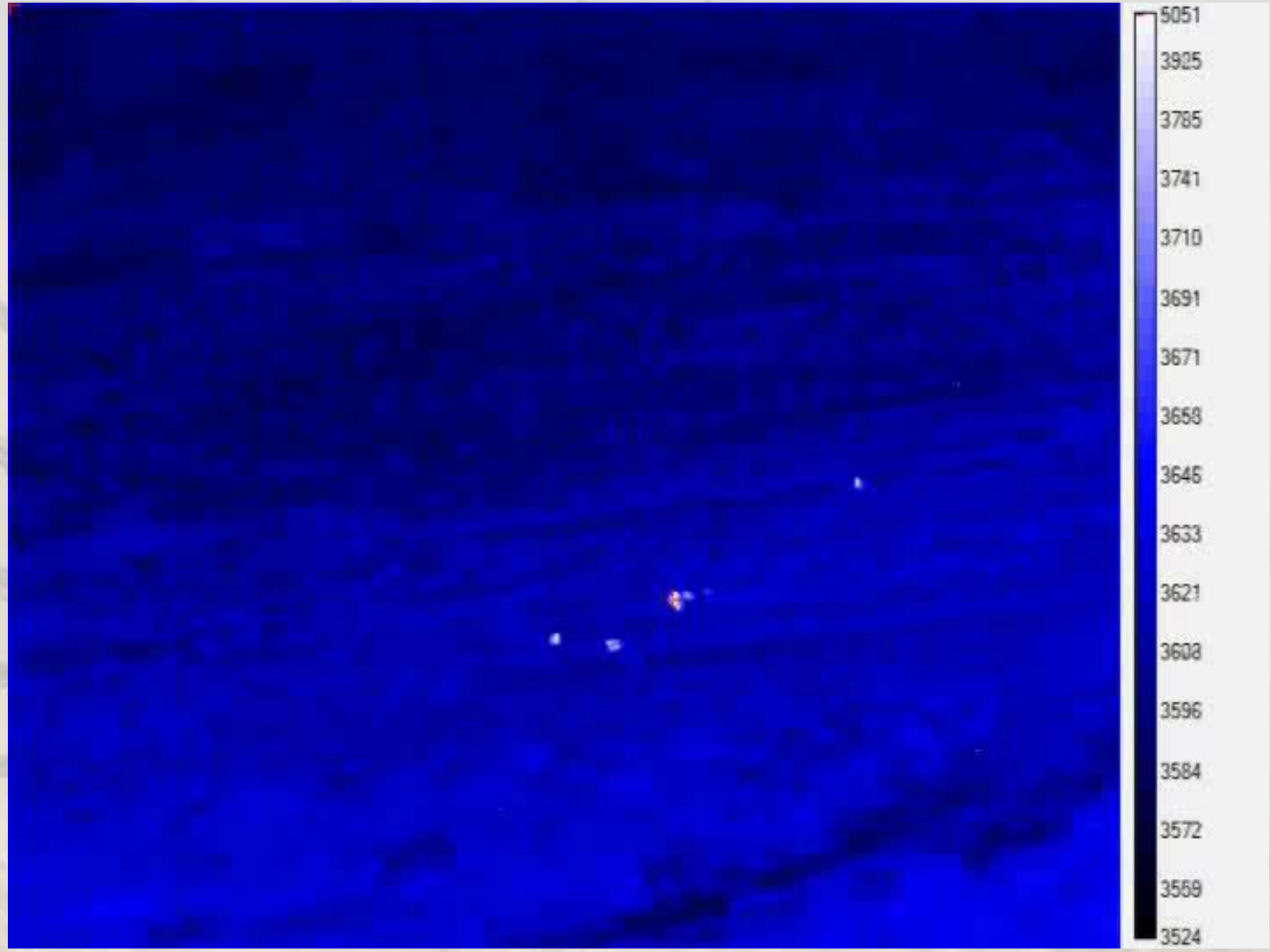


Accounting for visitation rate



Accounting for Detection Error

Accounting for Detection Error



ALT:4049ft TGT LAT:+44.959505° LON:-103.784142° EL:3,150ft DIST:0.5M
OWYHEE 06:14:17 Mon Apr 20 2015
HAZE OFF
VIDEO
SPLIT
MAP
SAT
STREET
FIND
20APR2015
05:14:17
UTC-7.0
AUTO
DV3
SCENE
SPA
IR
78
HIGH
AUTO
AUTO
147
N
MENU
-015°
REC
Delzer 3155
OFF
NONE
ACFT
44:57:33N
103:47:43W
193°
4048FT
3150FT
0.6MI
087°
LOS
#1 TGT
44:57:34N
103:47:03W
LESS
Old Highway 85 / Old County Highway 897
West Butte SD (Butte County)
[no markers]

Population Monitoring Tool

- Estimate trends across multiple spatial scales
- Establish an early warning system for populations in decline based on scale-dependent comparisons
- Align scale of demographic response to management action

Developing a Nested Population Hierarchy

Collaborator: Fort Collins Science Center, Cameron Aldridge

- Cluster leks located in similar habitat.
- Minimize movement between clusters and incorporate landscape barriers.
- Regionalize the landscape while capturing sage-grouse connectivity.
- Support a hierarchical population monitoring framework.

Process – clustering algorithm
Example of nesting scales

Small-Scale

Large-Scale

Early Warning System Steps

Estimated Growth Rates

↓

Spatial Thresholds
Destabilizing and Decoupling

↓

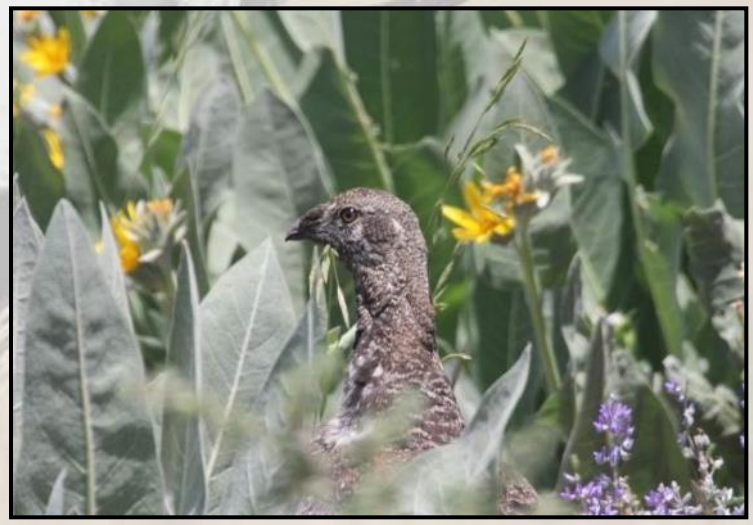
Warning

↓

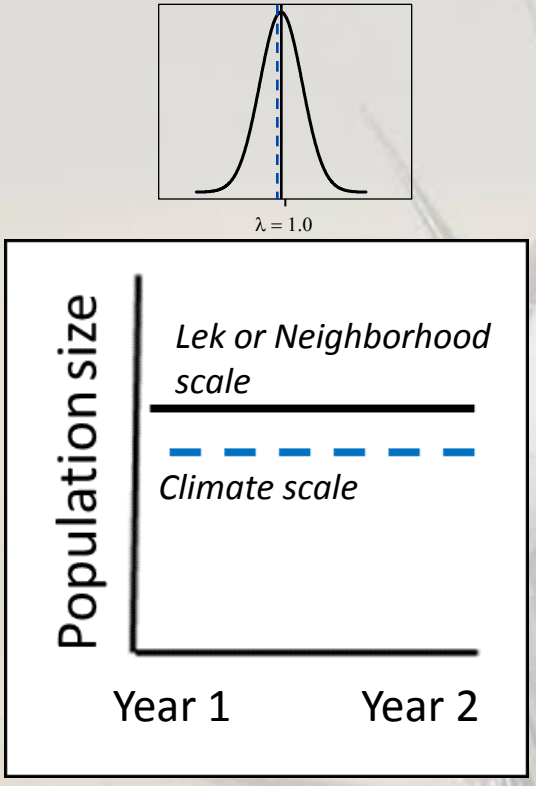
Temporal Threshold

↓

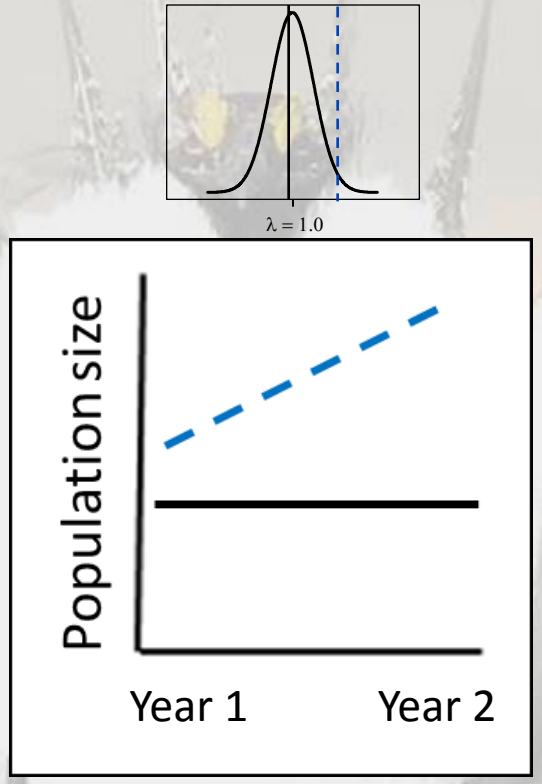
Signal
Hard or Soft



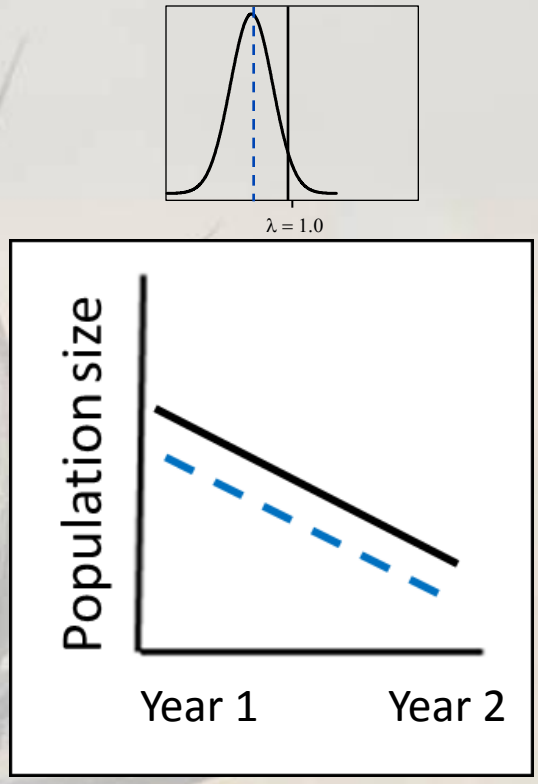
Early Warning System –
Must Cross Both Thresholds to Activate Warnings



Stable: Yes
Decoupled: No
||
No Warning

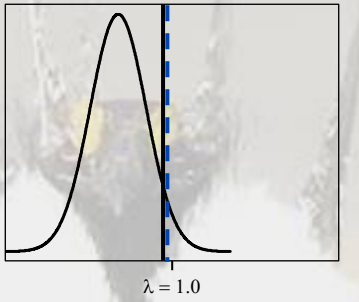


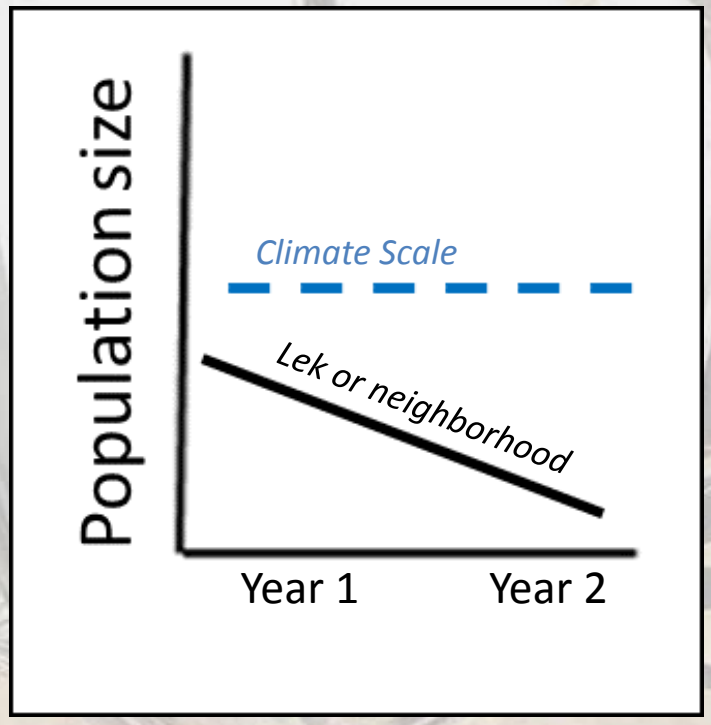
Stable: Yes
Decoupled: Yes
||
No Warning



Stable: No
Decoupled: No
||
No Warning

Early Warning System –
Crossing Destabilizing and Decoupling Thresholds to Activate Warnings





