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CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

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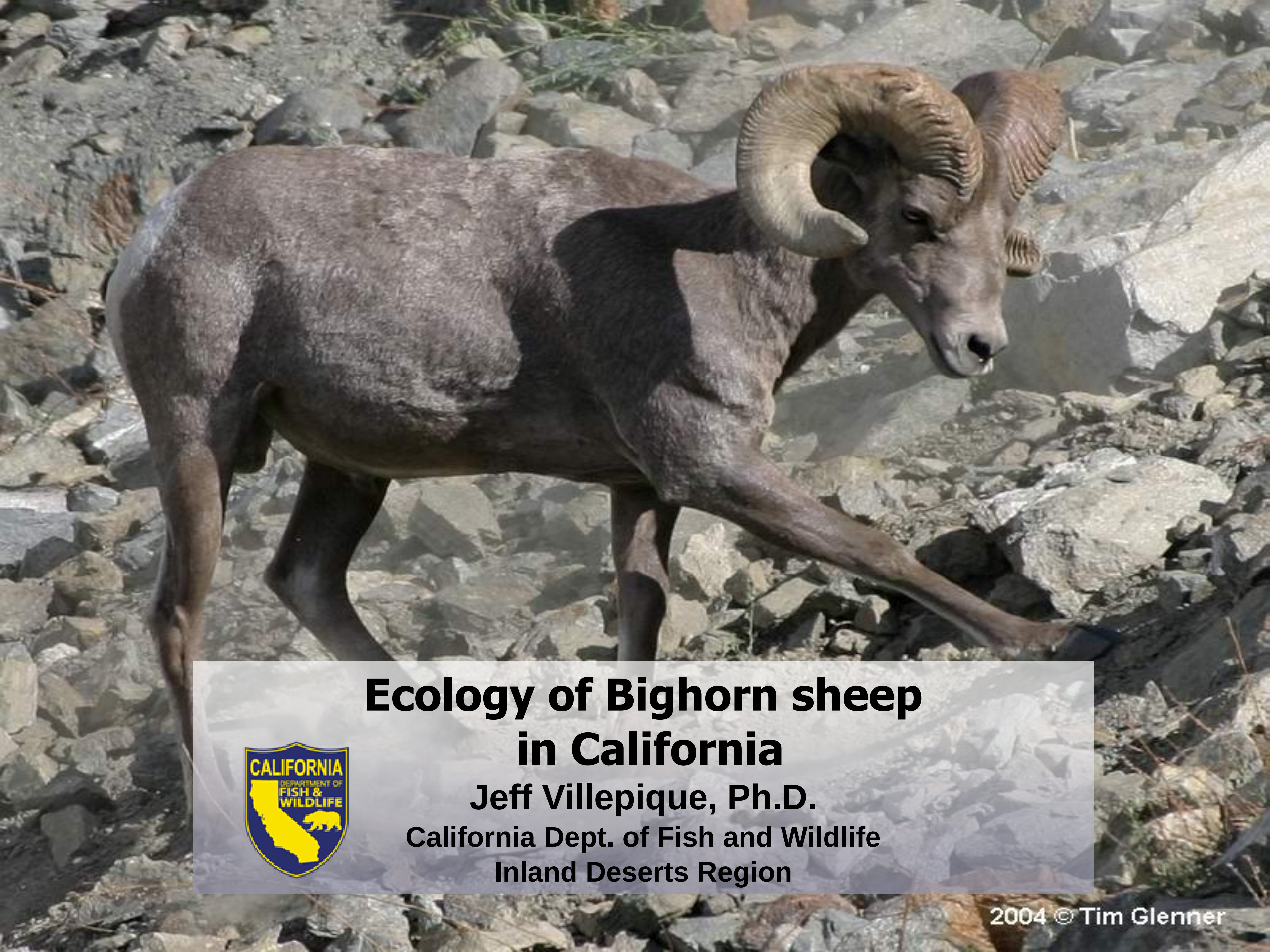
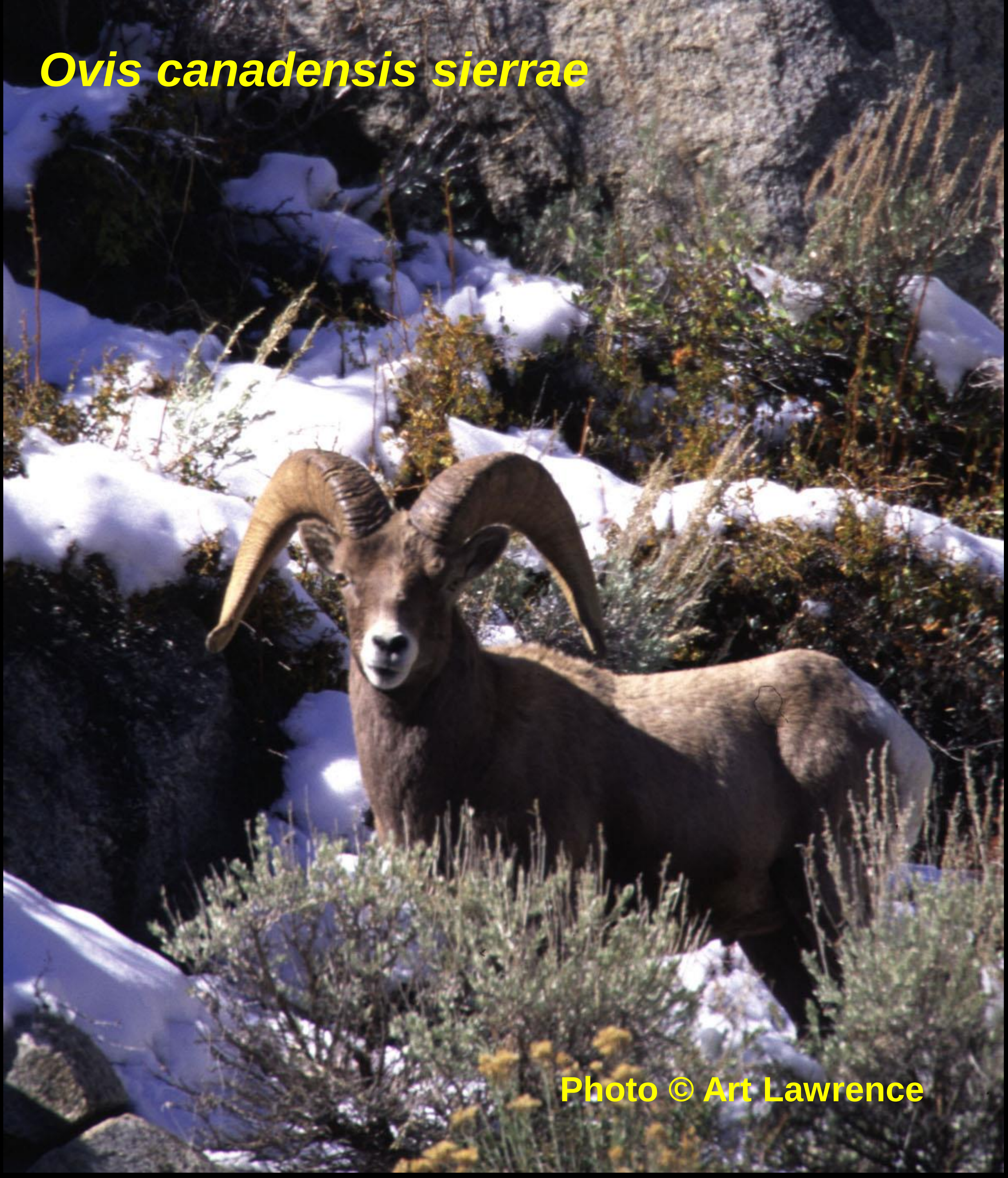


Ecology of Bighorn sheep in California

Jeff Villepique, Ph.D.
California Dept. of Fish and Wildlife
Inland Deserts Region