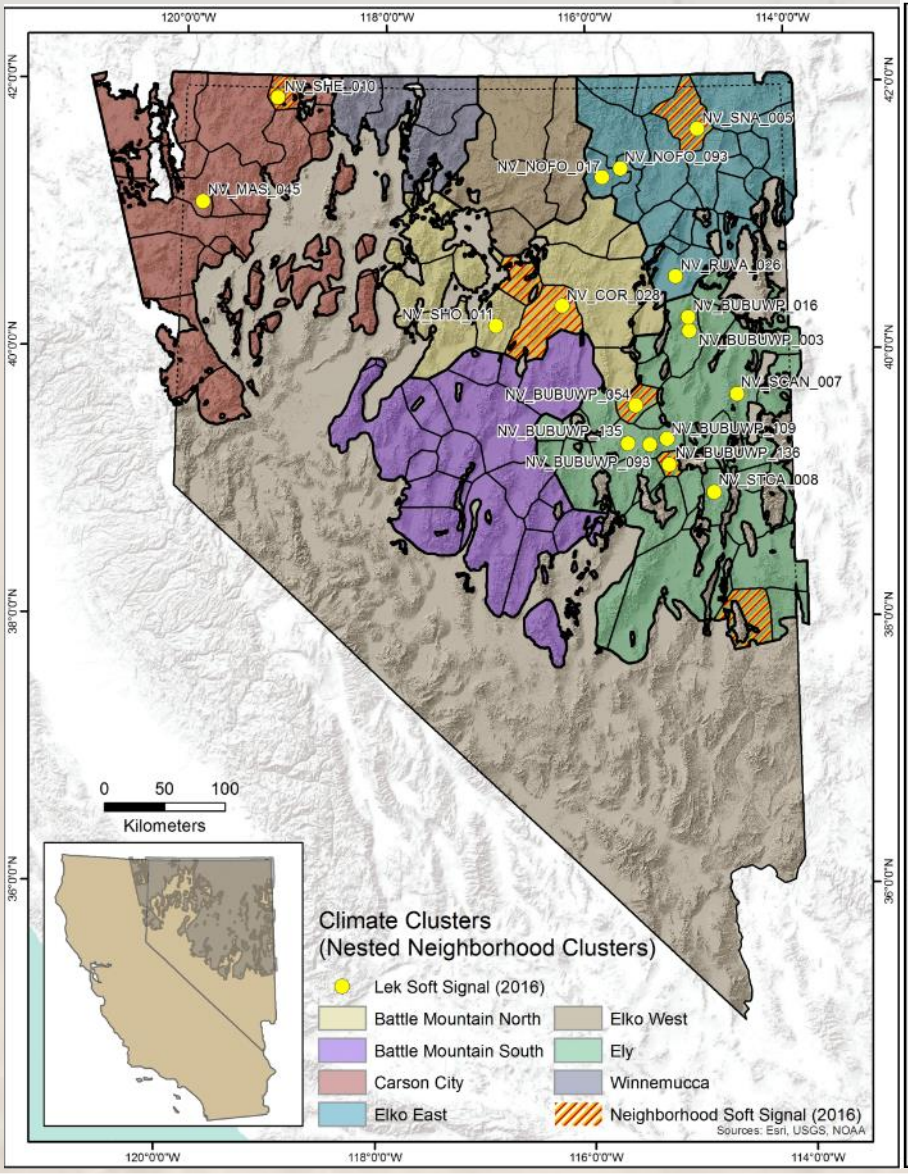
Stable: No

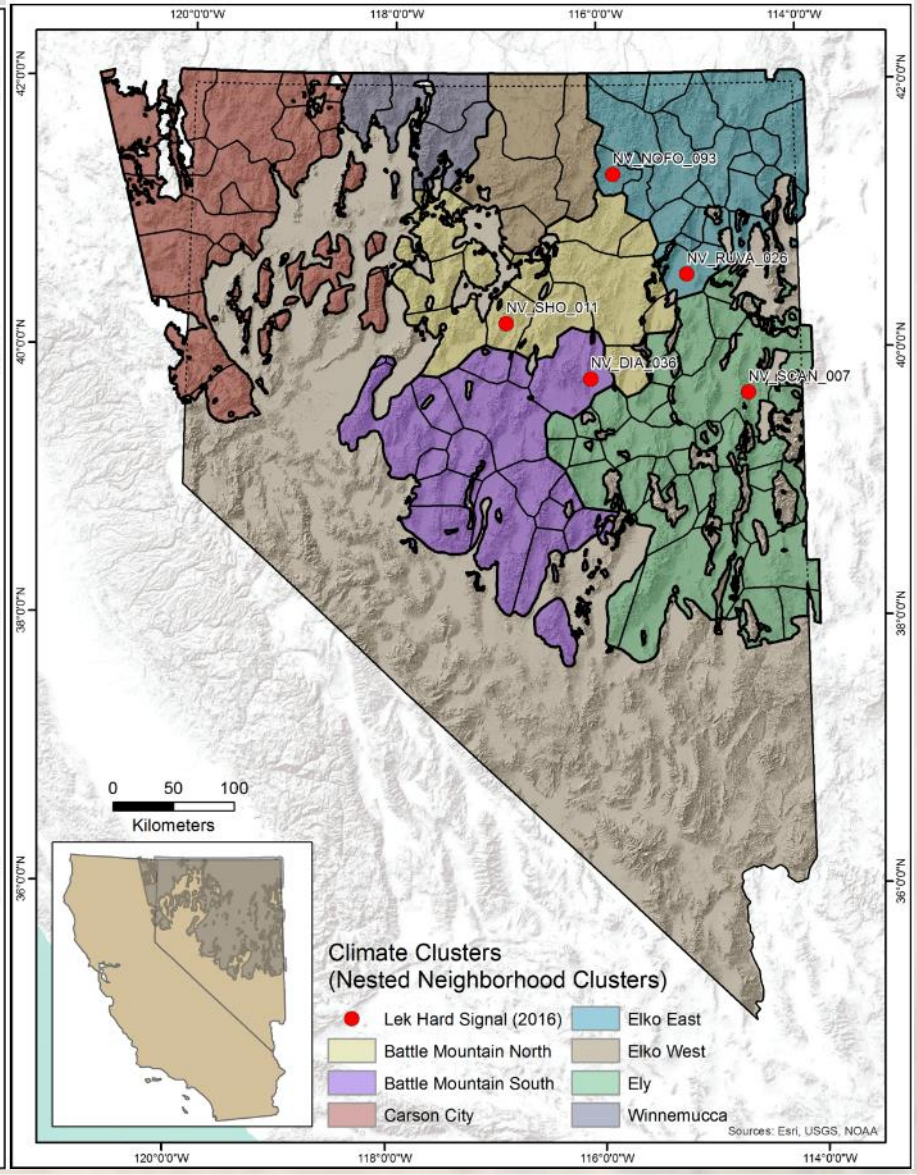
Decoupled: Yes

II

Warning

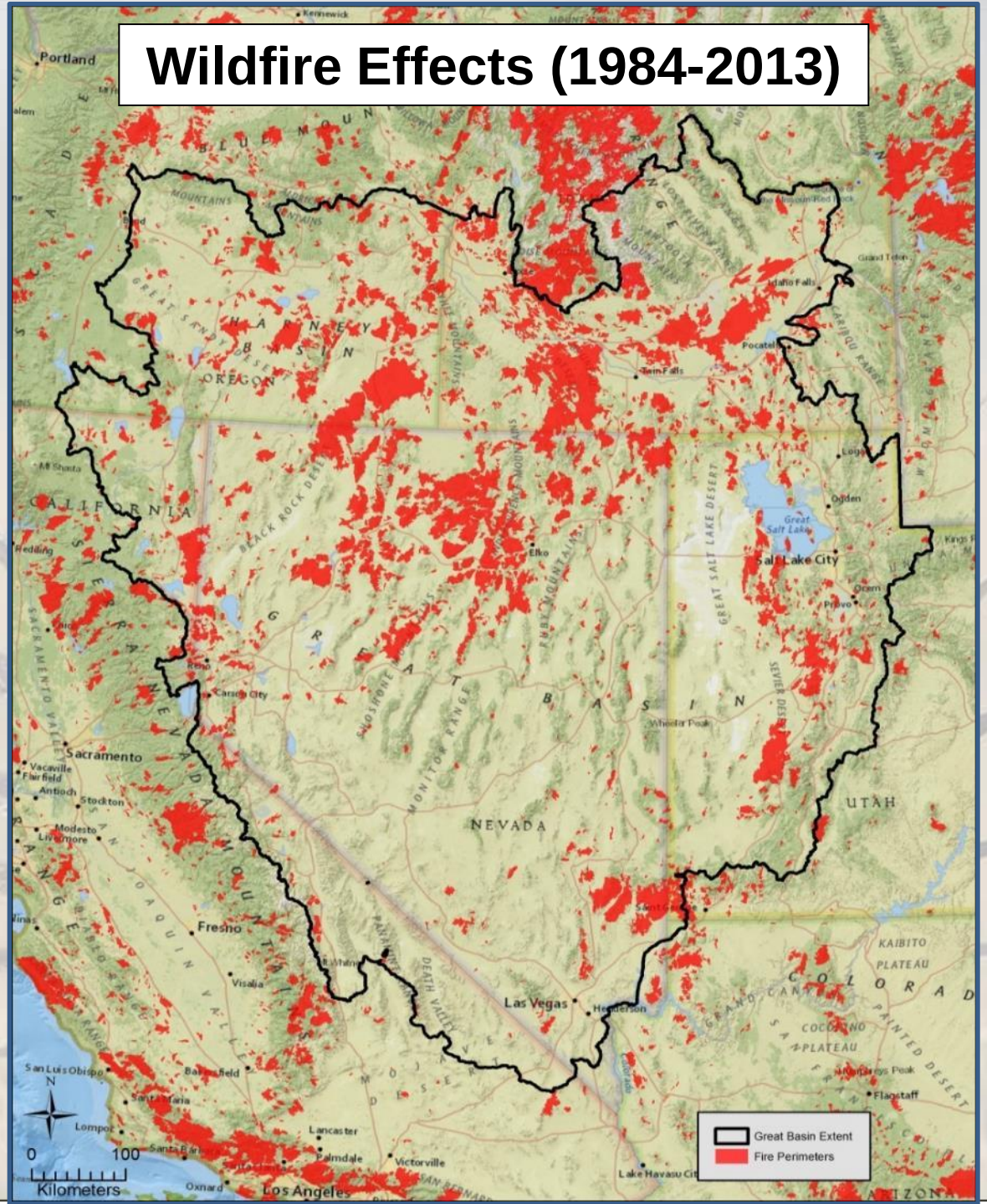
Signals in 2016





Coates et al. 2017

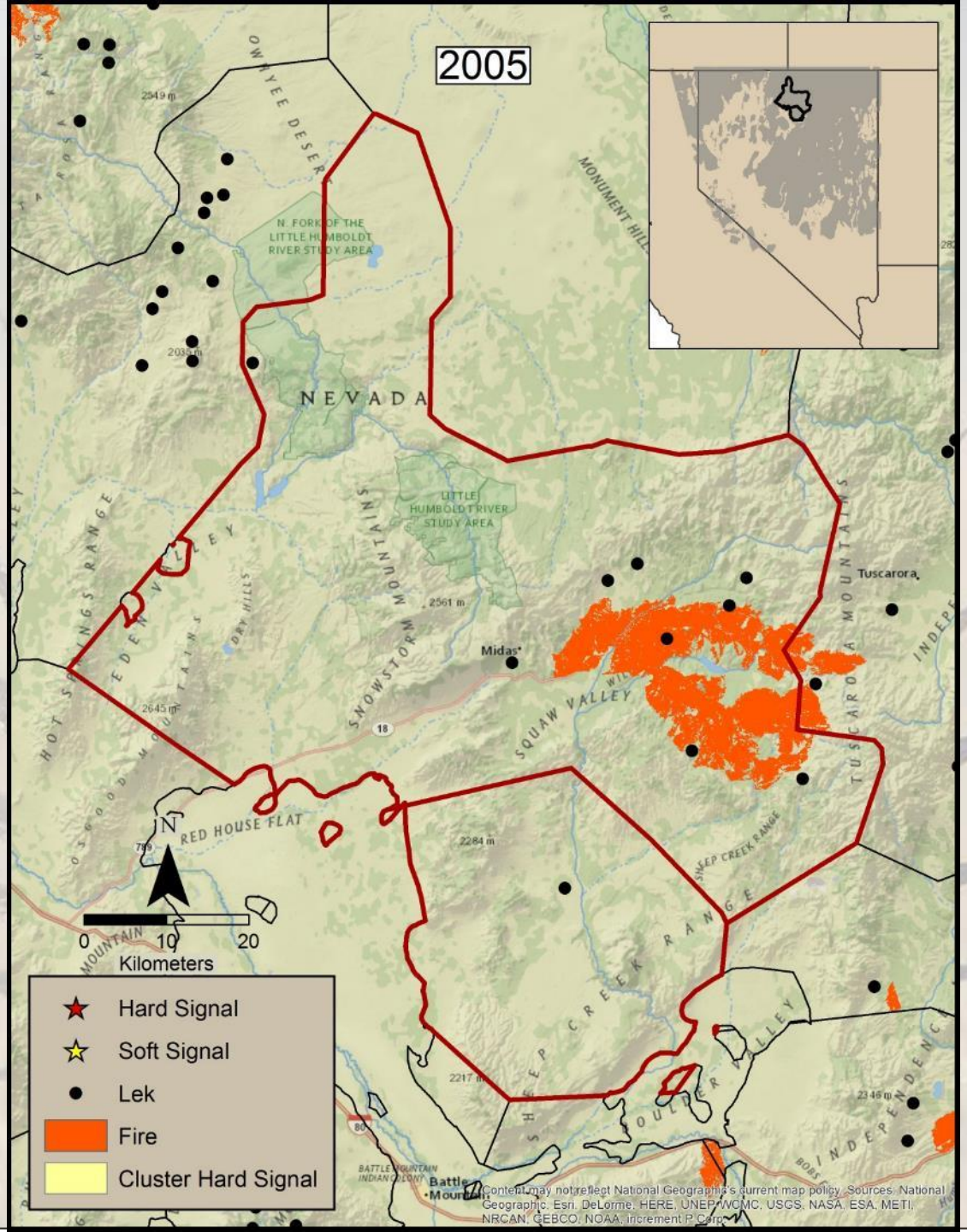
Wildfire Effects (1984-2013)