Ovis canadensis nelsoni


Ovis canadensis sierrae
Photo © Art Lawrence


Ovis canadensis sierrae
DFG Photo


Ovis canadensis nelsoni
Photo © Jeff Young
Photo courtesy of Jeff Young


Ancestral *Ovis*

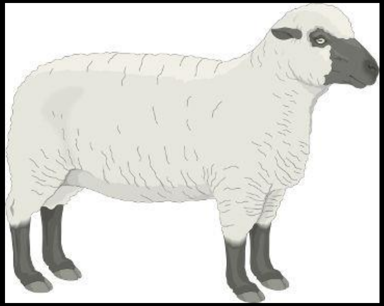
North America Wild Sheep

Ovis dalli dalli
O. d. stonei

O. canadensis canadensis
O. c. sierrae
O. c. nelsoni

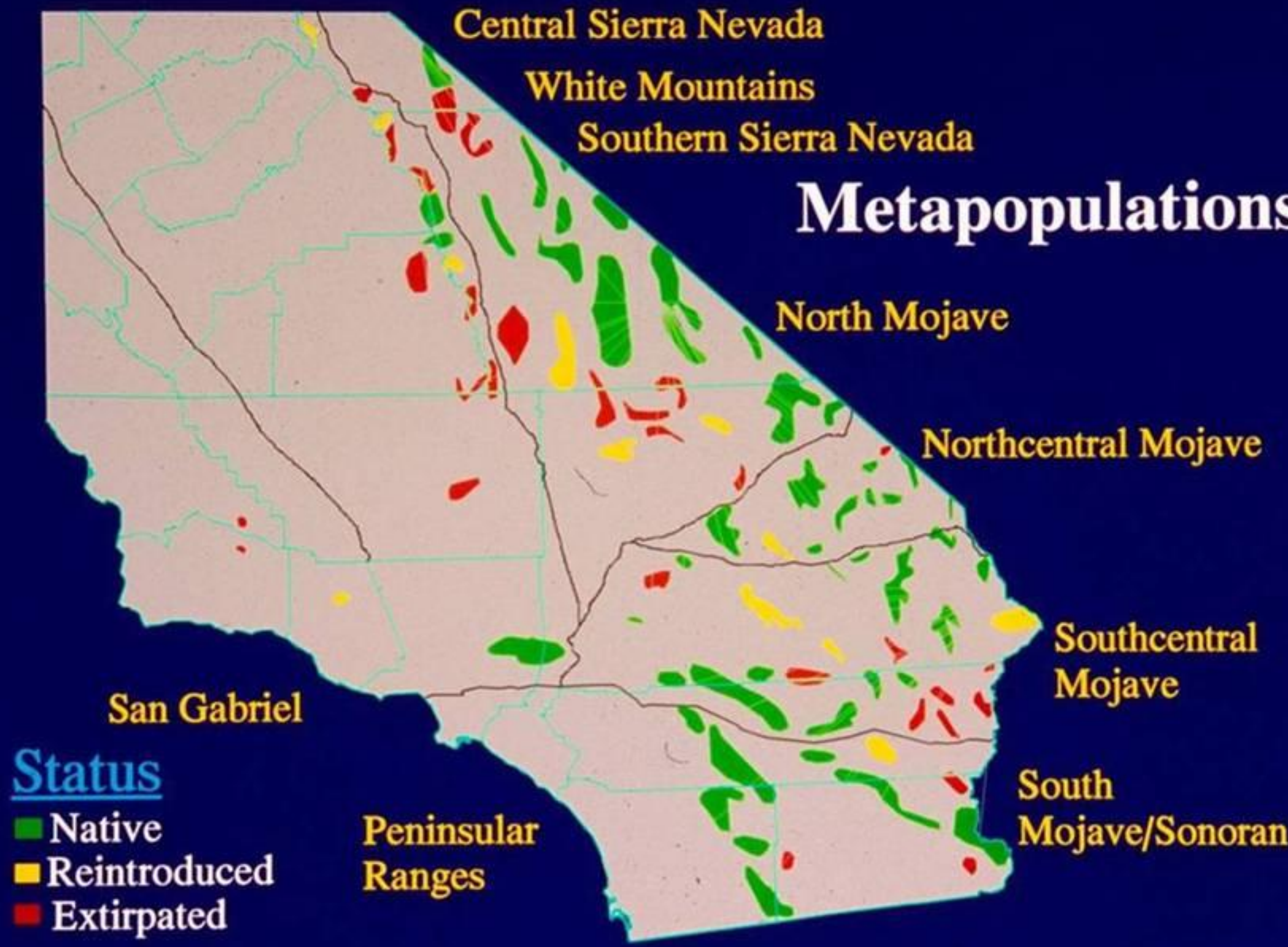
Bighorn Sheep

O. canadensis canadensis
O. c. sierrae
O. c. nelsoni



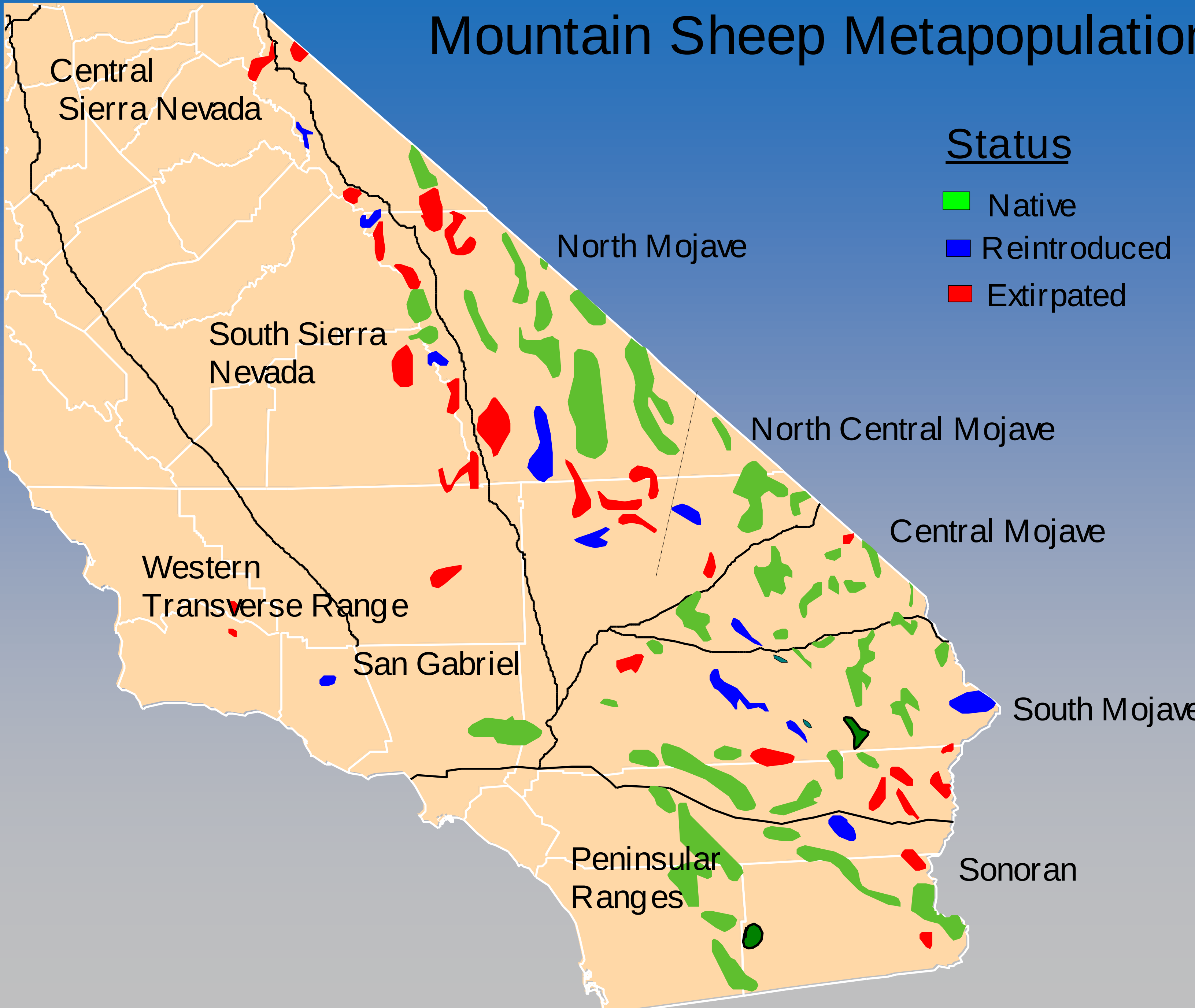
Desert Bighorn Sheep Metapopulations

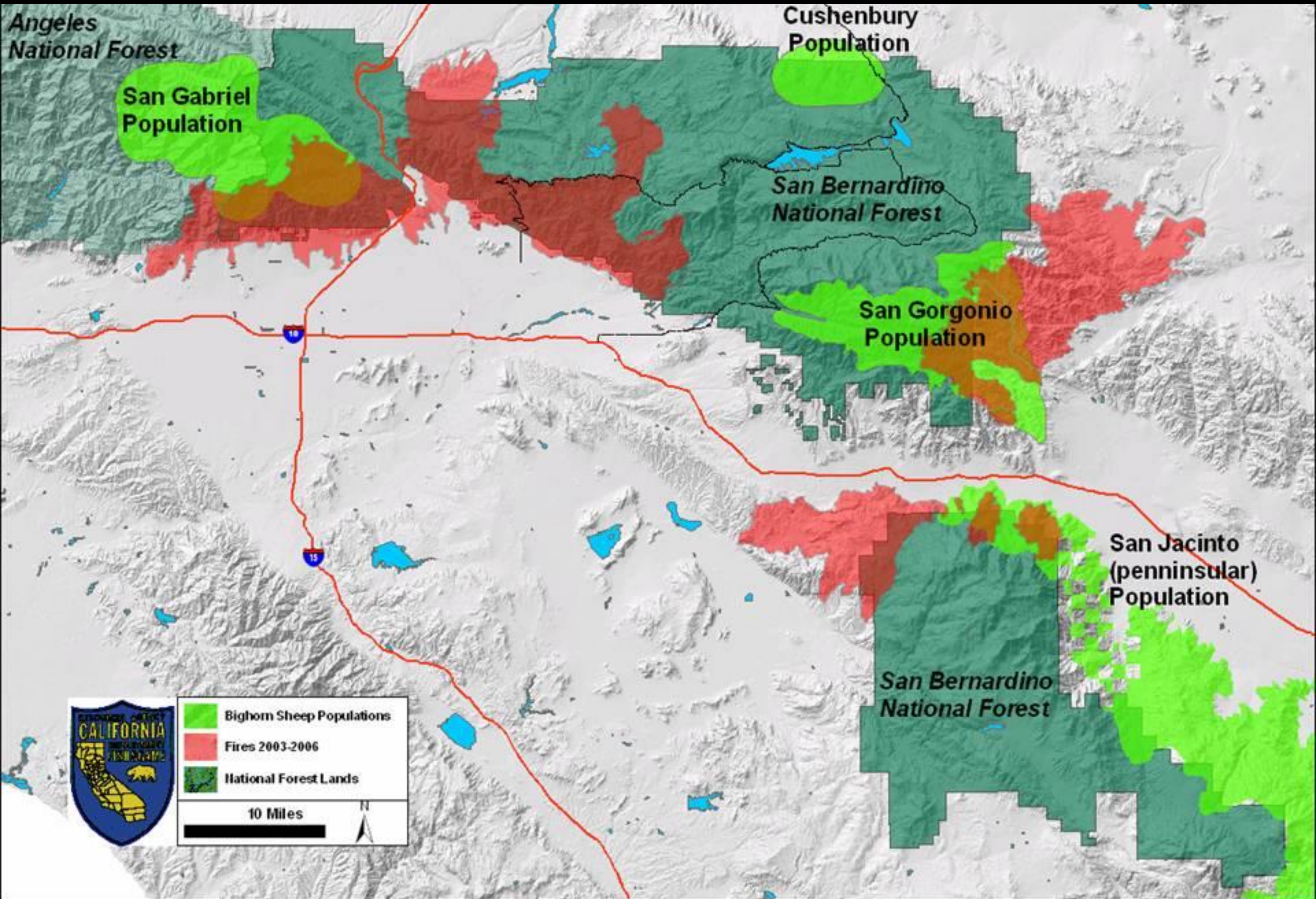
Metapopulations




16 11:29AM

Mountain Sheep Metapopulations




Angeles
National Forest
Cushenbury
Population
San Gabriel
Population
San Bernardino
National Forest
San Gorgonio
Population
San Jacinto
(penninsular)
Population
San Bernardino
National Forest
Bighorn Sheep Populations
Fires 2003-2006
National Forest Lands
10 Miles
N
10
15
CALIFORNIA


© 2004 NelsonBighorn.com

Population Trends 1976-2012

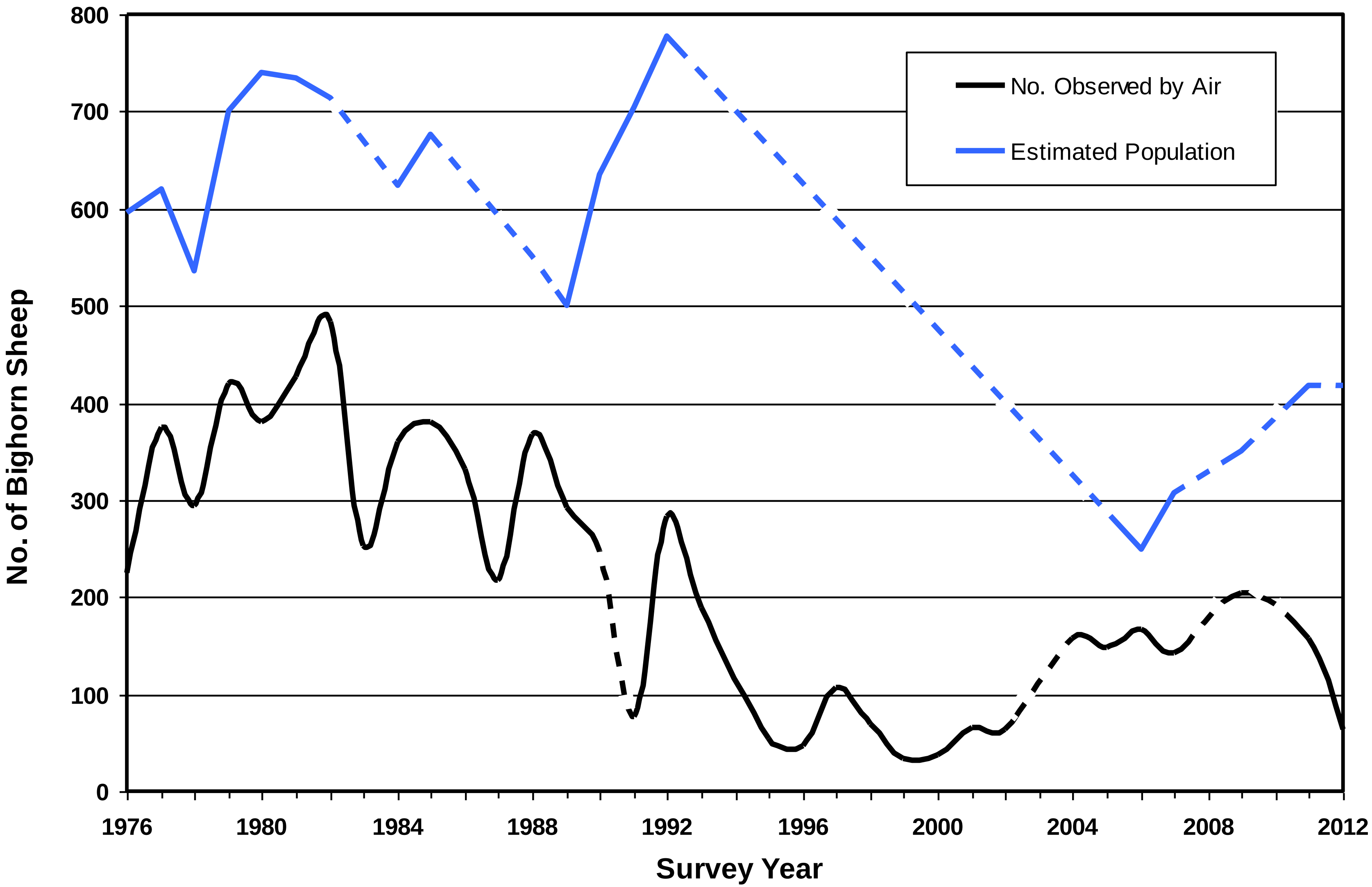



Photo © Tim Glenner


Photo © Kathie Meyer

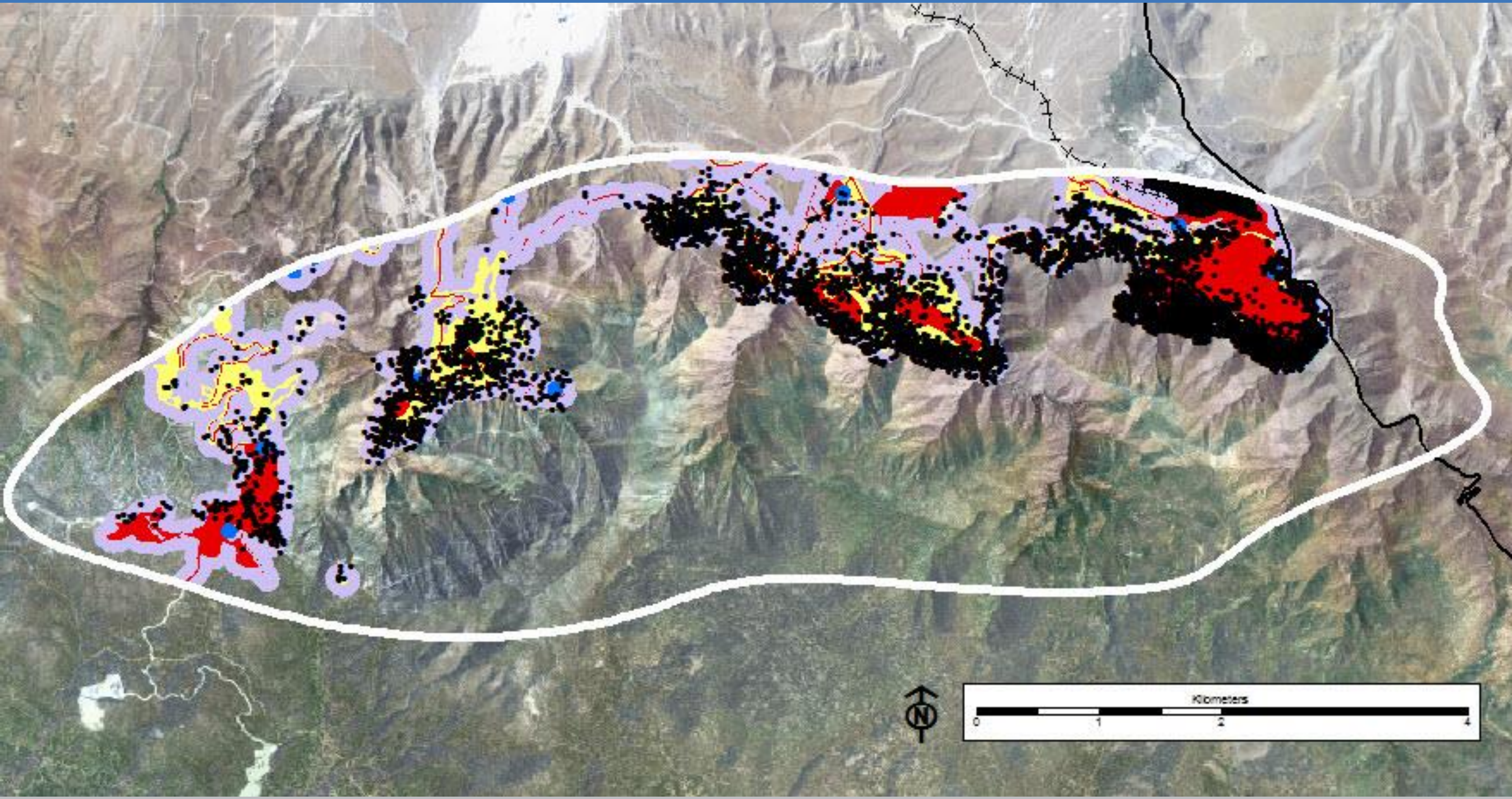
April 17, 2006 – 6:30 pm

Old Arctic Quarry

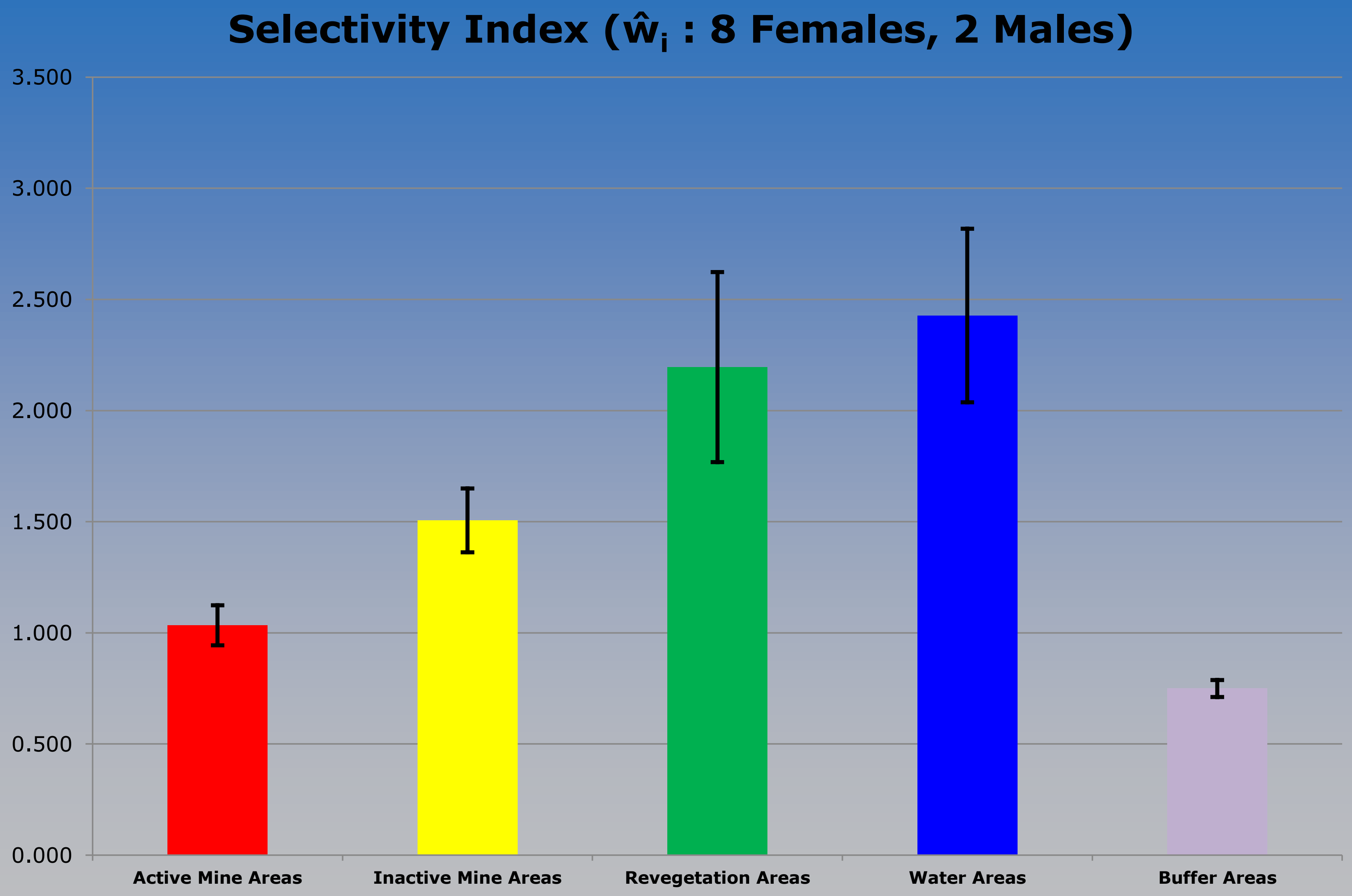
Specialty Minerals Inc., Lucerne Valley, CA