USGS
science for a changing world

Large-Scale Wildfire Example

Burned in 2005



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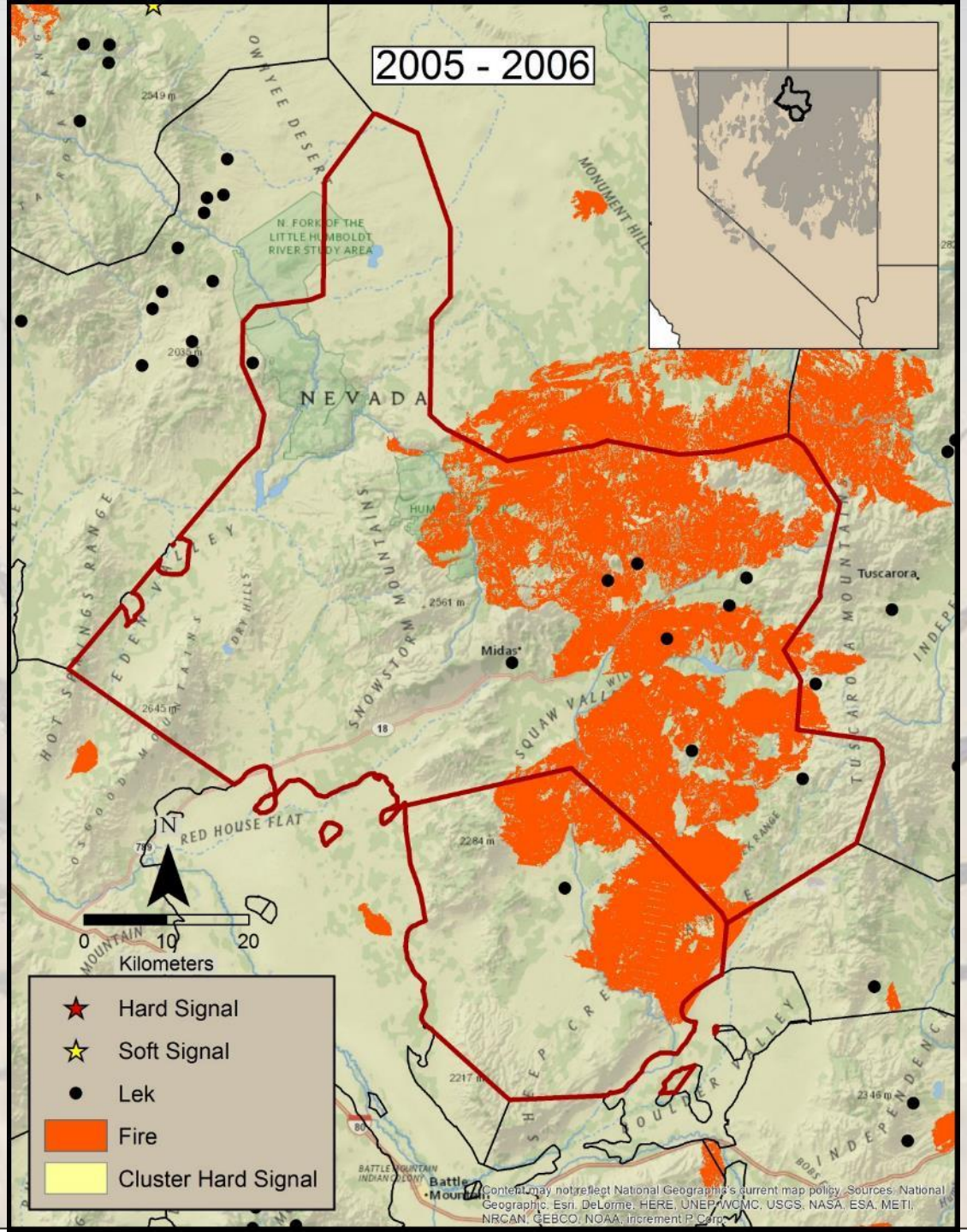
science for a changing world

Large-Scale Wildfire Example

Additional Burn in 2006



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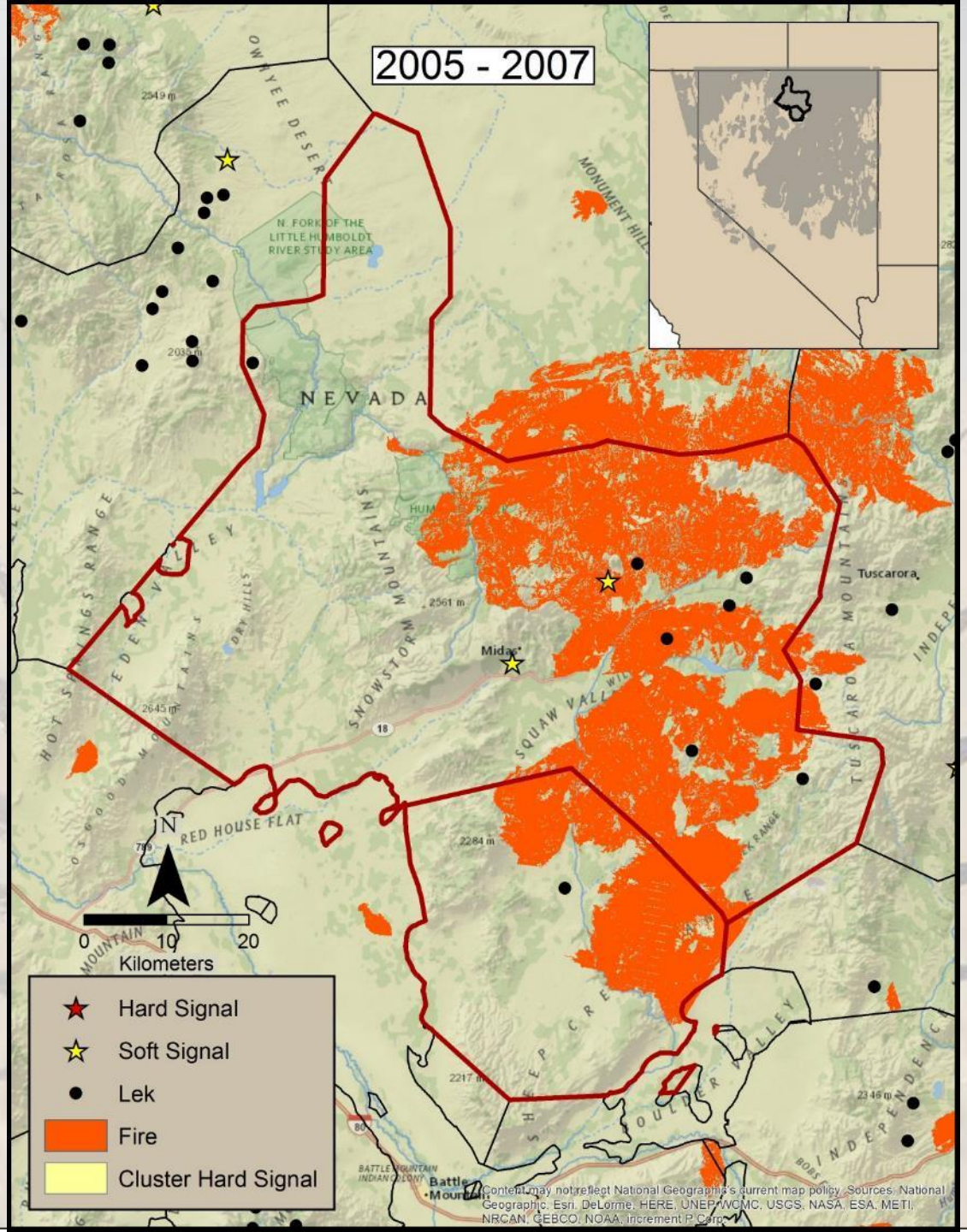
Large-Scale Wildfire Example

Soft Signal at Leks in 2007



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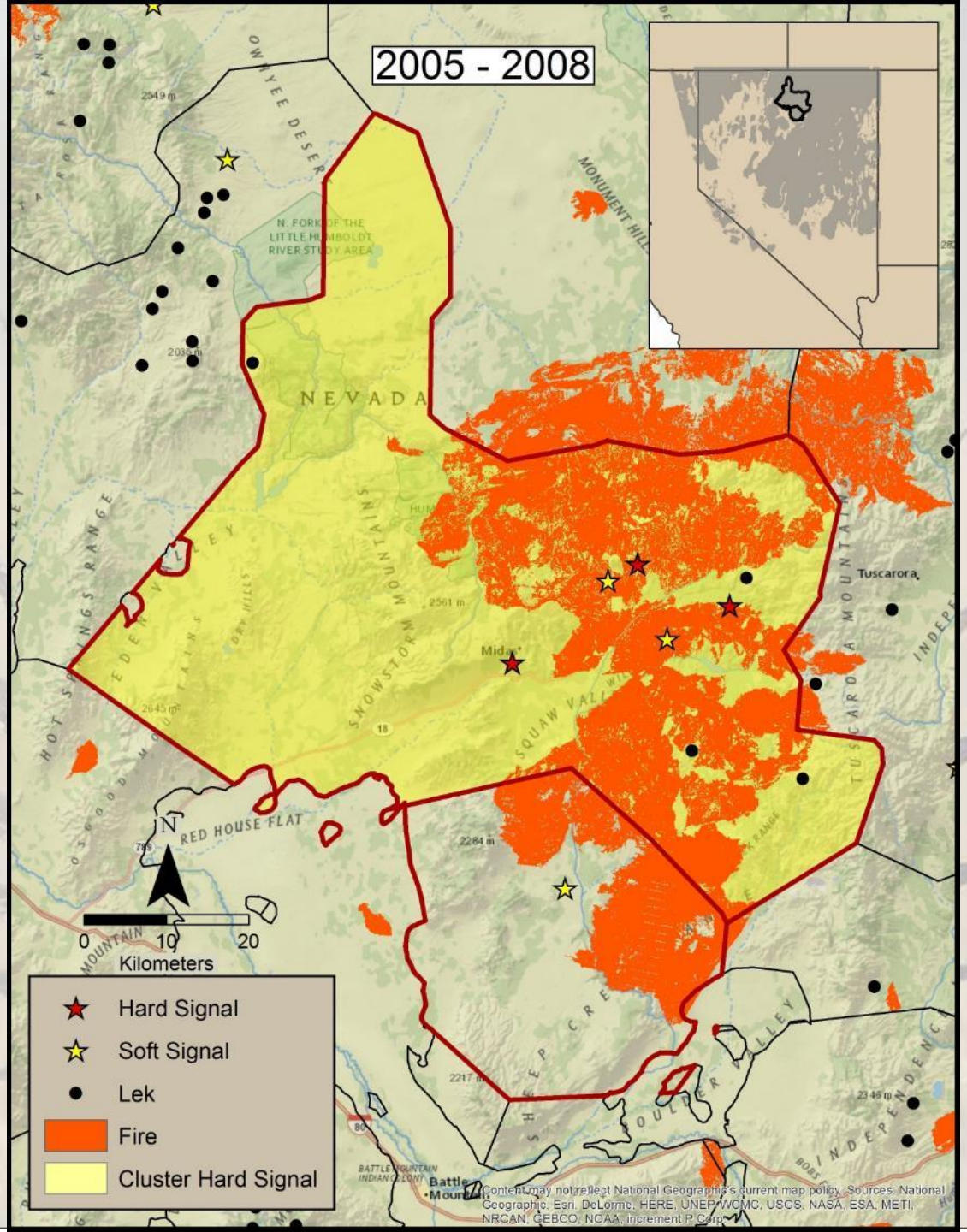
Large-Scale Wildfire Example

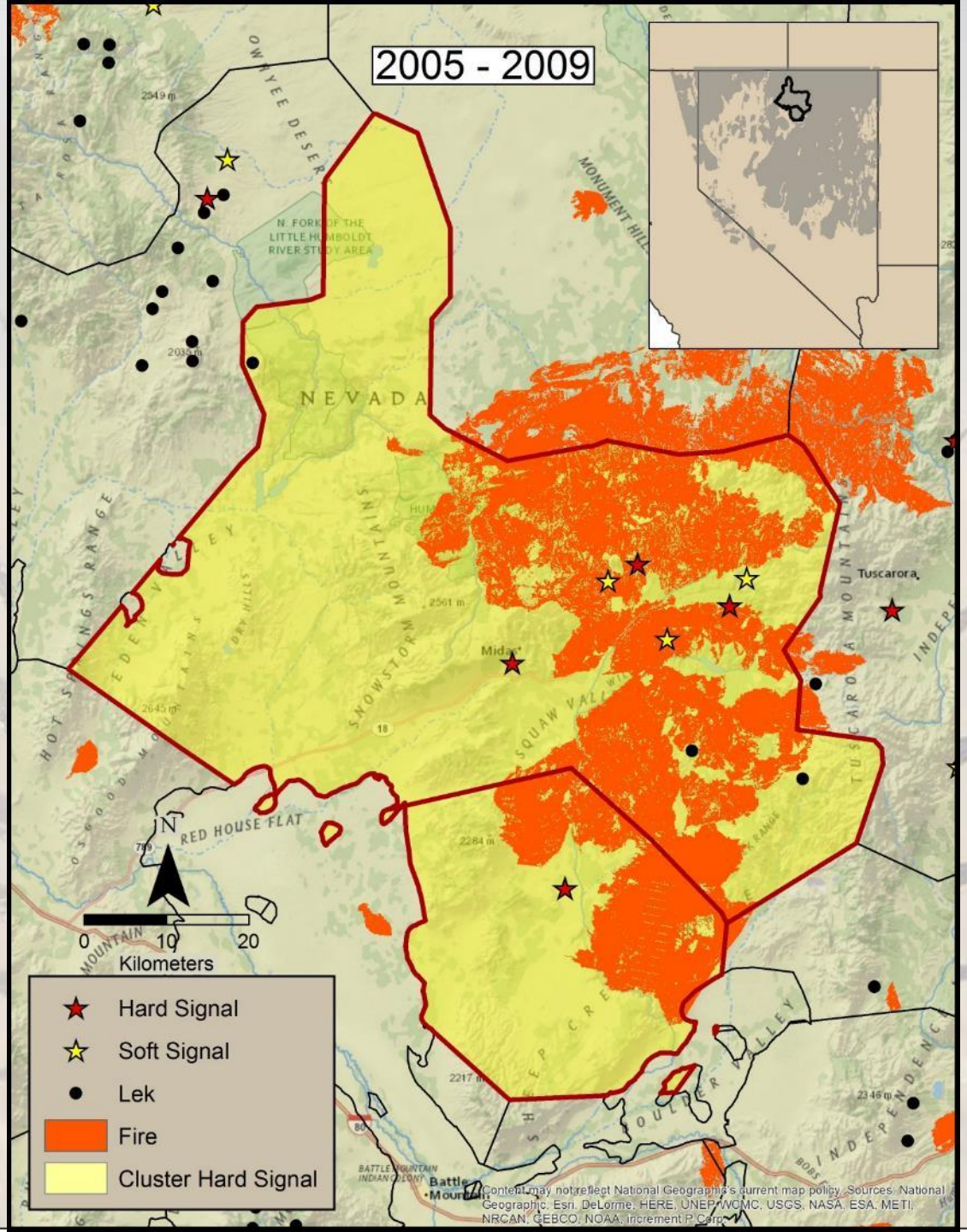
Hard Signal at Leks and Cluster in 2008



USGS science for a changing world

Small-Scale Energy Example

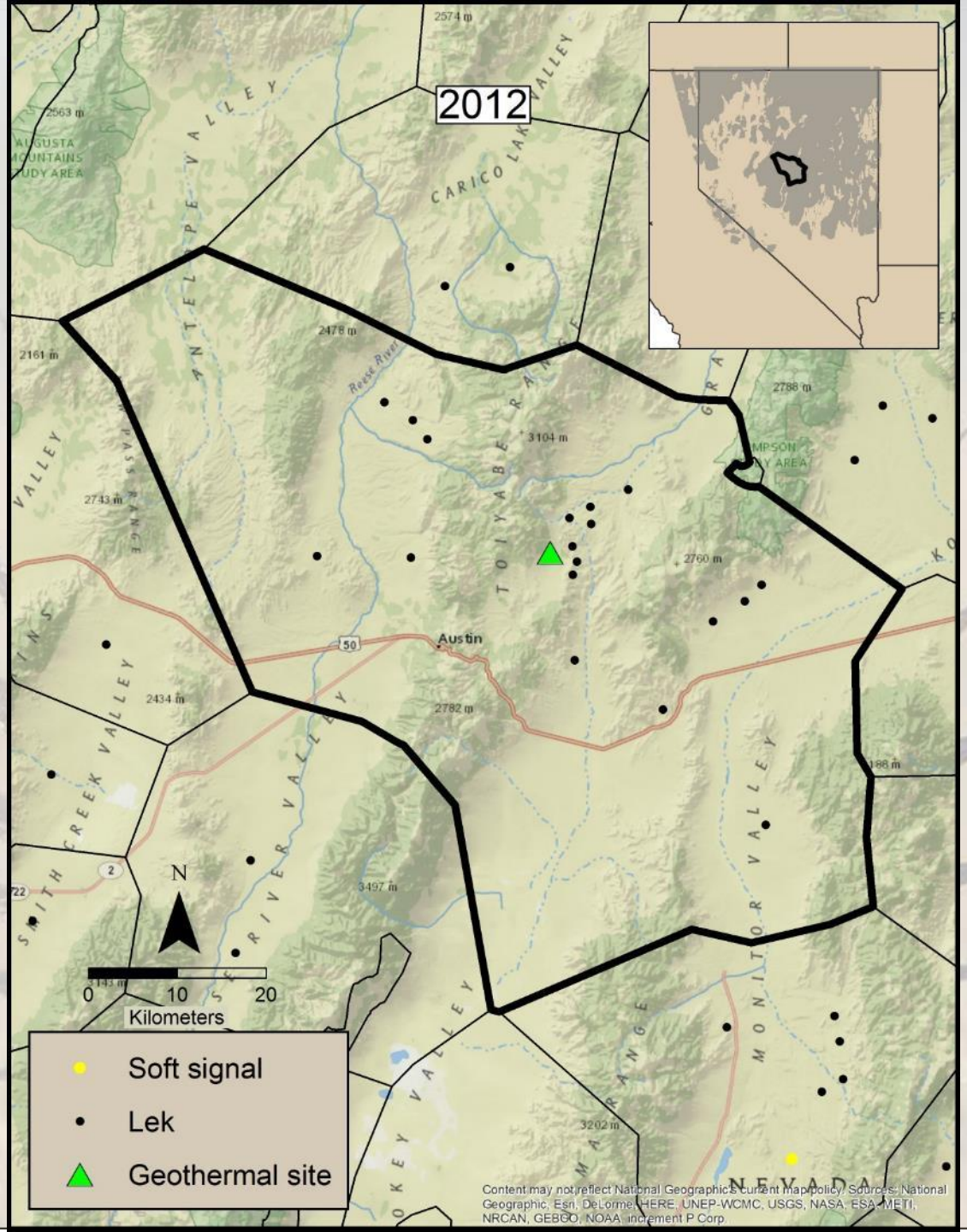
Additional Hard Signal at Leks and Cluster in 2008



USGS science for a changing world

Small-Scale Energy Example

Energy Plant Built in 2012



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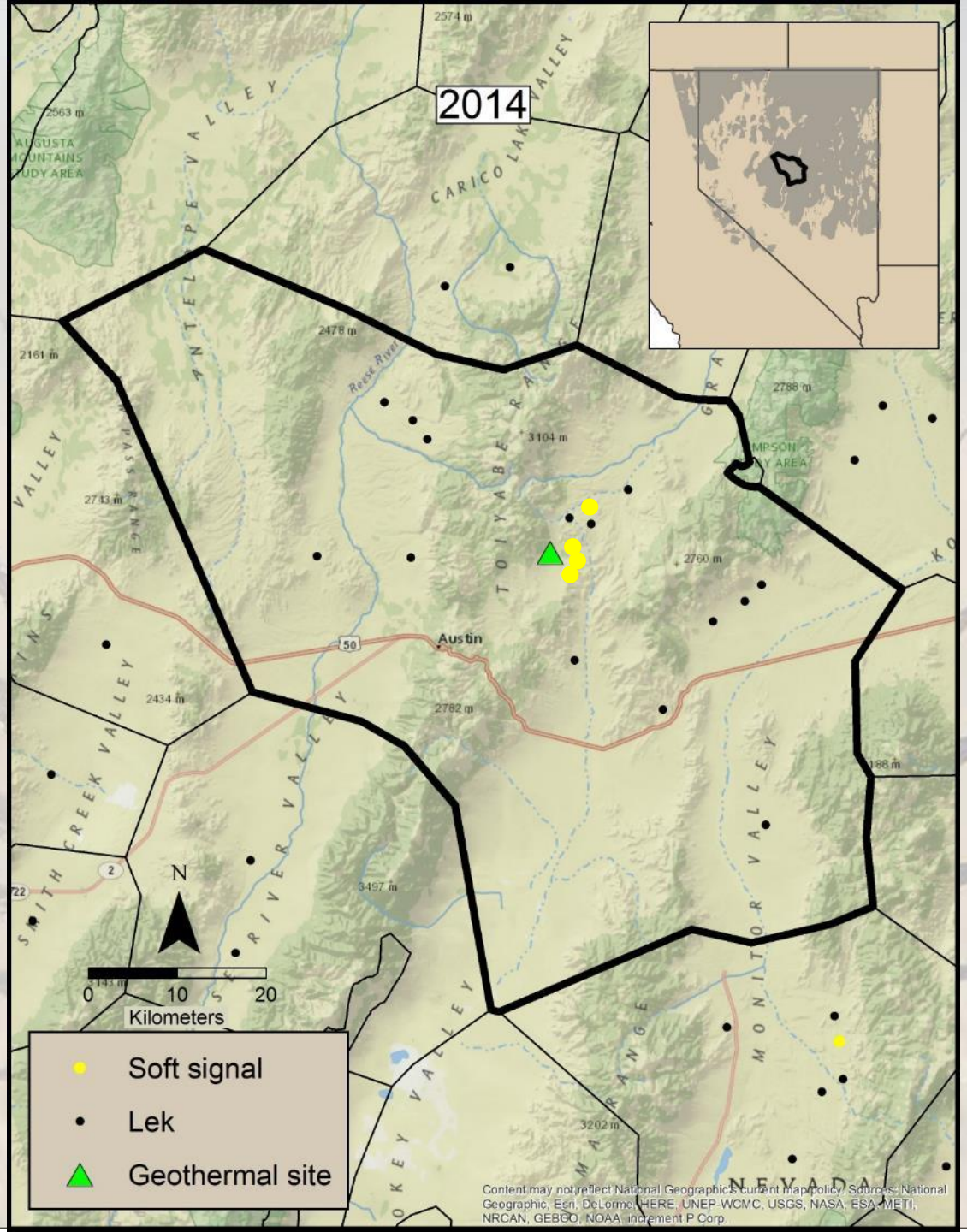
Small-Scale Energy Example

Signals occur in 2014



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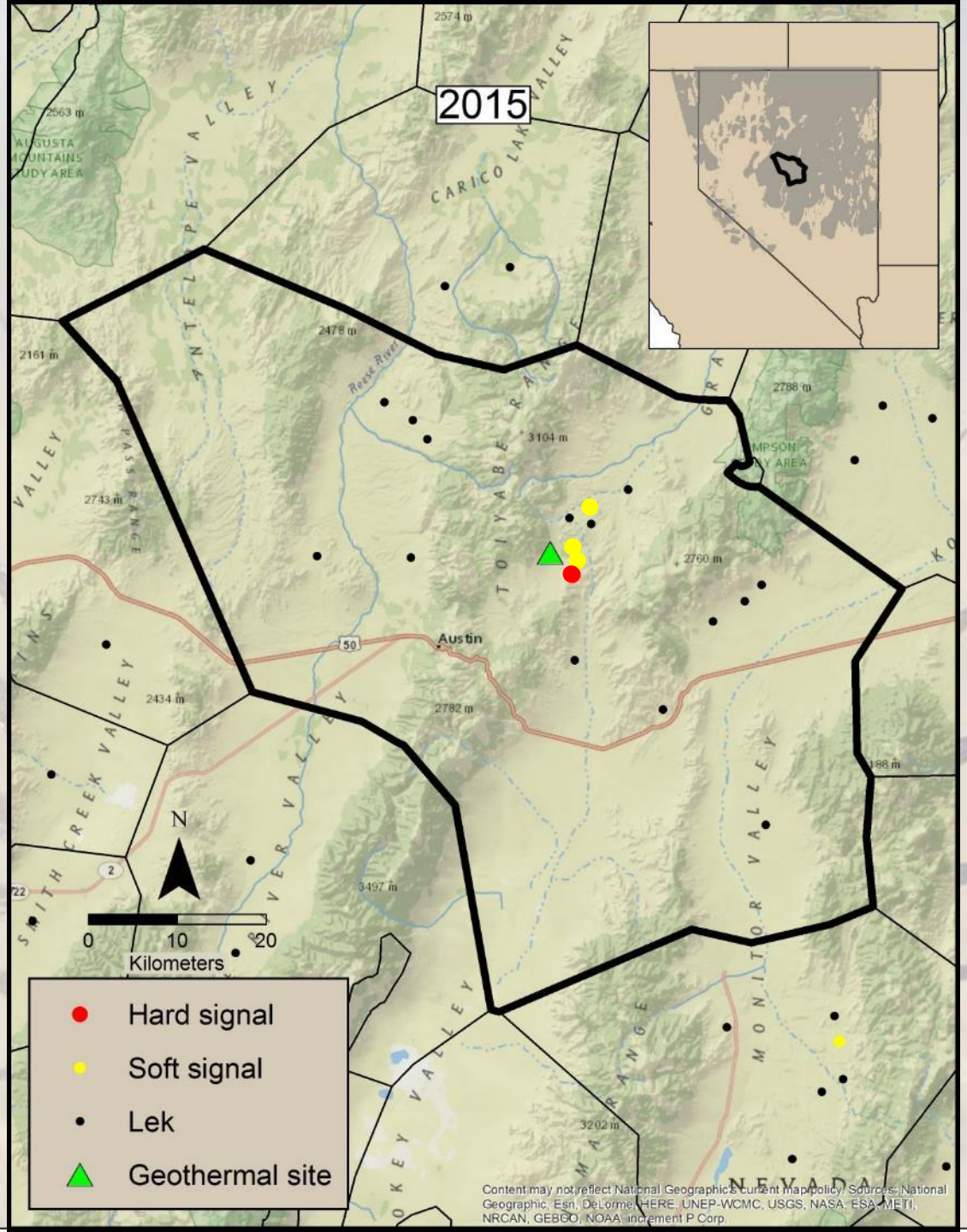
Small-Scale Energy Example

Hard Signal in 2015



USGS science for a changing world

Integrated Population Model

State Process
Demographic Data

Estimated Pop. Size (N_{t-1})

↓

Survival and Fecundity Parameters

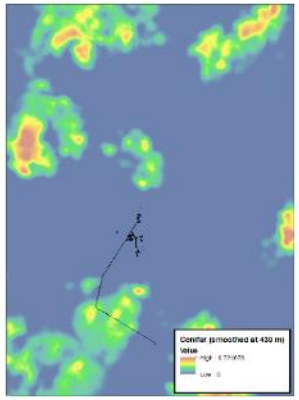
↓

Estimated Pop. Size (N_t)

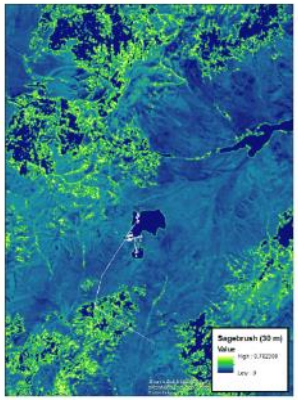
← **Fitting spatial covariates to individual life stage responses**

LOCAL EXAMPLE – Process Driving Pattern

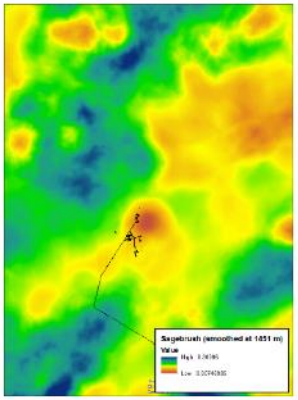
CONIFER COVER
(Smoothed at 439 m)