Photo Courtesy of Dayan Anderson

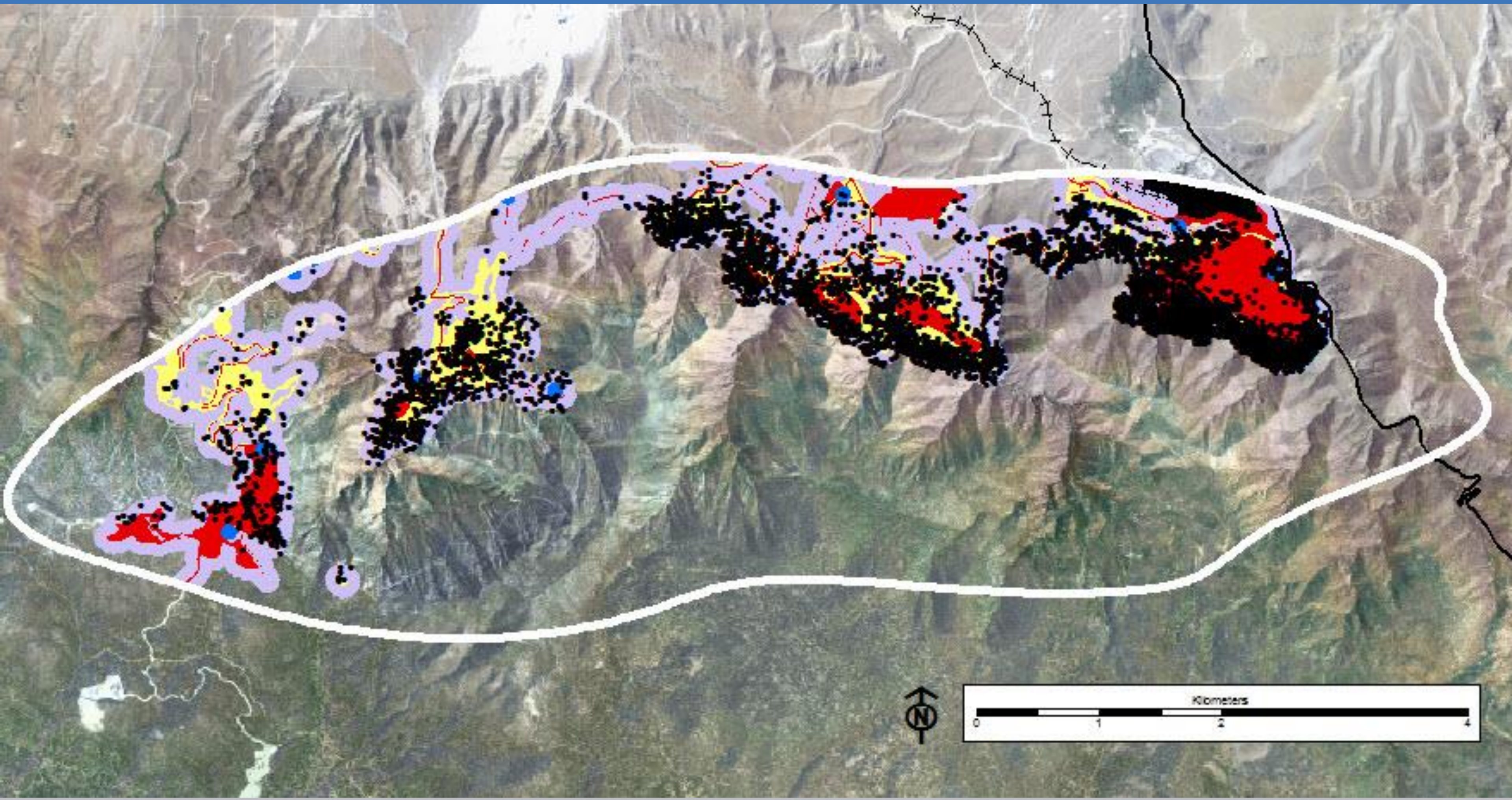
Habitat Classification & Sheep Locations



Active Mine Areas
Inactive Mine Areas
Water Sources
Revegetation Areas
Buffer Areas (100m)
Sheep Locations


Selectivity Index (ŵi : 8 Females, 2 Males)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Active Mine Areas
Inactive Mine Areas
Revegetation Areas
Water Areas
Buffer Areas

Habitat Classification & Sheep Locations



Active Mine Areas

Inactive Mine Areas

Water Sources

Revegetation Areas

Buffer Areas (100m)

Sheep Locations

Photo Courtesy of Dayan Anderson

THE SOUTHWESTERN NATURALIST 56(2):187–192 JUNE 2011

DIET OF COUGARS (*PUMA CONCOLOR*) FOLLOWING A DECLINE IN A POPULATION OF MULE DEER (*ODOCOILEUS HEMIONUS*): LACK OF EVIDENCE FOR SWITCHING PREY

JEFFREY T. VILLEPIQUE,* BECKY M. PIERCE, VERNON C. BLEICH, AND R. TERRY BOWYER

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Sierra Nevada Bighorn Sheep Recovery Program, California Department of Fish and Game, 407 West Line Street, Bishop, CA 93514 (BMP, VCB)
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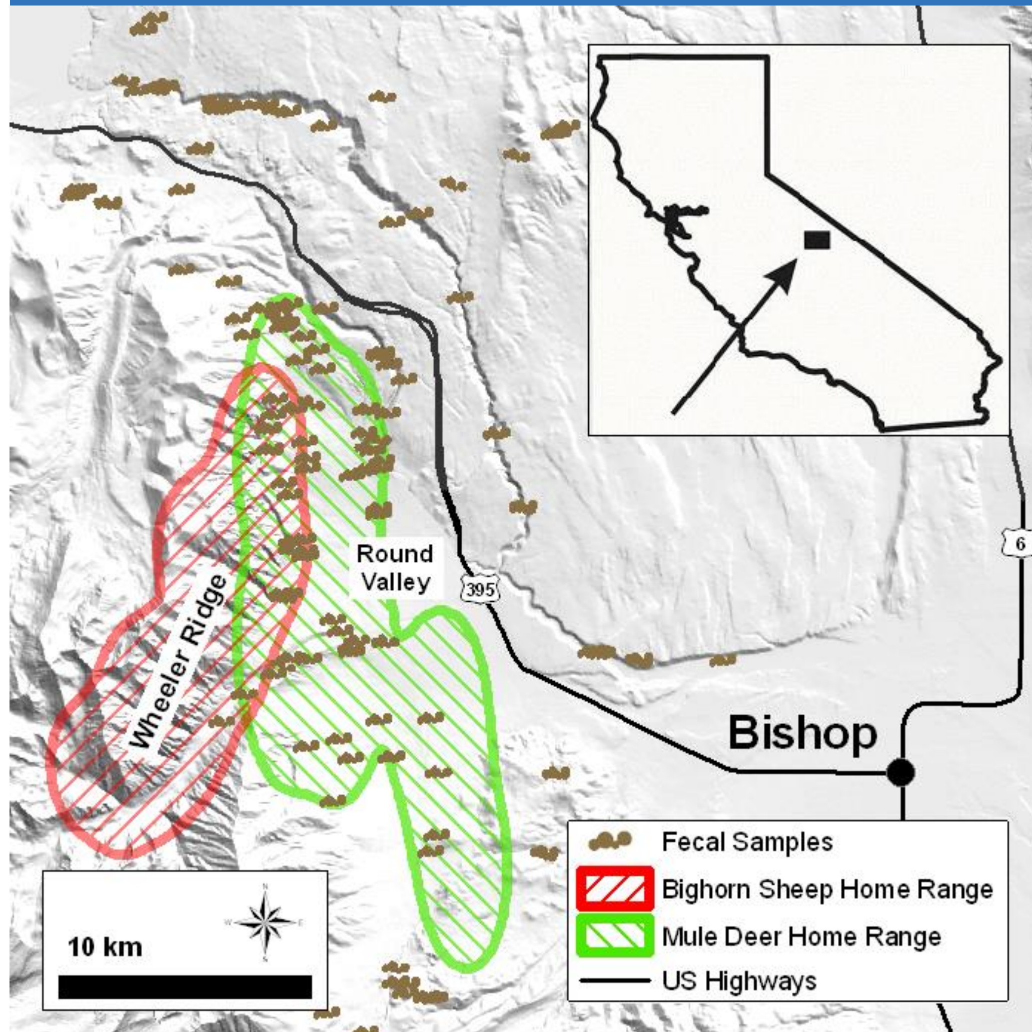
**Correspondent: jvillepique@dfg.ca.gov*

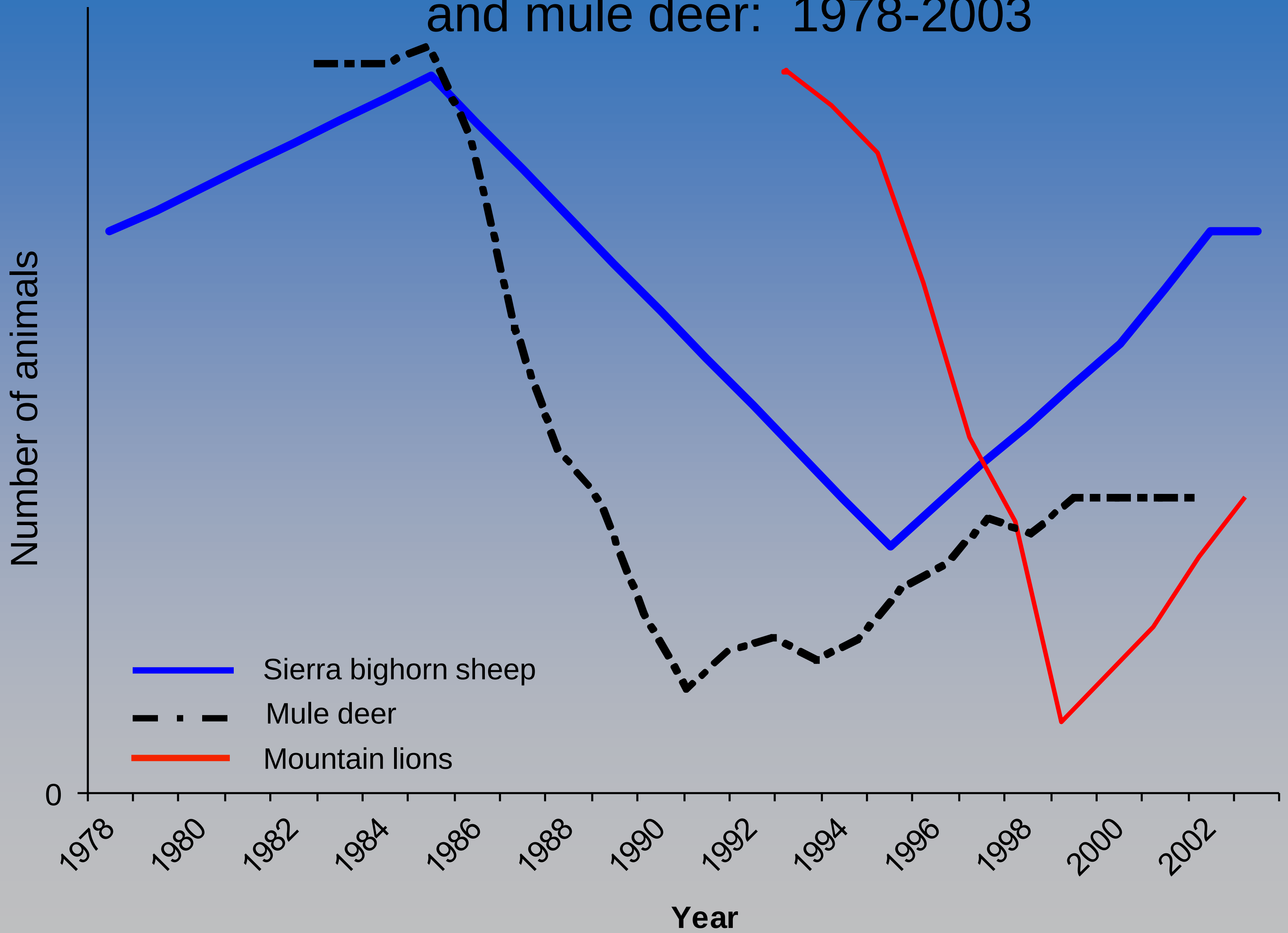
ABSTRACT—We investigated diet of cougars (*Puma concolor*) in the eastern Sierra Nevada, California, following a decline in the population of mule deer (*Odocoileus hemionus*). Mule deer declined 84% from 1985 to 1991, a period concurrent with declines in bighorn sheep (*Ovis canadensis sierrae*, an endangered taxon). An index to numbers of cougars lagged behind those declines, with a reduction of ca. 50% during 1992–1996. We determined diet of cougars by analysis of fecal samples collected during 1991–1995, when the population of mule deer was <25% of its former size. Mule deer was in 79% of 178 feces in winter and 58% of 74 feces in summer. Although most (69%) fecal samples in winter were <5 km from, or within (25%) winter range of bighorn sheep, none contained evidence of bighorn sheep. One fecal sample in summer contained remains of bighorn sheep, indicating that those ungulates were not an important component of the diet during our investigation.

RESUMEN—Investigamos la dieta del puma (*Puma concolor*) en la parte este de la Sierra Nevada en California después de una disminución en la población del venado bura (*Odocoileus hemionus*). El venado bura disminuyó 84% desde 1985 hasta 1991, una época simultánea con disminución en las poblaciones del borrego cimarrón (*Ovis canadensis sierrae*, un taxón en vías de extinción). Un índice de números de pumas se quedó atrás de esas disminuciones, con una reducción de aproximadamente 50% durante los años de 1992–1996. Determinamos la dieta del puma con un análisis de muestras fecales que colectamos durante los años de 1991–1995, cuando la población del venado bura fue menos que 25% de su tamaño anterior. Restos del venado bura se encontraron en 79% de las 178 muestras fecales en el invierno y en 58% de las 74 muestras fecales en el verano. Aunque más muestras fecales (69%) que colectamos en el invierno estuvieron localizadas <5 km de o dentro de (25%) la distribución invernal de los borregos cimarrones, ninguna contuvo evidencia de borrego cimarrón. Una muestra fecal en el verano tuvo restos de borrego cimarrón, lo que indica que esos ungulados no fueron un componente importante de la dieta del puma durante nuestra investigación.

Mule deer (*Odocoileus hemionus*) are the primary prey of cougars (*Puma concolor*) in the Great Basin (Pierce et al., 1999, 2000*a*). Cougars select prey based upon size or sex (Pierce et al., 2000*b*), and can respond to declines of prey by switching to alternative prey (Logan and Sweanor, 2001; Rominger et al., 2004). We studied diets of cougars reconstructed from fecal samples collected following a decline in populations of mule deer (Bowyer et al., 2005) and bighorn sheep (*Ovis canadensis*; Wehausen, 1996) in a Great Basin ecosystem. We hypothesized that occurrence of mule deer in diets of cougars would be more common when mule deer were concentrated on winter range than during summer, when alternative prey were expected to occur more frequently. We further postulated that the decline and persistent low populations of mule



Trends in mountain lions, bighorn sheep and mule deer: 1978-2003



Wehausen hypothesis

Wehausen, J. W. 1996. Effects of mountain lion predation on bighorn sheep in the Sierra Nevada and Granite Mountains of California. Wildlife Society Bulletin 34:471-479.

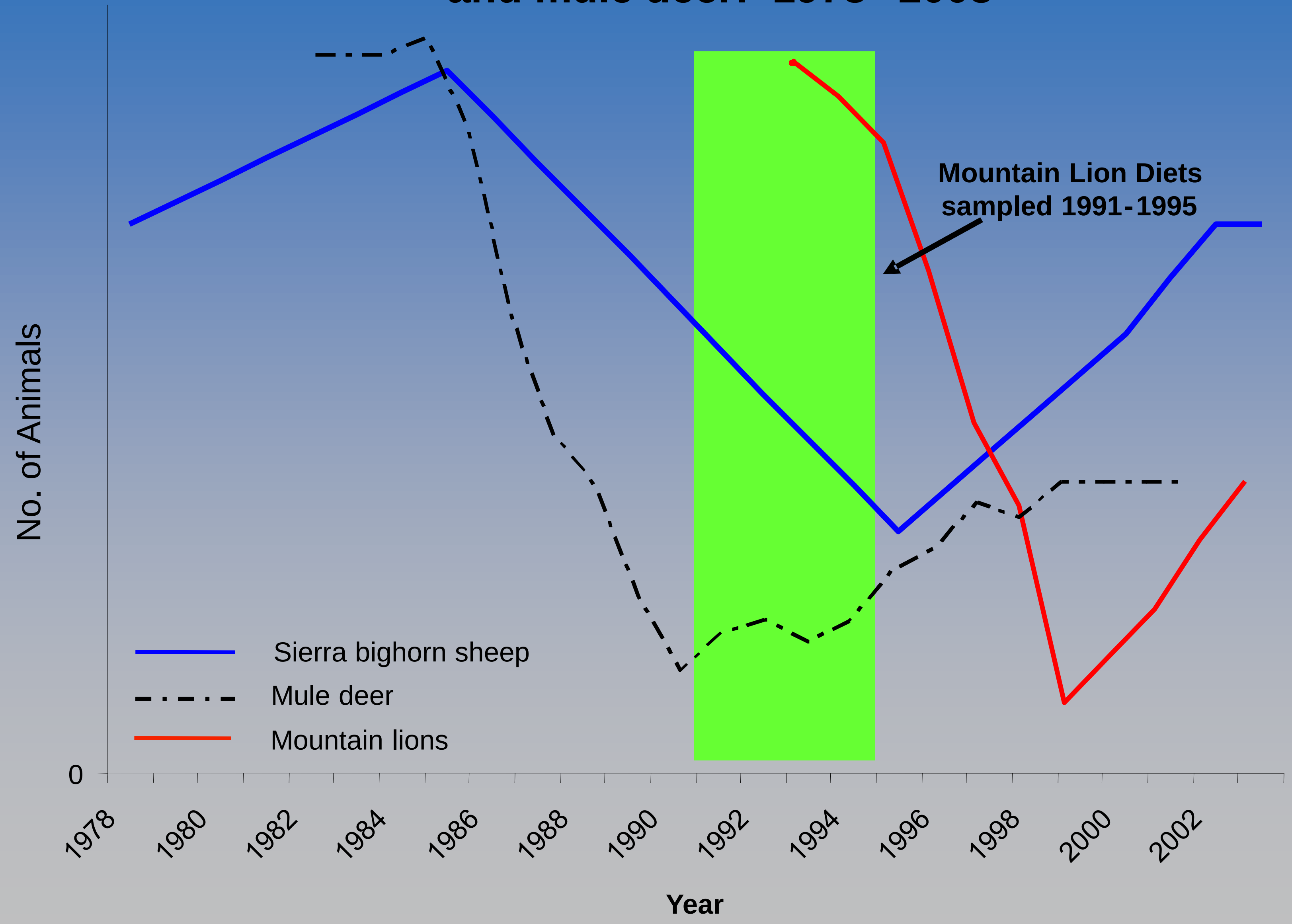
"Range abandonment"

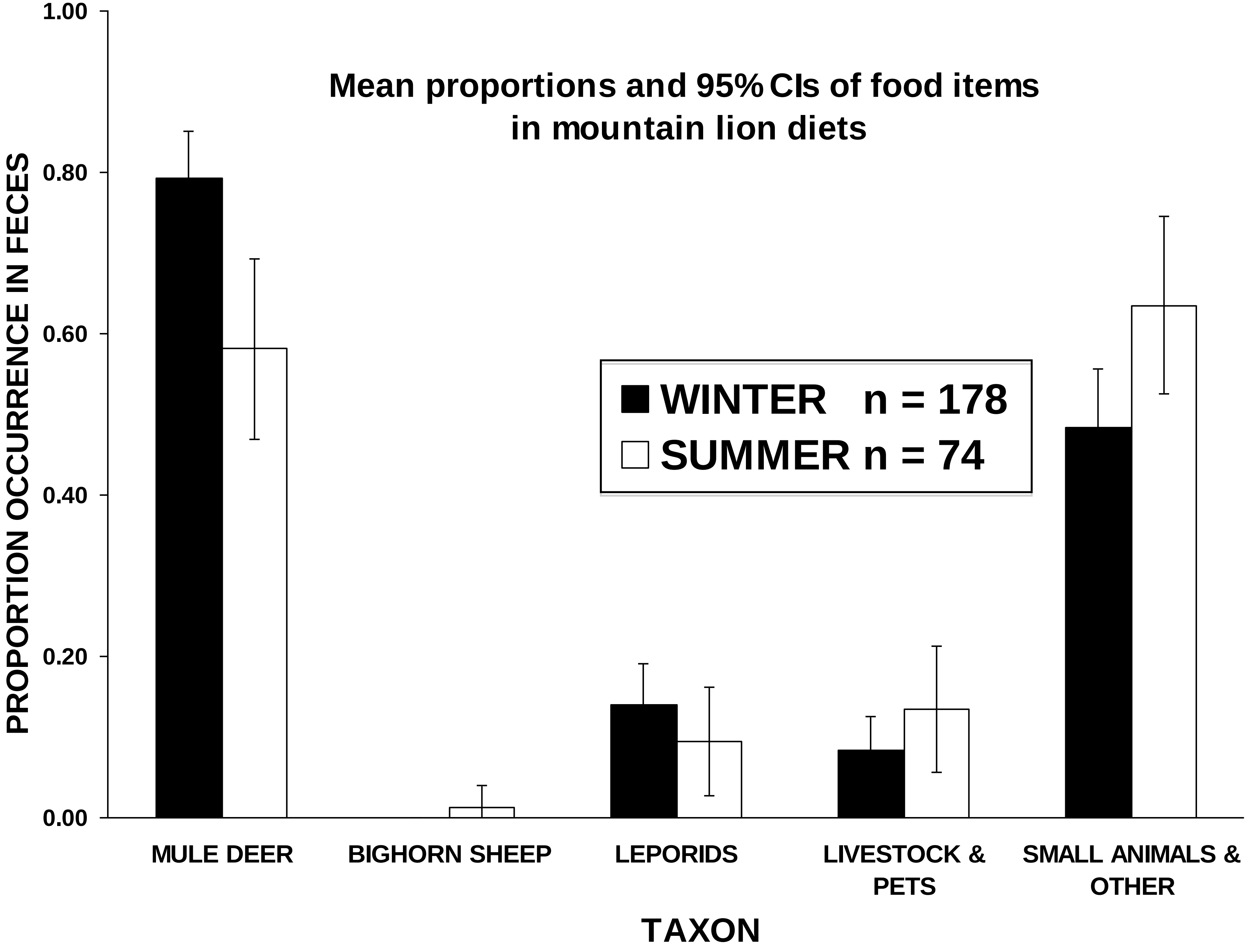
Bighorn sheep avoided low-elevation winter range, subsisted on poor-quality forage, suffered energetically from high-elevation winter conditions, and died in avalanches. Poor survival and recruitment of lambs were the result.

Bighorn sheep chose to remain at high elevation rather than risk predation by mountain lions on low elevation range.