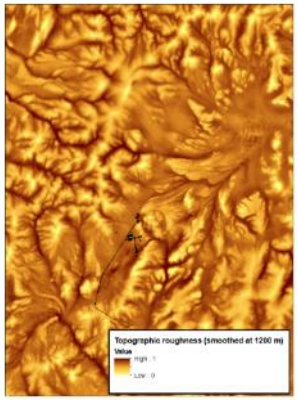
SAGEBRUSH COVER
(Smoothed at 30 m)



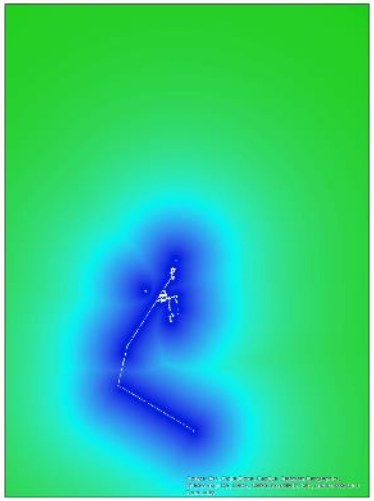
SAGEBRUSH COVER
(Smoothed at 1451 m)



TOPOGRAPHIC ROUGHNESS
(Smoothed at 1200 m)

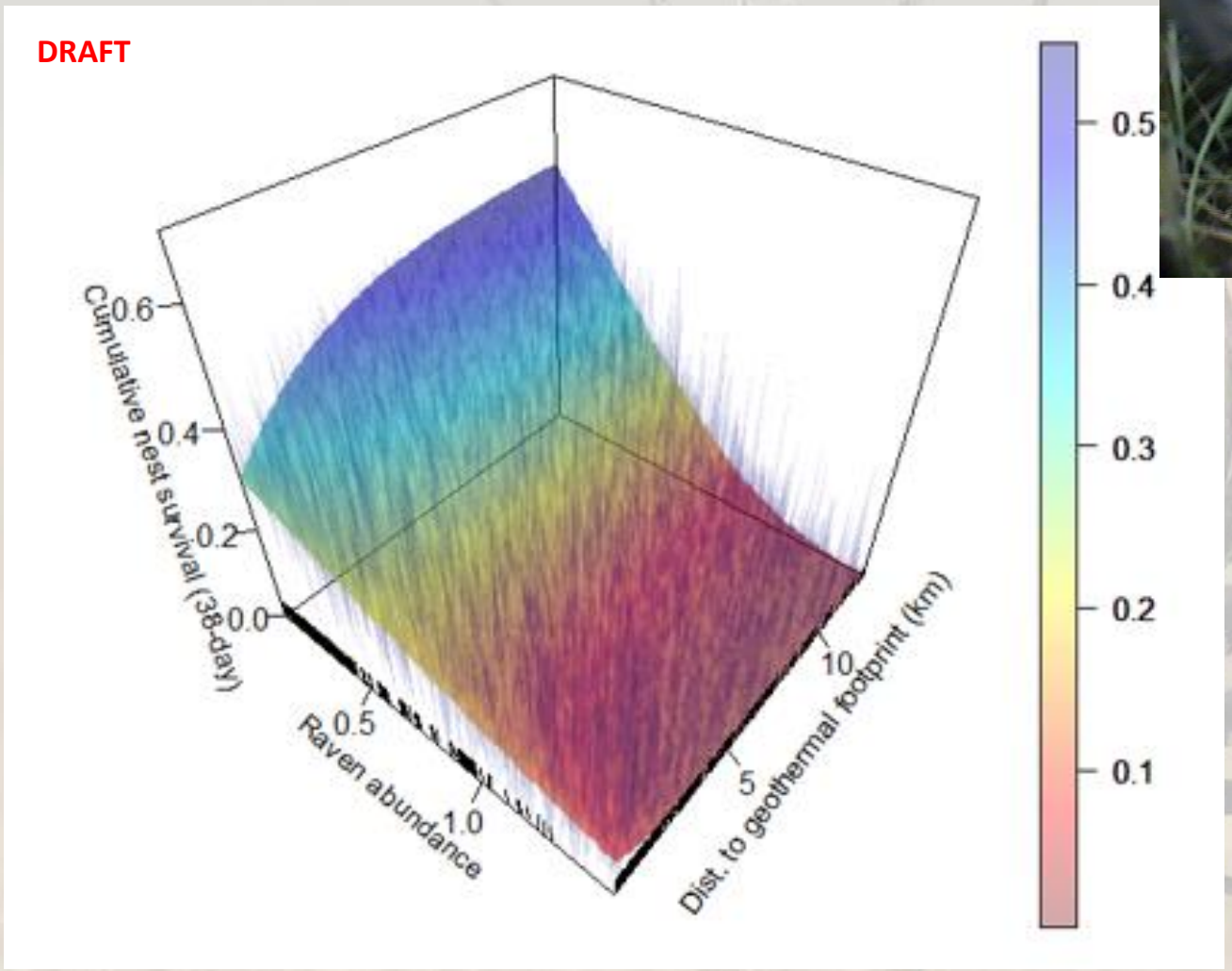


DISTANCE TO GEOTHERMAL INFRASTRUCTURE



Black/white represents geothermal infrastructure
Slide does not include all land cover types

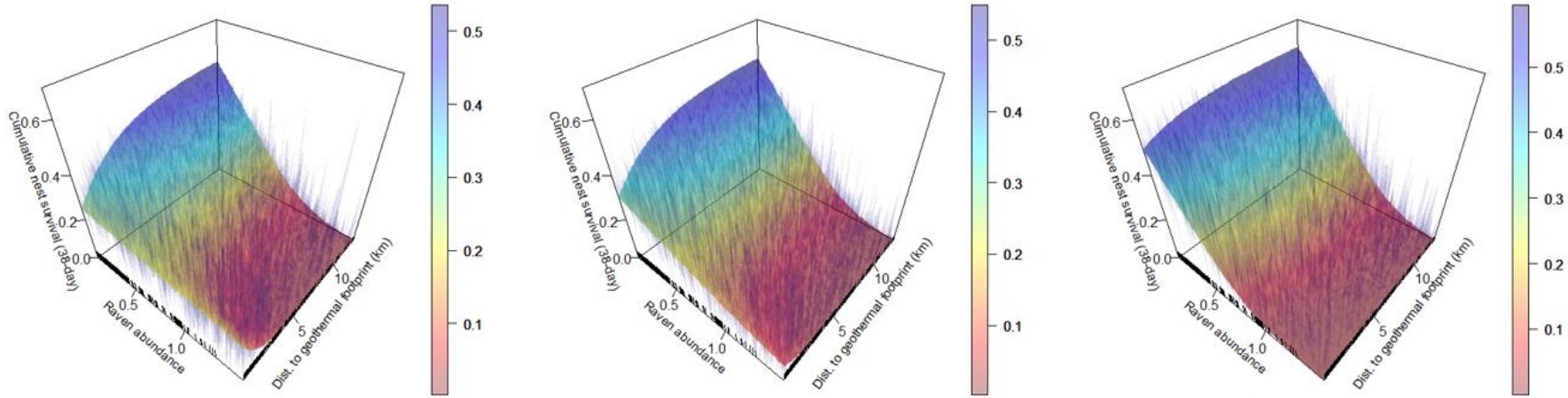
LOCAL EXAMPLE – Process Driving Pattern



LOCAL EXAMPLE – Process Driving Pattern

DRAFT

Increasing Topography



25th percentile

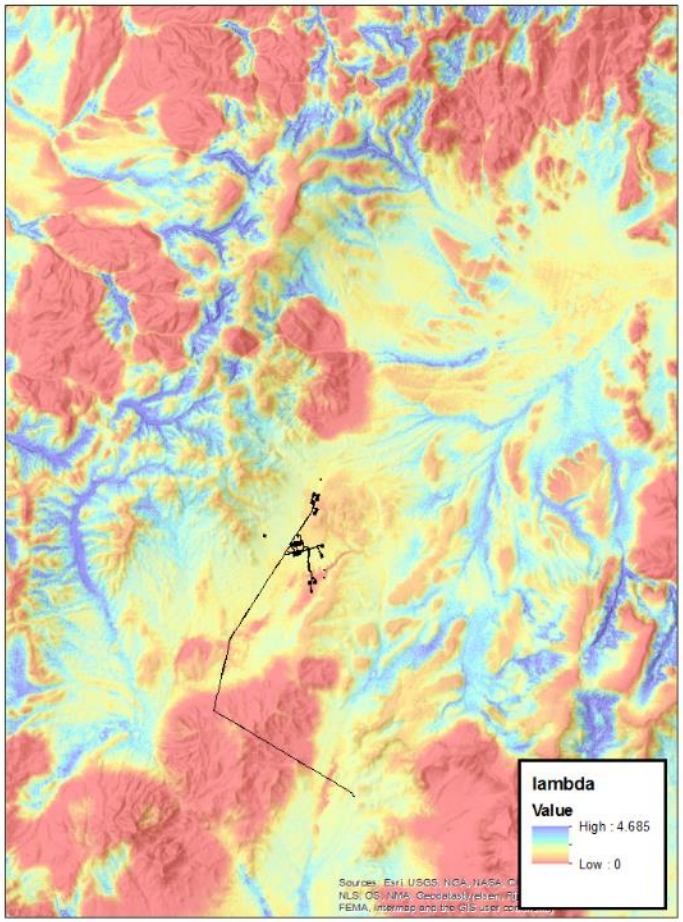
50th percentile

75th percentile

LOCAL EXAMPLE – Process Driving Pattern

Lambda (no energy plant)

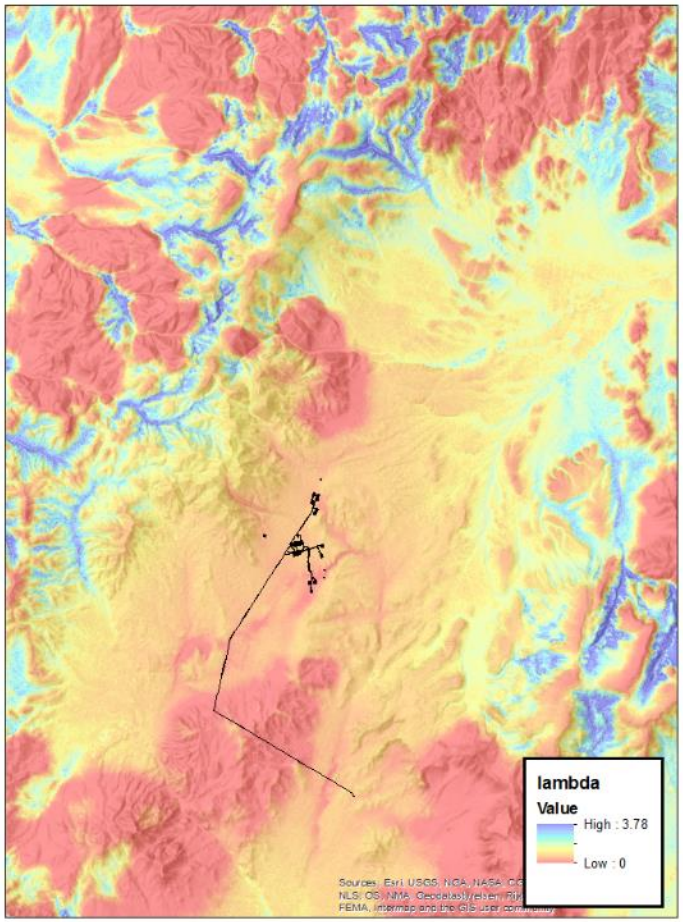
DRAFT



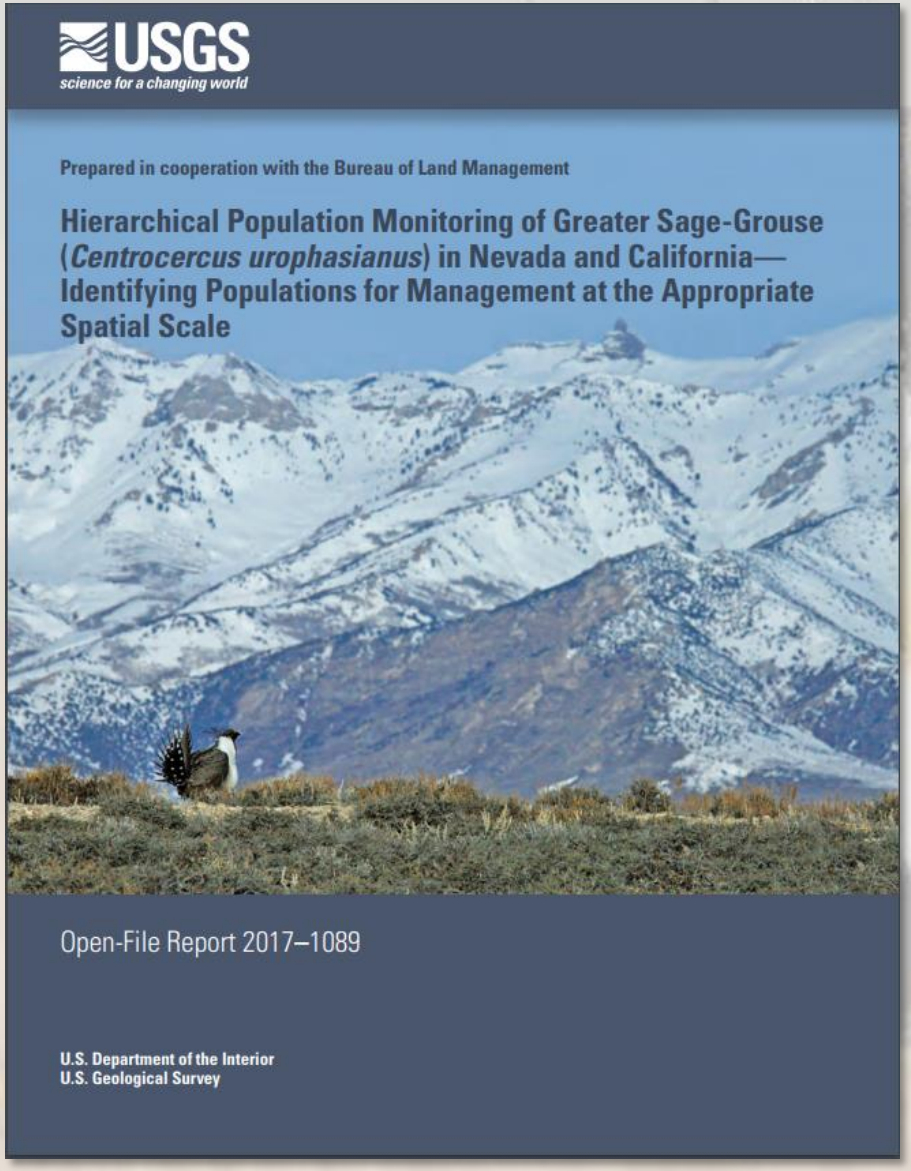
LOCAL EXAMPLE – Process Driving Pattern

Lambda (with energy plant)