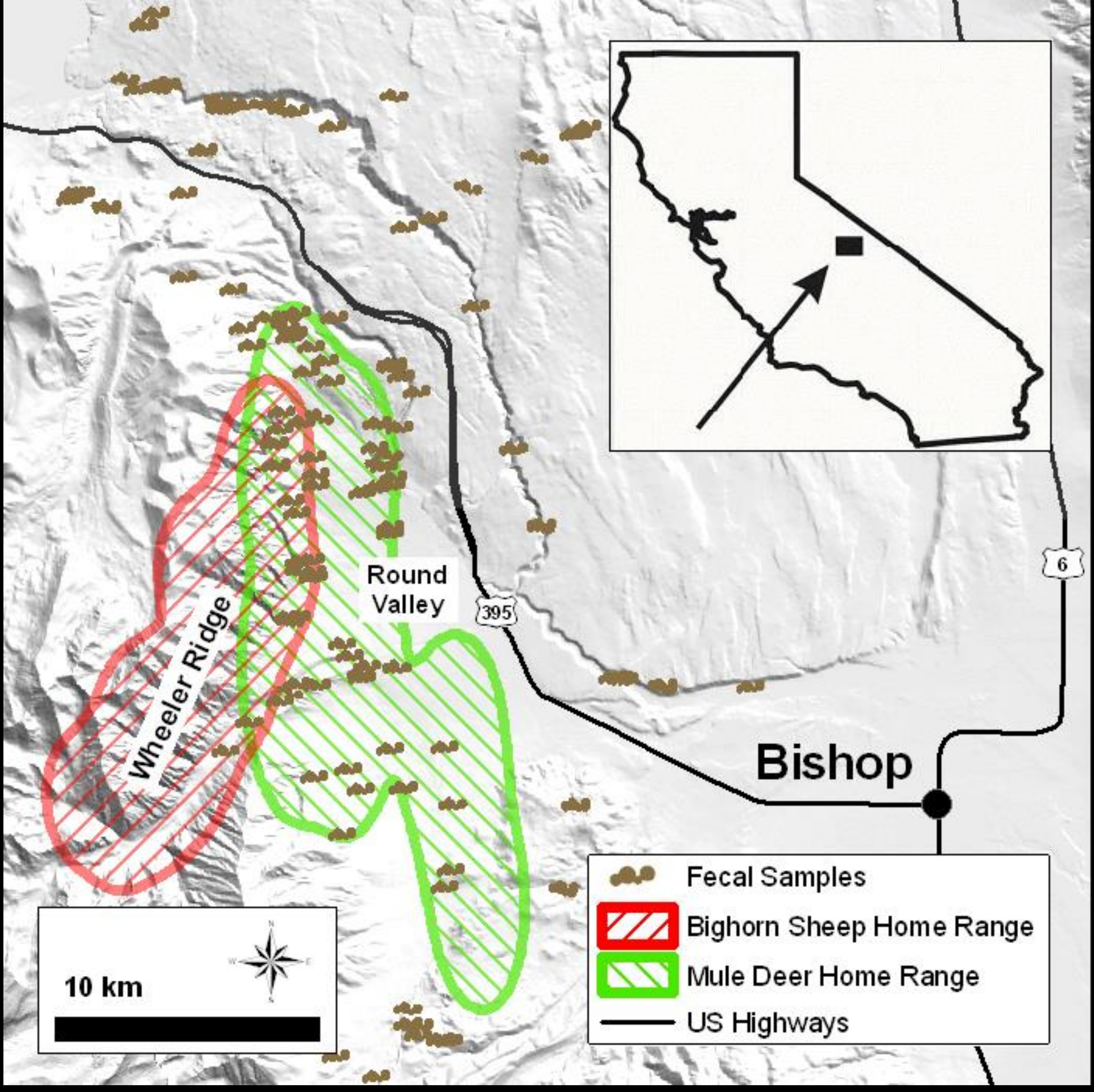

15 19:10

Trends in mountain lions, bighorn sheep, and mule deer: 1978 - 2003





Mean proportions and 95% CIs of food items
in mountain lion diets
WINTER n = 178
SUMMER n = 74
PROPORTION OCCURRENCE IN FECES
1.00
0.80
0.60
0.40
0.20
0.00
MULE DEER
BIGHORN SHEEP
LEPORIDS
LIVESTOCK & PETS
SMALL ANIMALS & OTHER
TAXON


Wheeler Ridge
Round Valley
395
6
Bishop
10 km
N
E
S
W
Fecal Samples
Bighorn Sheep Home Range
Mule Deer Home Range
US Highways

RESPONSES OF DESERT BIGHORN SHEEP TO EXPERIMENTAL SIMULATION OF RISK OF PREDATIOM BY MOUNTAIN LION

Jeff Villepique, Becky Pierce, Terry Bowyer, Vern Bleich

California Dept. of Fish and Wildlife
& Idaho State University


photo by Jeff Villepique

Predator evasion strategies

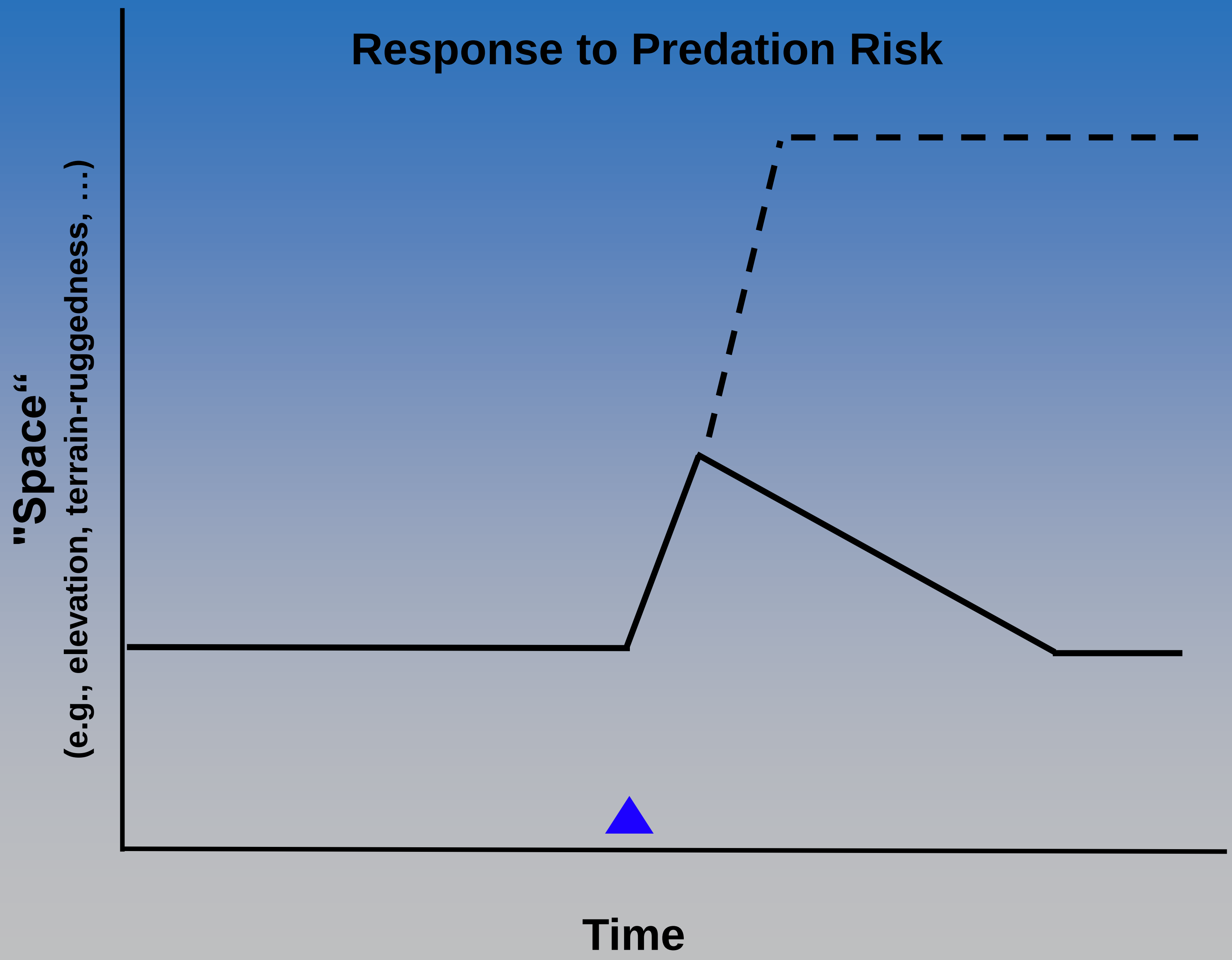
- Indirect: Reduce chance of encounter
  - Habitat selection, sociality, vigilance
- Direct: Response to presence of predator
  - Flight ("escape terrain"), inspection, aggression

Reduce chance of encounter

- **Habitat selection**
  Visibility, proximity to escape terrain
- **Sociality**
  Dilution of risk, more ears, eyes, noses
- **Vigilance**
  Foraging efficiency, trade-offs

Responses when predator is perceived

- **Sociality**
  - Signaling, defensive posture
- **Flight**
  - Speed, agility, escape terrain
- **Inspection**
  - Safe distance, assess potential predator, maintain surveillance
- **Aggression**
  - Asymmetry of risk


Response to Predation Risk
"Space“
(e.g., elevation, terrain-ruggedness, ...)
Time

Postulates

If bighorn sheep respond to mountain lions at a **landscape** scale, the presence of a mountain lion will cause bighorn to:

- **Move to high elevation**
- **Move long distances**

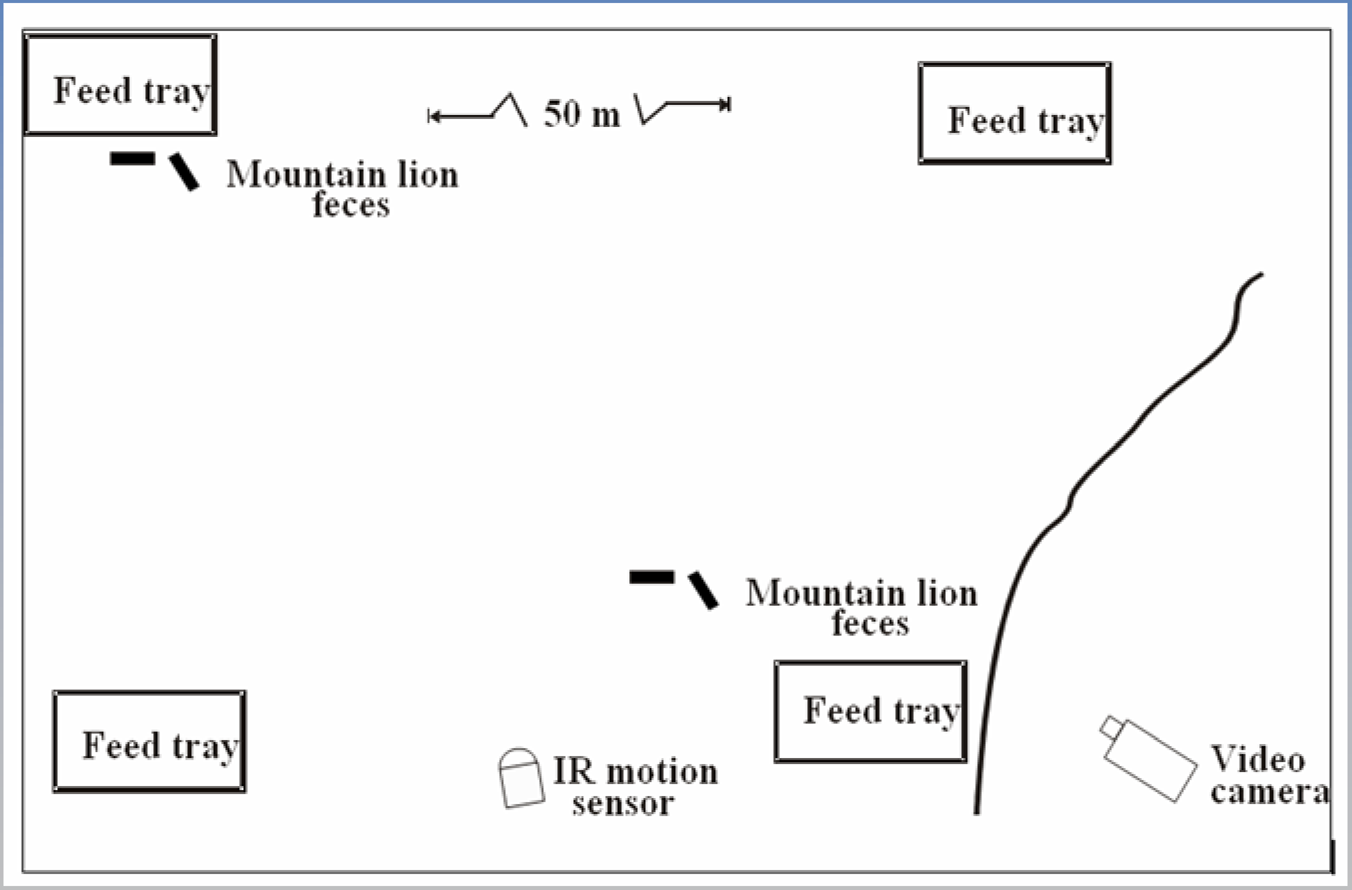
Postulates

If bighorn sheep respond to mountain lions through at a **local** scale, the presence of a mountain lion will cause bighorn to:

- **Move away from the lion**
- **Move to rugged terrain**
- **Increase vigilance**

Test: feeding trials

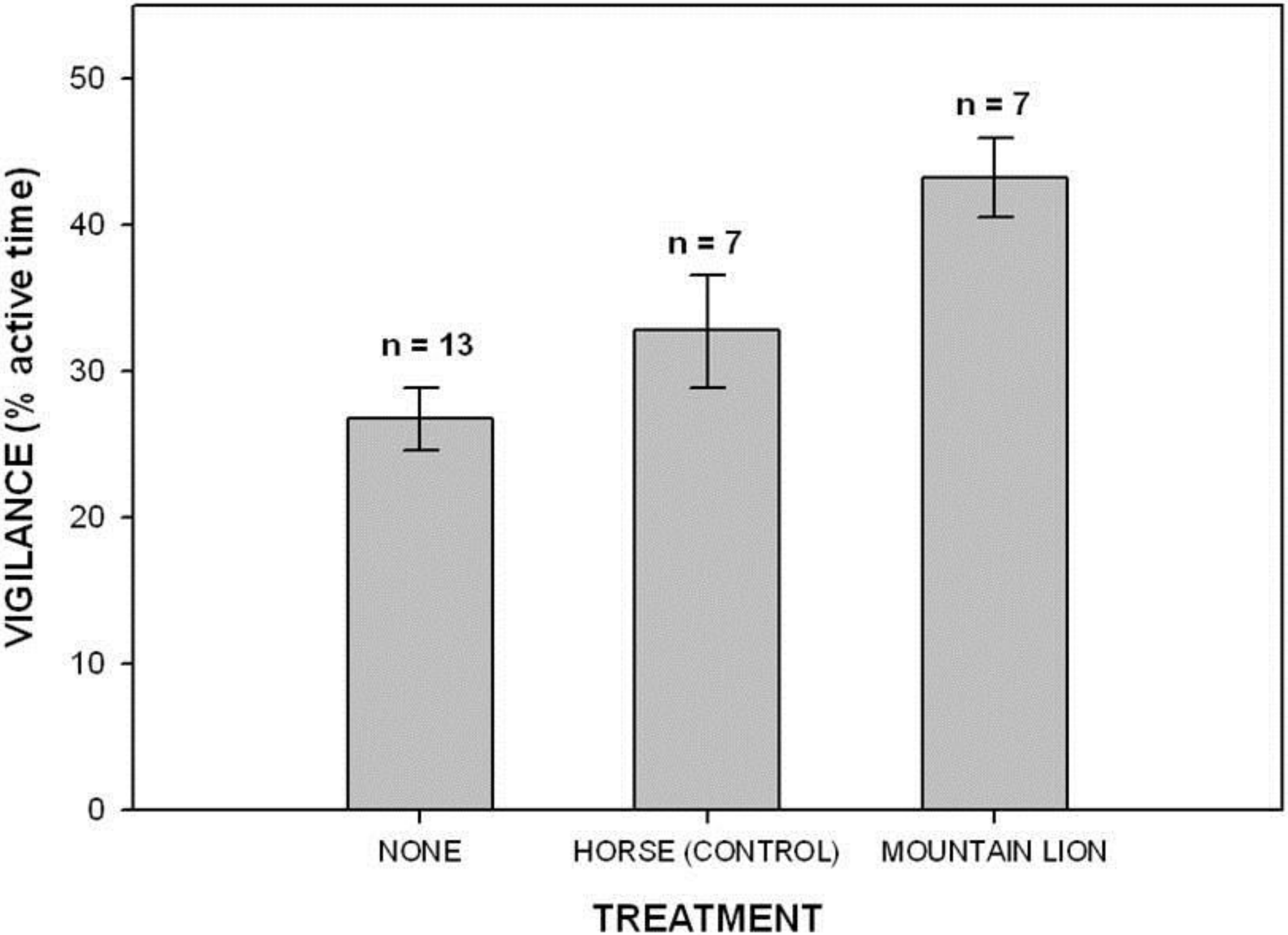
- “Giving-up density”



Behavior categories

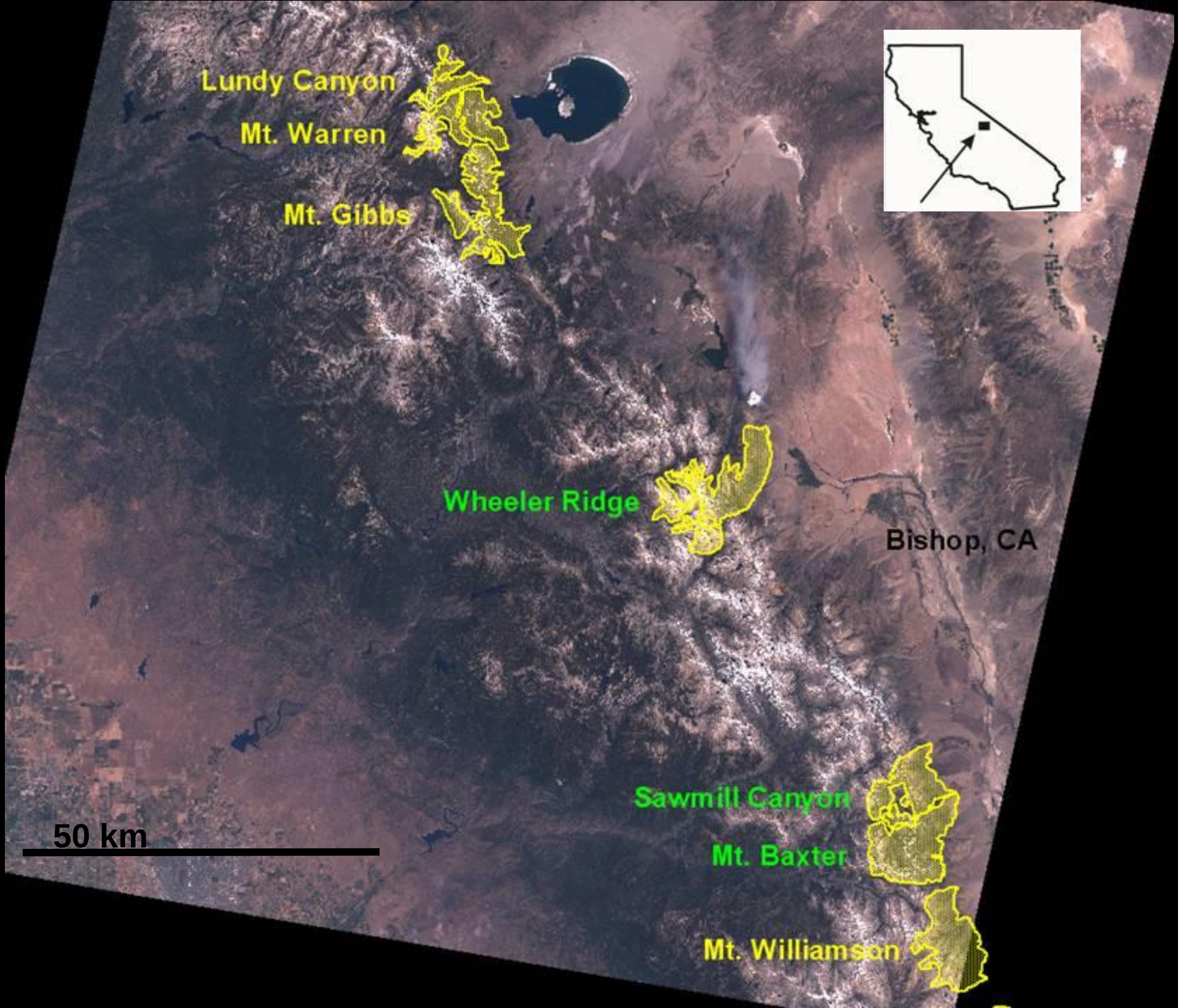
Table 2. Definitions of behaviors evaluated during focal animal observations.

Behavior Category & Activity	Definition
Foraging	
Standing Feeding	Standing, biting vegetation or masticating with head oriented toward ground or tall vegetation
Walking Feeding	Walking with head oriented toward ground or tall vegetation
Vigilance	
Standing, looking	Standing with head held above plane of back, head oriented away from vegetation, other members of group Ruminating may occur
Walking, looking	Walking with head above plane of back, head oriented away from direction of travel or pausing to look back followed by continued walking
Movement	
Running	Running, jumping across rocks
Walking	Walking (including jumping across rocks) with head oriented in the direction of travel
Social	
Looking at conspecifics	Head oriented towards other group members (typical of lambs)
Play	Jumping, sprinting, butting conspecifics
Nursing	Lamb in contact with underside of ewe
Bedding	
Lying ruminating	Lying down masticating head up
Lying resting	Lying down, head up or down, not masticating
Other	Behavior not specified above



VIGILANCE (% active time)
0
10
20
30
40
50
n = 13
n = 7
n = 7
NONE
HORSE (CONTROL)
MOUNTAIN LION
TREATMENT

Original distribution of Sierra Nevada bighorn sheep


Lundy Canyon
Mt. Warren
Mt. Gibbs
Wheeler Ridge
Bishop, CA
Sawmill Canyon
Mt. Baxter
Mt. Williamson
50 km