DRAFT



Take Home Points



- Hierarchical EWS identifies populations affected by more local disturbances versus those operating at larger scales
  - Help facilitate efficient and effective management
- Can be modified to signal populations preforming well (i.e., responding positively to management)
- Next steps
  - Develop thresholds and implement in other states (e.g. cluster delineations for Wyoming complete) and rangewide*
  - Conduct analyses to determine causes of past signals
  - Develop add-on module for PopR website at University of Montana

Conclusions and Next Steps

- **Continued and additional monitoring of focal species at appropriate scales to inform science-based management decisions**

- **Increase the extent of scenario-based conservation planning tools to better predict outcomes for focal species**

- **Continue to overcome challenges with incorporating best-available-science into current management practices and policy**

T. Gettelman, USGS

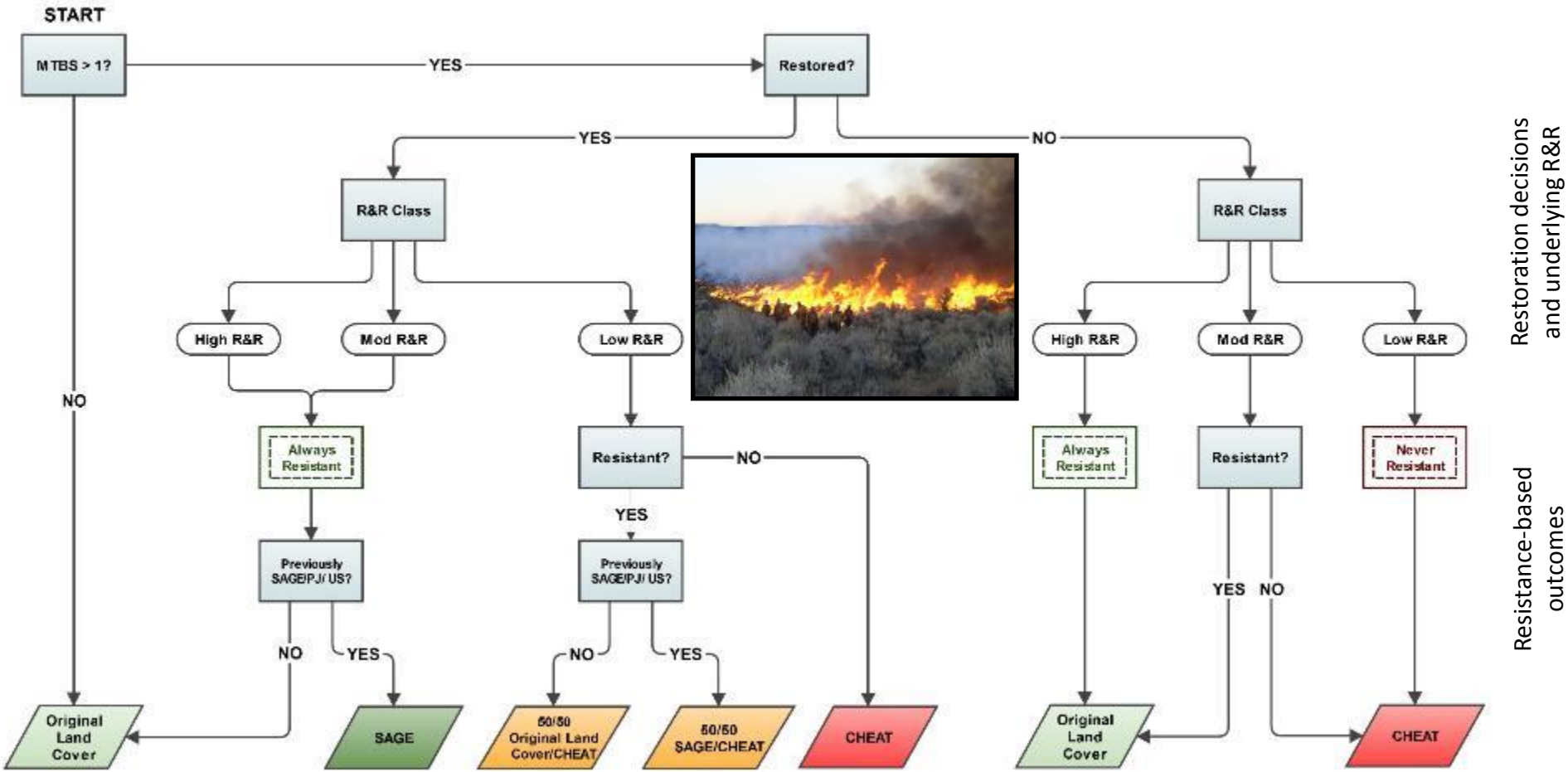
Acknowledgements

Nevada Sagebrush Ecosystem Program
(SEC and SETT)
Nevada Department Of Wildlife
California Department of Fish and Game
University of Nevada Reno
Idaho State University
University of Idaho
Bureau of Land Management (CA)
Bureau of Land Management (NV)
US Fish and Wildlife Service
Private industry partners (ORMAT, GRP, LS Power)

T. Gettelman, USGS

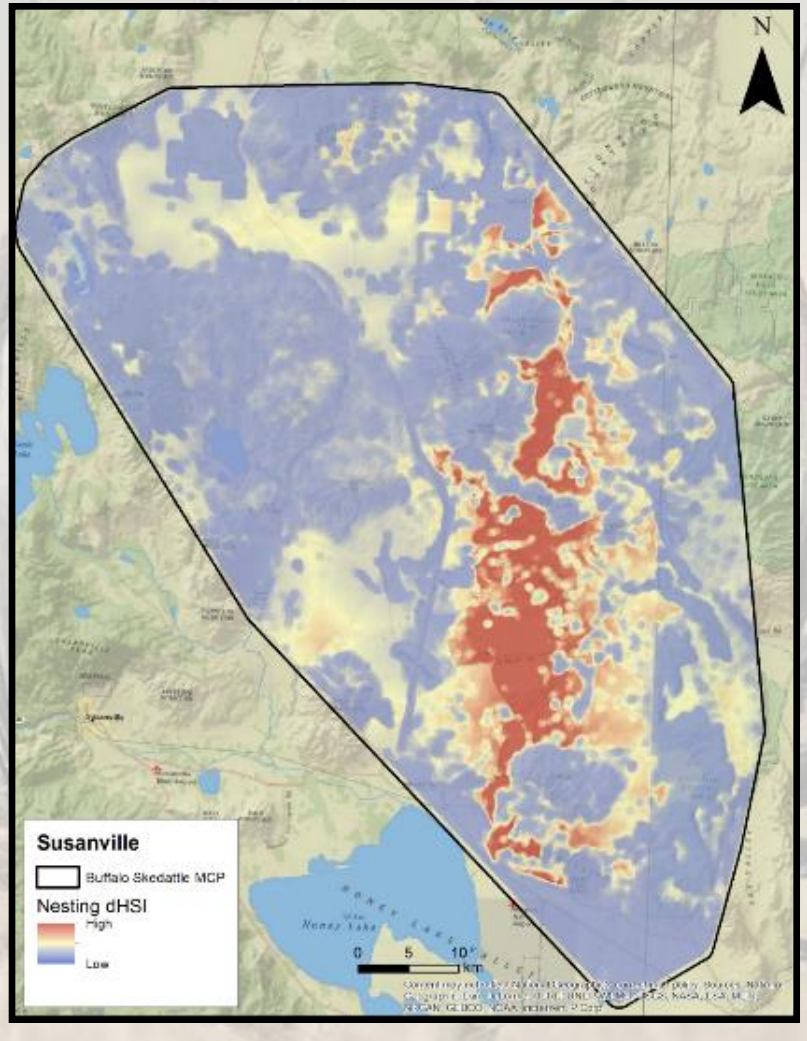
Conservation Planning Tool :

Simulate Predicted Outcomes and Quantify Predicted Sage-Grouse Performance

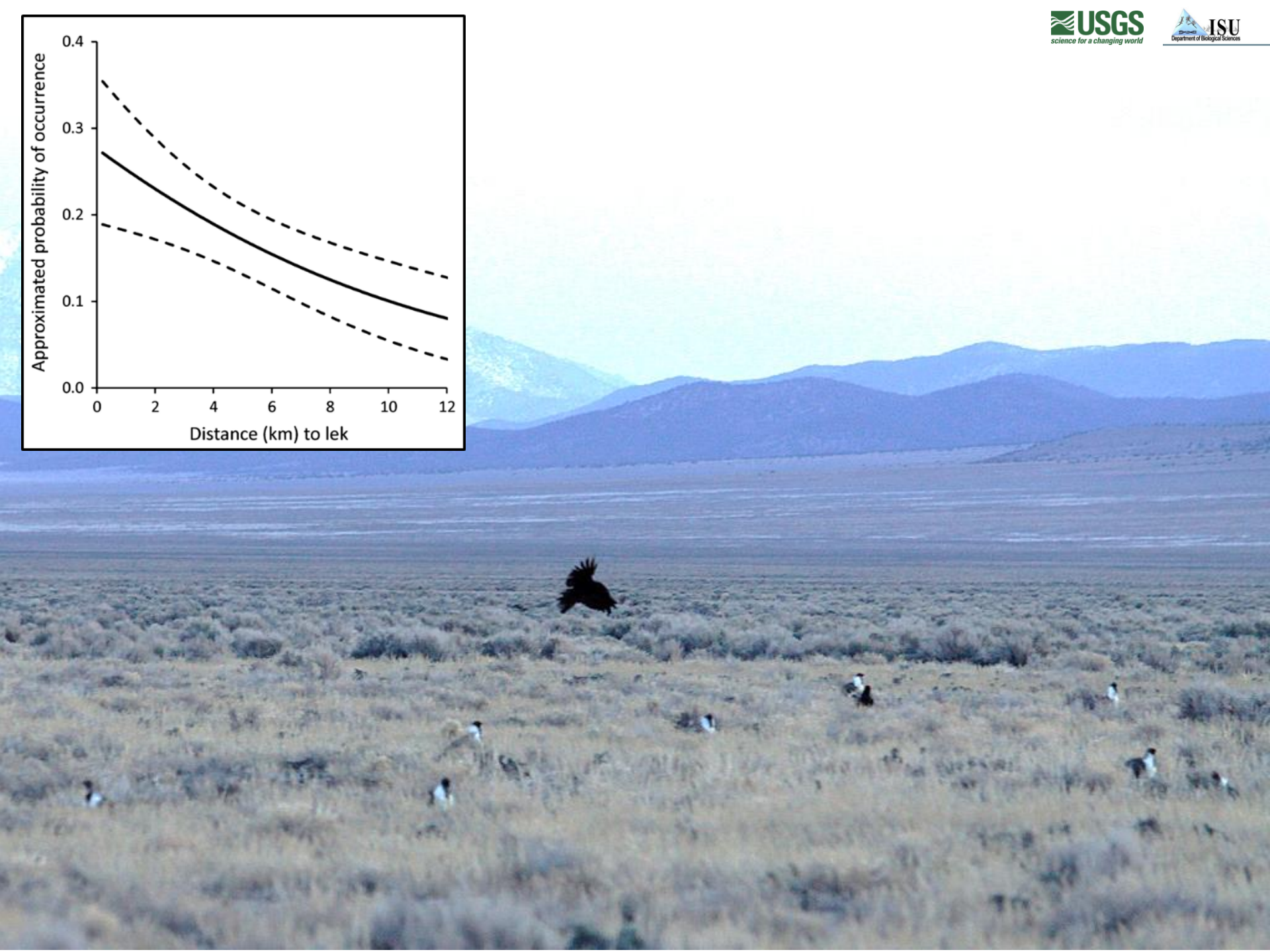


Conservation Planning Tool :

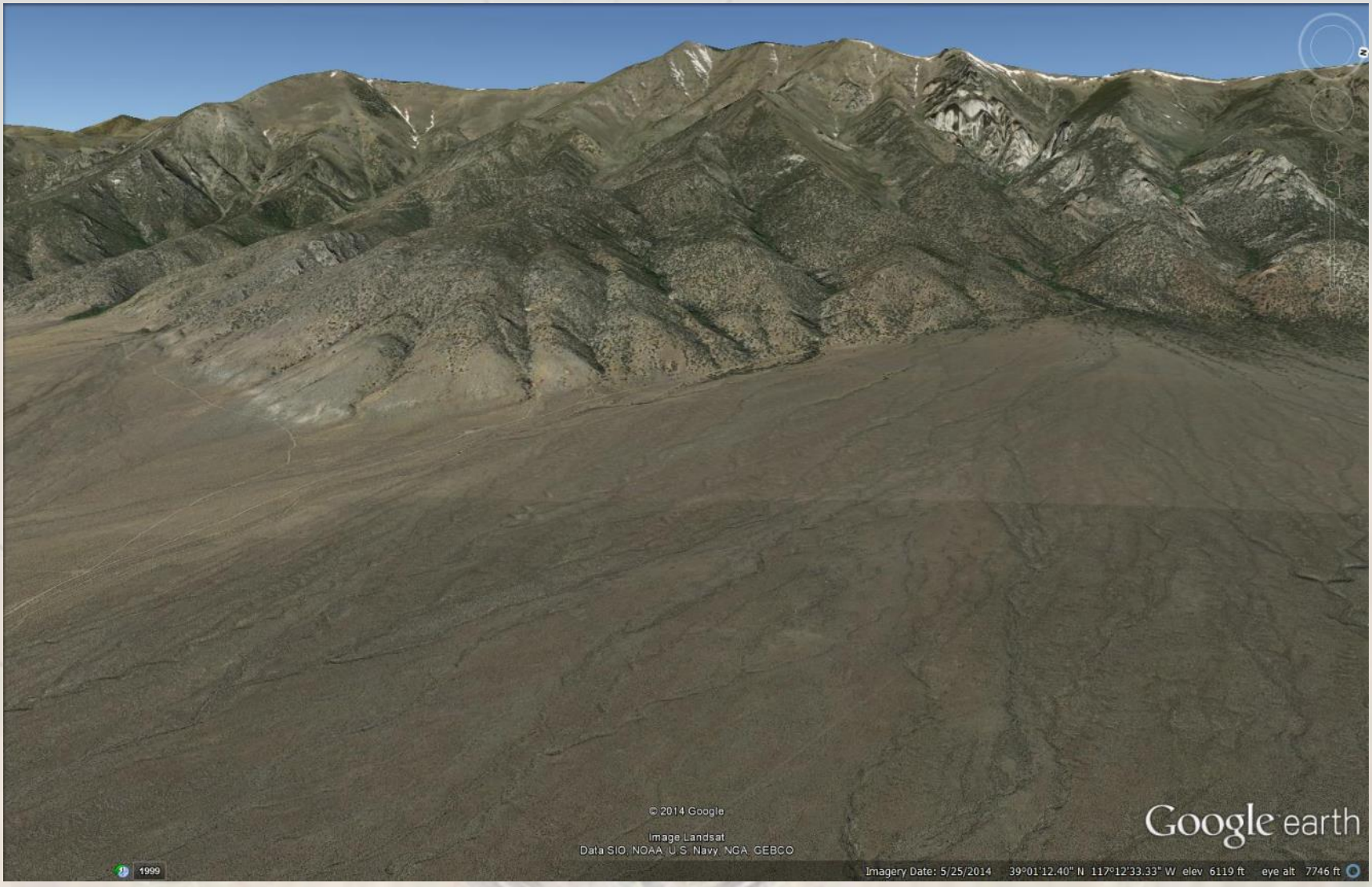
Simulate Predicted Outcomes and Quantify Predicted Sage-Grouse Performance



Preliminary Information—Subject to Revision. Not for Citation or Distribution


Approximated probability of occurrence
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
Distance (km) to lek

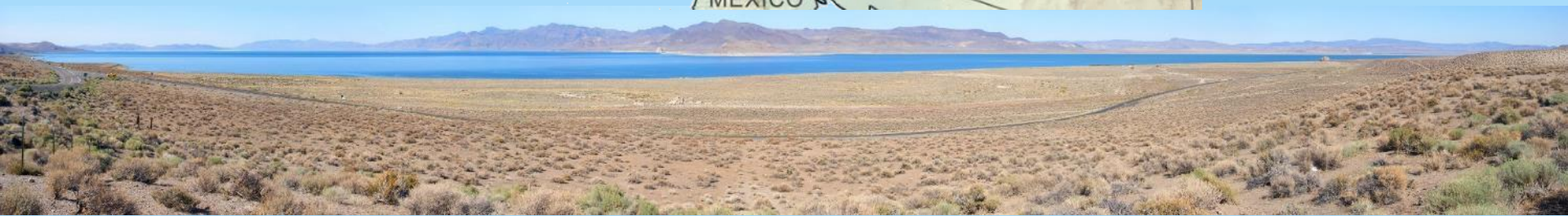
CONIFER EXPANSION


© 2014 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
1999
Imagery Date: 5/25/2014 39°01'12.40" N 117°12'33.33" W elev 6119 ft eye alt 7746 ft

©Ron Dudley

Credit: Jeremy Maestas, USDA-NRCS

OREGON
IDAHO
WYOMING
Cascade Range
Columbia Plateau
Snake River Plain
Rocky Mts.
Boise
Silvies
Harney Basin
Lake Malheur
Lake Abert
Goose Lake
Warner Mts
Quinn
Black Rock Desert
Humboldt
Reese
Ruby Mts
Pyramid Lake
Reno
Carson
Carson City
Great Basin
Sierra Nevada
Sacramento
Lake Tahoe
Walker
Mono Lake
San Francisco
Owens
Death Valley
Amargosa
NEVADA
CALIFORNIA
Las Vegas
Mojave Desert
Mojave
Lancaster
Palmdale
Victorville
San Bernardino Mts
Los Angeles
Salton Sea
Imperial Valley
San Diego
Mexicali
Sonoran Desert
MEXICO
Bear
Great Salt Lake
Ogden
Salt Lake City
Great Salt Lake Desert
Utah Lake
Provo
Wasatch Range
Sevier
Escalante Desert
Colorado Plateau
UTAH
ARIZONA



H. Copeland

R. Arkle

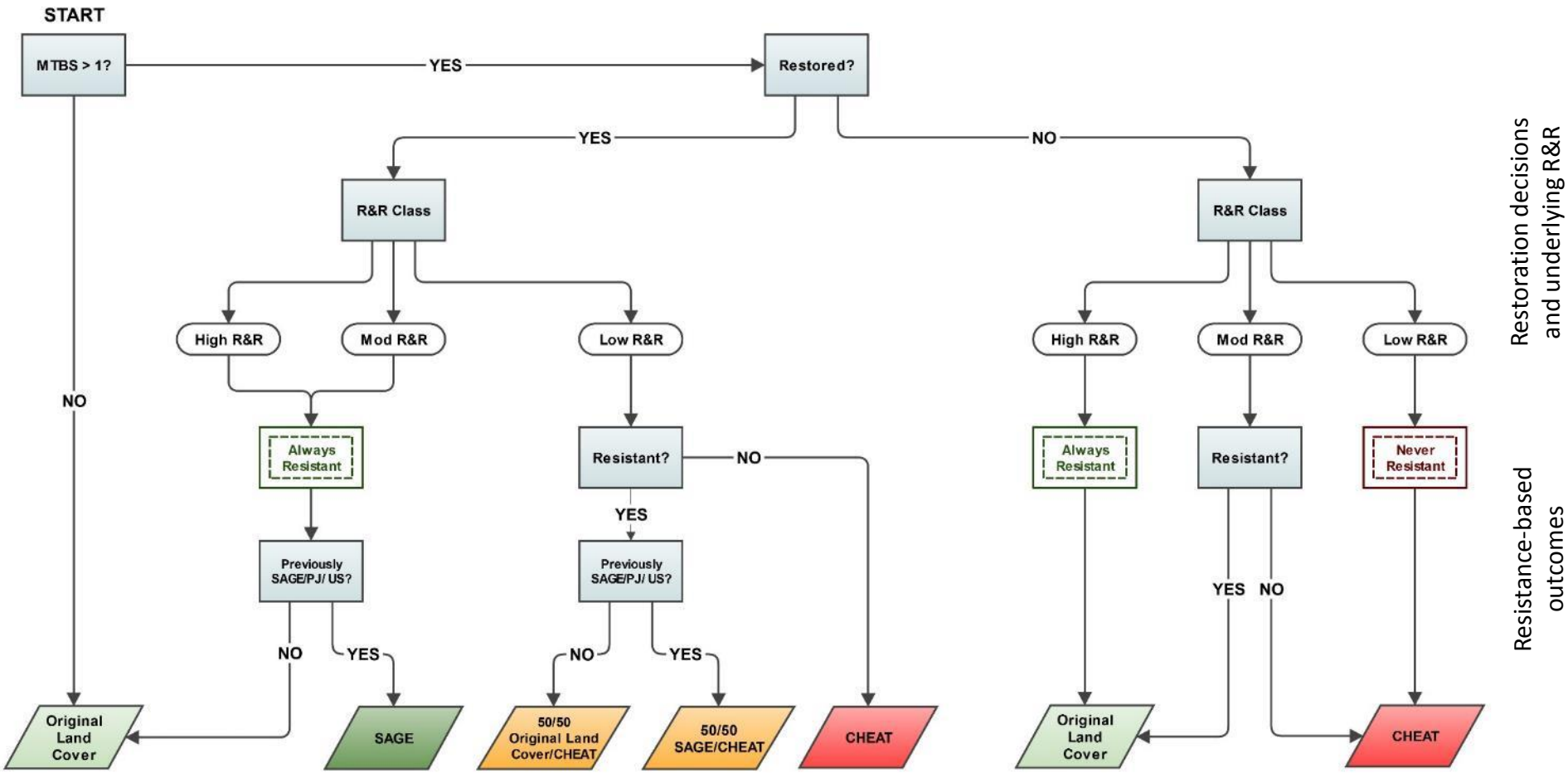
USGS

G. Vyn

M. Schoeder

Post-fire conservation planning tools

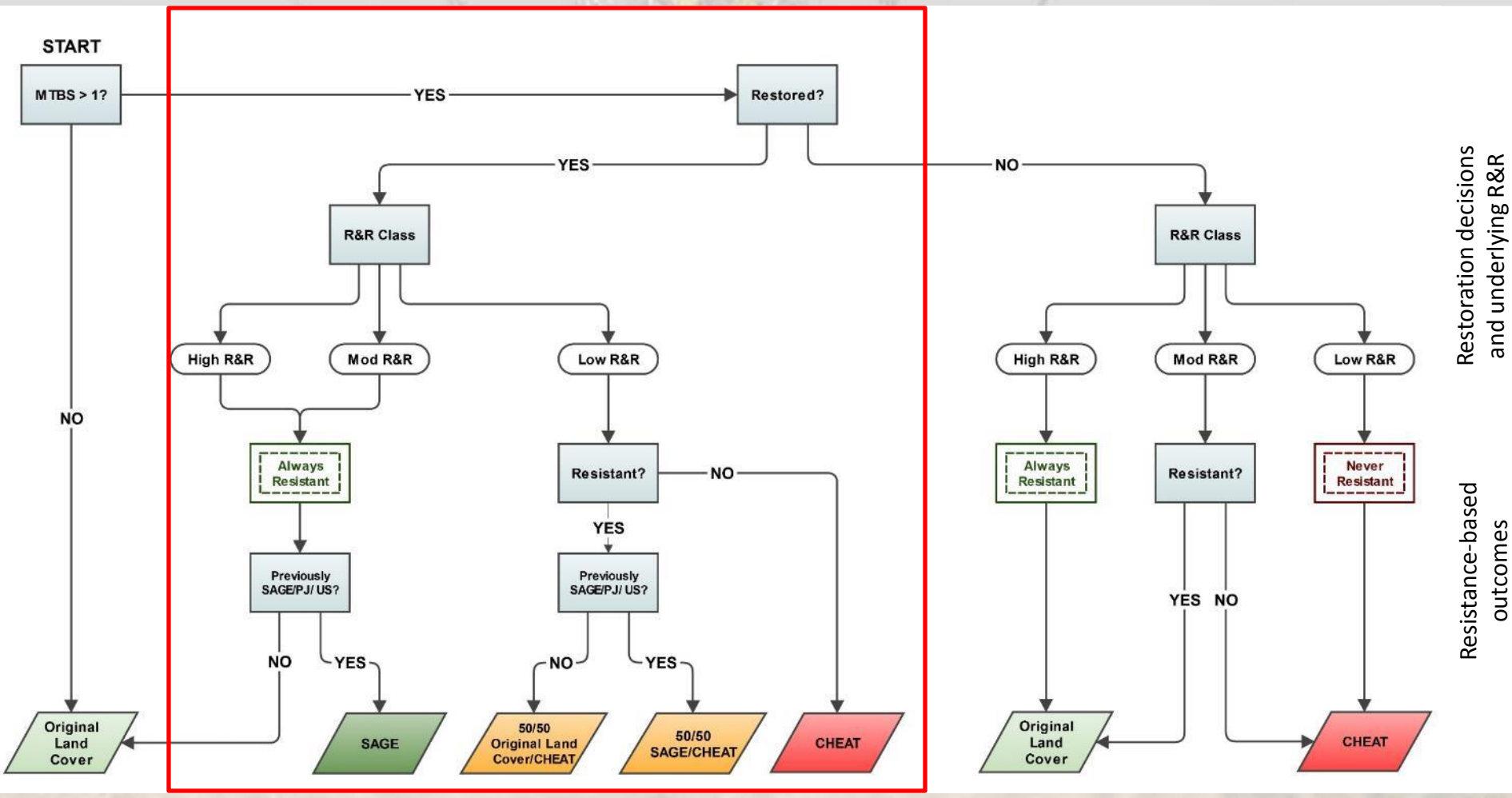
Decision Tree Model: Identifying the 'best' burns to restore



Ricca et al., In Press; Ecological Application

Post-fire conservation planning tools

Decision Tree Model: Identifying the 'best' burns to restore



Ricca et al., In Press; Ecological Application

Post-fire conservation planning tools

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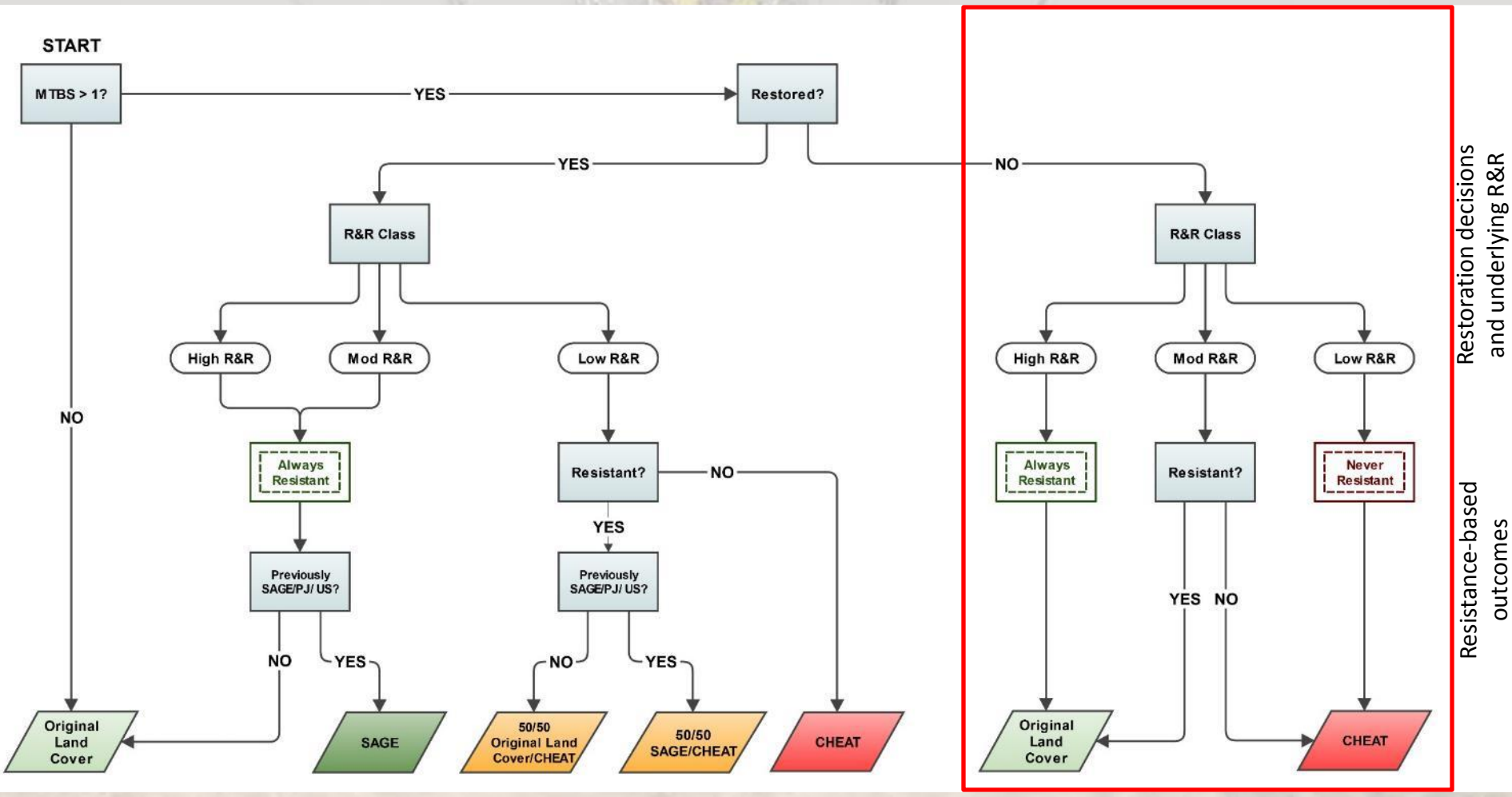

Ricca et al., In Press; Ecological Application

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science for a changing world

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USGS Western Ecological Research Center
Research Profile

Greater Sage-Grouse and the Sagebrush Ecosystem

Informing management solutions that can successfully balance multiple land use objectives for the sagebrush ecosystem.

The **Greater Sage-grouse** (*Centrocercus urophasianus*) is an iconic symbol of the American west. This bird relies on the vast "sagebrush sea" spanning eleven western states for food and shelter, and a place to strut its famed courtship dance on breeding grounds centuries old. Conservation efforts aimed at greater sage-grouse can also benefit many other species that rely on sagebrush ecosystems during parts or all of their lives.

The **USGS Western Ecological Research Center (WERC)** leads multiple ongoing research projects aimed at informing federal and state management of sage-grouse populations and the sagebrush ecosystems they inhabit. Sage-grouse numbers have declined markedly across their range, and remaining populations face numerous threats that include wildfire and invasive grasses, conifer expansion, energy and infrastructure development, urbanization, and agricultural practices. A diverse group of managers and stakeholders that include federal, state, industry, non-profit, and academic partners, and private landowners are using WERC science to balance the nation's needs for natural resources with the maintenance of healthy sagebrush ecosystems.

WERC's sage-grouse applied research program collects data at more than 15 field locations across the Great Basin. Using data from these efforts, along with other information collected by partners across the species' range, WERC scientists generate science-based, user-friendly tools for managers. These include: regional maps of annual and seasonal sage-grouse macro-habitat needs; standards to guide site-level evaluation of sage-grouse microhabitat suitability (such as nesting and brood-rearing sites); models that predict how threats such as wildfire and invasive grasses impact sage-grouse population growth rates and habitat use; an early warning system for detecting sage-grouse population declines; decision support tools to guide sagebrush restoration projects; and protocols for translocations of sage-grouse to rescue imperiled populations.

These are just some of the many ways in which WERC delivers research findings with real world applications to resource agencies and community forums in the Great Basin and beyond — we help provide science for the changing world of sagebrush ecosystems.

RESEARCH CONTACTS

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WERC Greater Sage-Grouse Research

Wildflowers of the Great Basin/Steven Schwarzbach

Scientist tracking tagged sage-grouse/USGS

Greater Sage-grouse chick/USGS

BI-STATE SAGE-GROUSE CONSERVATION

The Bi-State Distinct Population Segment of greater sage-grouse straddles the borders of California and Nevada at the southwestern extreme of the species' range. These sage-grouse are physically isolated and genetically distinct from those found in the rest of their range, leaving them at a higher risk of population collapse. WERC has developed a suite of conservation planning tools based on results from statistical models of sage-grouse habitat suitability, spatial distribution, and gene flow. These models help guide implementation of habitat restoration to yield benefits to sage-grouse while accounting for project costs and ecosystem resilience to disturbance and resistance to invasive species. The overall conservation planning tool framework is being applied to other sage-grouse populations across the species' range.

WILDFIRE, INVASIVE ANNUAL GRASSES, AND CONIFER ENCROACHMENT

Sage-grouse in the Great Basin are threatened by the interacting hazards of wildfire, annual grass invasion, and conifer expansion that fragment and destroy sagebrush ecosystems. Non-native annual grasses, like cheatgrass, can fuel larger and more frequent fires that eliminate sagebrush. Conifers, such as pinyon pine and juniper trees, are expanding into sagebrush stands and reducing sagebrush habitat, as well as fueling more intense fires and providing perches for predators like raptors. WERC scientists and colleagues are quantifying thresholds for effects of these threats on sage-grouse populations. Thresholds provide practical targets that federal and state resource managers may use to reduce the impacts of these threats.

LAND USE PLANNING

WERC researchers map habitat suitability for sage-grouse during critical life periods (nesting, brood-rearing, over-wintering) at spatial scales that range from microsites to large landscapes across the Great Basin. This research provides an understanding of the influence of anthropogenic activities such as mineral extraction, geothermal energy production, hydraulic fracturing for oil, and transmission line development on sage-grouse habitat suitability, and ultimately populations. Study findings can be used by land and resource managers to inform the amelioration of the effects of human activities on sage-grouse.

Female sage-grouse with foal/USGS

NEST SURVIVAL, MICRO-HABITAT CONDITIONS, AND PREDATORS

Nesting is a critical life period for sage-grouse. Nest survival can be influenced by factors that include micro-habitat characteristics (sagebrush cover, grass height), plant growth and seasonal patterns, and predators. WERC conducts long-term studies of sage-grouse nesting ecology at multiple sites in the Great Basin. Moreover, common ravens are a major predator of sage-grouse nests. WERC scientists are developing multi-scale maps that predict raven occurrence and density throughout the Great Basin. This information is valuable for managers focused on improving habitat conditions for sage-grouse nest survival, and reducing features that attract predators to nests.

EARLY WARNING SYSTEMS

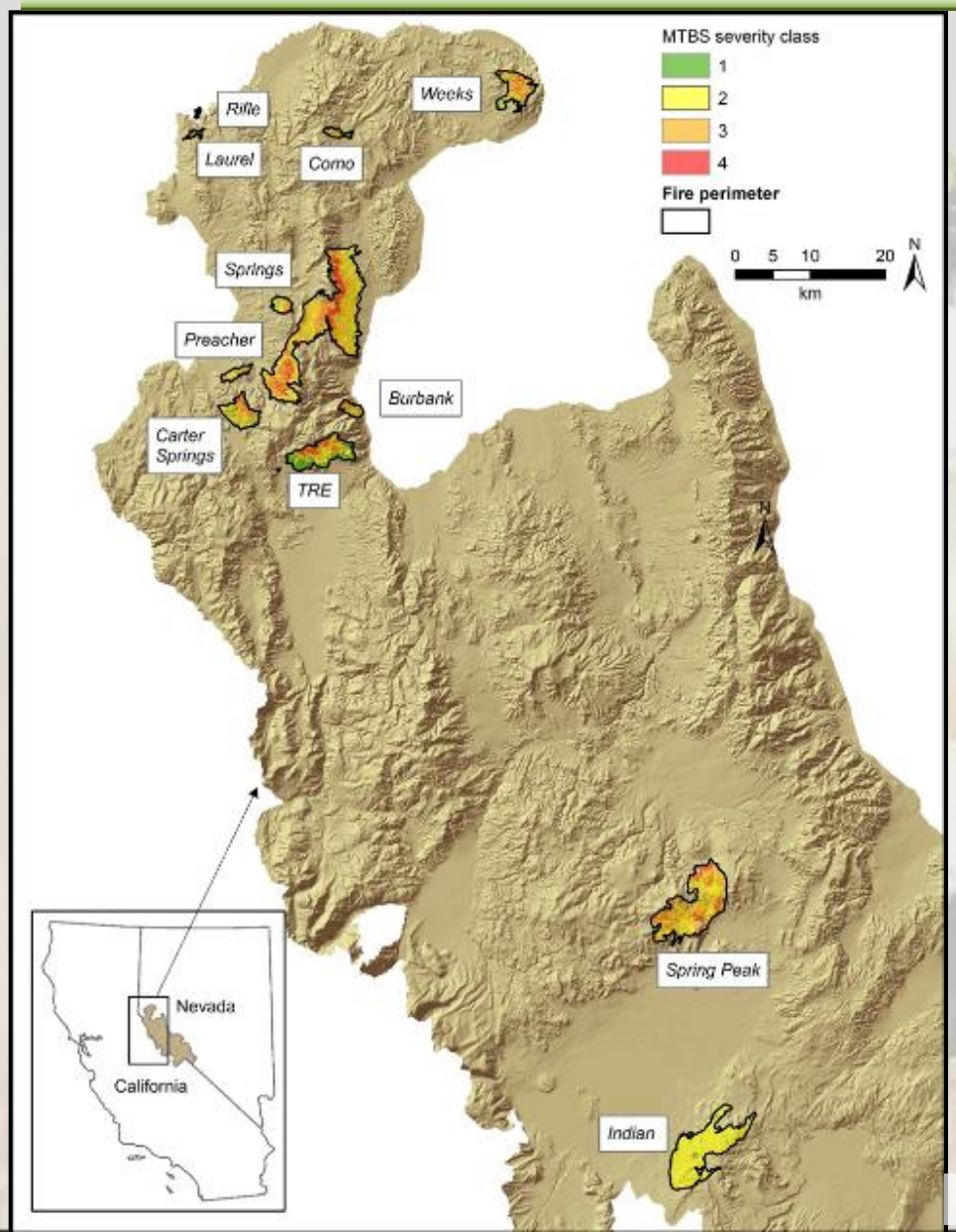
WERC research shows that sage-grouse populations respond positively to infrequent periods of heavy rainfall, allowing them to survive through prolonged droughts. Managers need to know whether local or regional population declines are influenced by broader climate patterns, versus declines in response to other environmental changes that could be managed. A multi-partner coalition has developed a hierarchical population model for sage-grouse in Nevada and northern California that detects: 1) if vulnerable populations are declining; and 2) if rates of declines are faster than those of surrounding populations influenced by similar climatic and habitat conditions. This population-based framework for understanding when management intervention is needed can ultimately be applied to sage-grouse populations rangewide.

WERC partners in greater sage-grouse research include (alphabetically): Bureau of Land Management • California Department of Fish and Wildlife • Idaho Department of Fish and Game • Idaho State University • Nevada Department of Conservation and Natural Resources • Nevada Department of Wildlife • public and private community members • State of Nevada Sagebrush Ecosystem Program • Western Association of Fish and Wildlife Agencies • University of California, Davis • University of Idaho • University of Nevada, Reno • USDA Natural Resource Conservation Service • U.S. Fish and Wildlife Service • U.S. Forest Service • USGS Earth Resources Observation and Science Center • USGS Forest and Rangeland Ecosystem Science Center • USGS Fort Collins Science Center • Wildlife Conservation Society

The USGS Western Ecological Research Center (WERC) is an Ecosystems mission science center serving California and Nevada. Online at www.usgs.gov/centers/werc

Post-fire conservation planning tools

Decision Tree Model: Identifying the 'best' burns to restore



Fire	Area burned (ha)	Average ΔGBI / ha	Cumulative ΔGBI / ha	rank [a]
Spring Peak	5759	25.49	0.61	1 (1,1)
TRE	2471	8.75	0.81	2 (2,3)
Indian	5089	5.16	0.94	3 (3,2)
Como	311	0.96	0.96	4 (4,6)
Bison	9657	0.66	0.98	5 (5,4)
Carter Springs	1400	0.65	0.99	6 (6,5)
Burbank	450	0.19	1.00	7 (7,7)
Preacher	435	0.09	1.00	8 (8,8)
Springs	483	0.07	1.00	9 (9,9)
Laurel	130	0.00	1.00	10 (10,10)
Rifle	50	0.00	1.00	11 (11,11)
Weeks	1563	0.00	1.00	12 (12,12)

Ricca et al. In Press, Ecological Applications