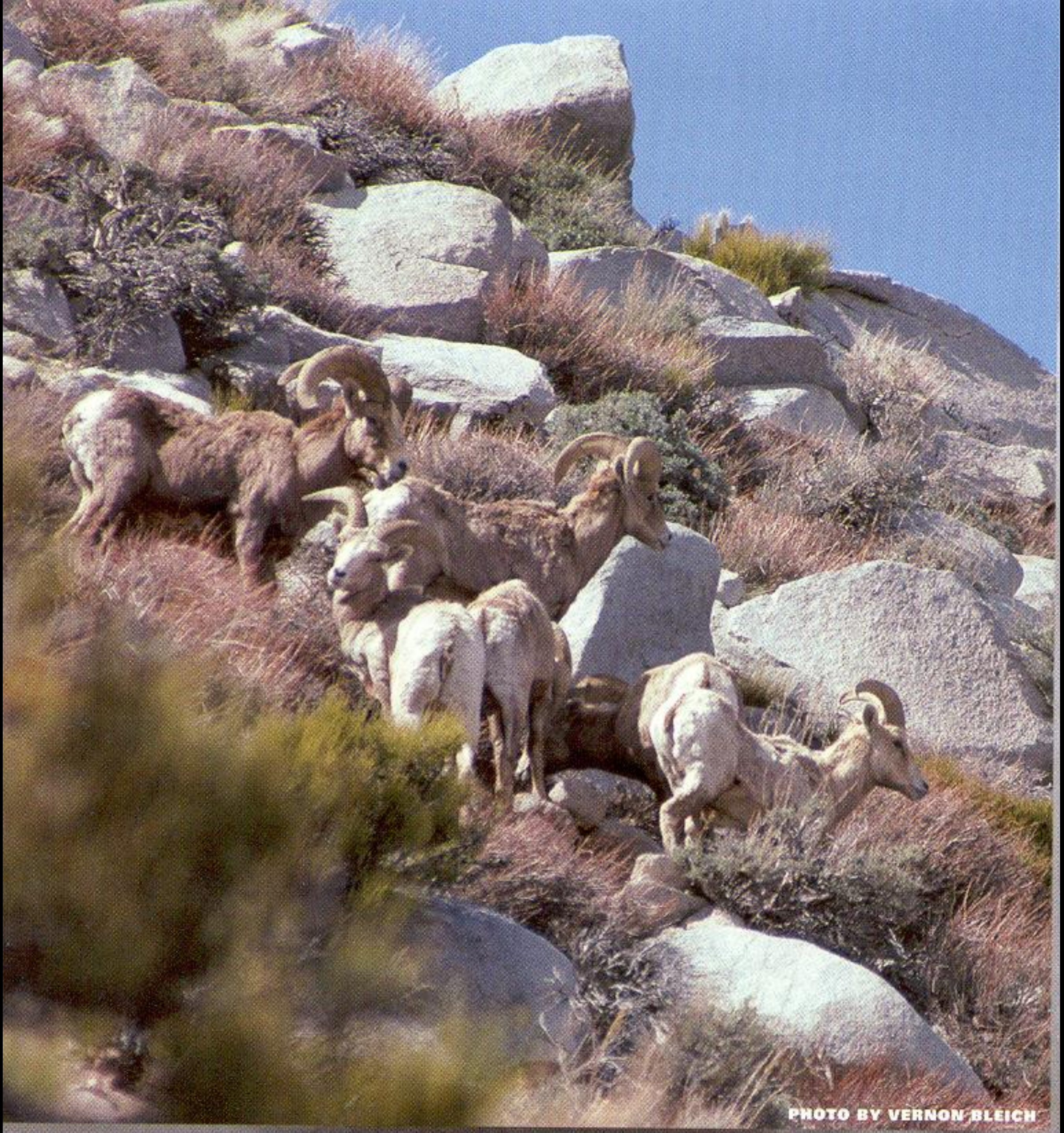


PHOTO BY VERNON BLEICH


16 19:18
CDFG photo

Study Approach

1) Contemporary data: RSF

What influence does risk of predation by mountain lions have on resource selection by Sierra Nevada bighorn sheep?

2) Historical review: Remotely sensed data

Do data from the period of decline in Sierra Nevada bighorn sheep support the “range abandonment” hypothesis (Wehausen 1996), or is there greater support for alternatives?

RSF - Predictions

Resource selection by Sierra Nevada bighorn sheep is strongly influenced by
***direct* risk of predation**

AVOID

-Areas where mountain lions are active

-Areas where mountain lions kill bighorn sheep

RSF - Predictions

Resource selection by bighorn is strongly influenced by ***indirect*** **risk of predation**

SELECT FOR:

- **-Higher elevations**
- **-Steeper slopes**
- **-Rugged terrain (all radii)**
- **-Convexity at animal location (15-30 m radius)**
- **-Rock cover type**

and **AVOID**

- **-Convexity within flight distance (100-150 m radius)**
- **-Tree and shrub cover**

RSF - Predictions

Resource selection by bigh

forage availability

SELECT FOR:

-Higher NDVI values

-Greater solar radiation

and **AVOID**

-Snow cover

Forage tradeoff hypothesis

Benefit of migration to low elevation
in drought years is less than in normal years

NDVI Tradeoff in wet years > NDVI Tradeoff in dry years

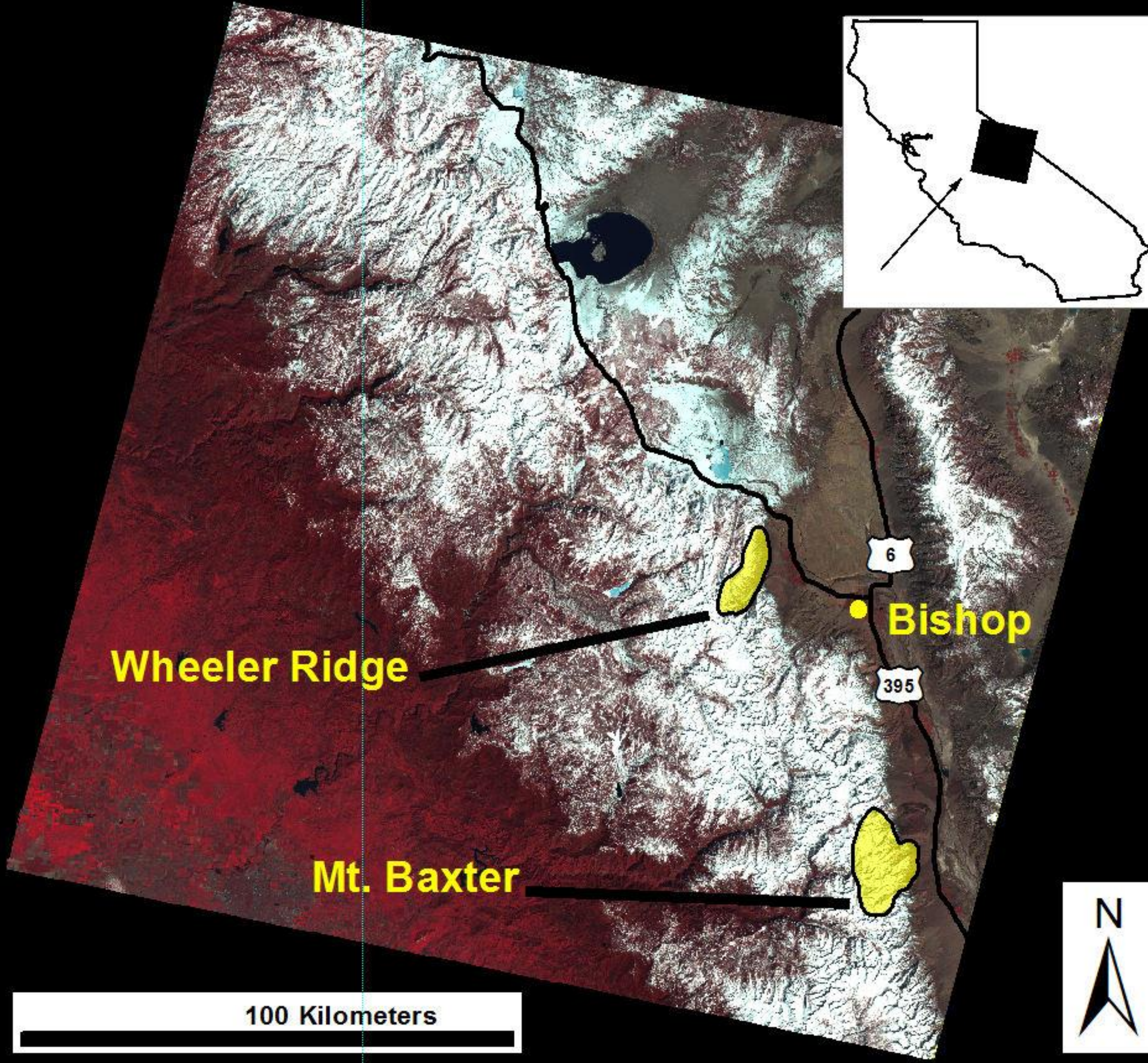
Animal Capture

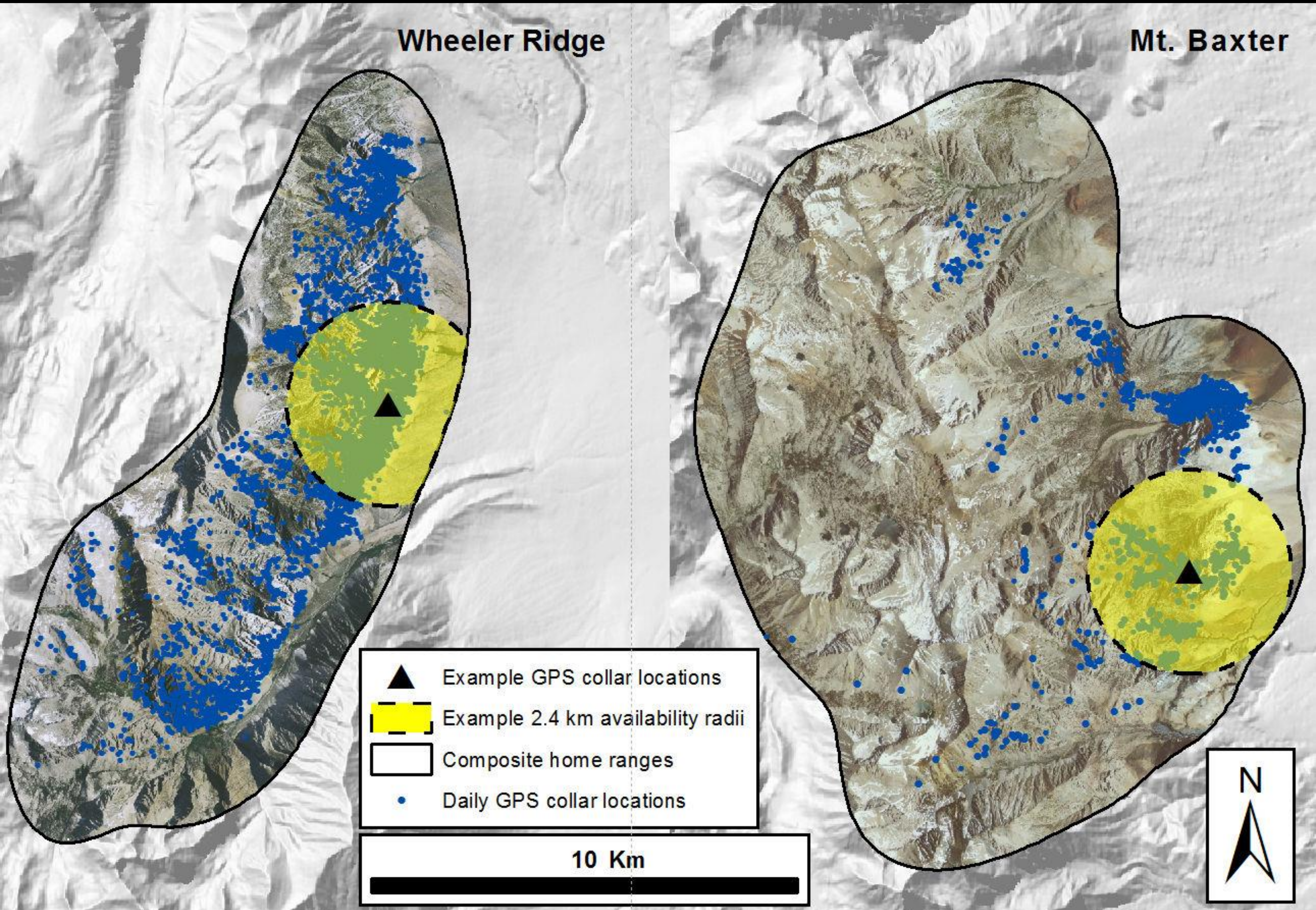

N185BC



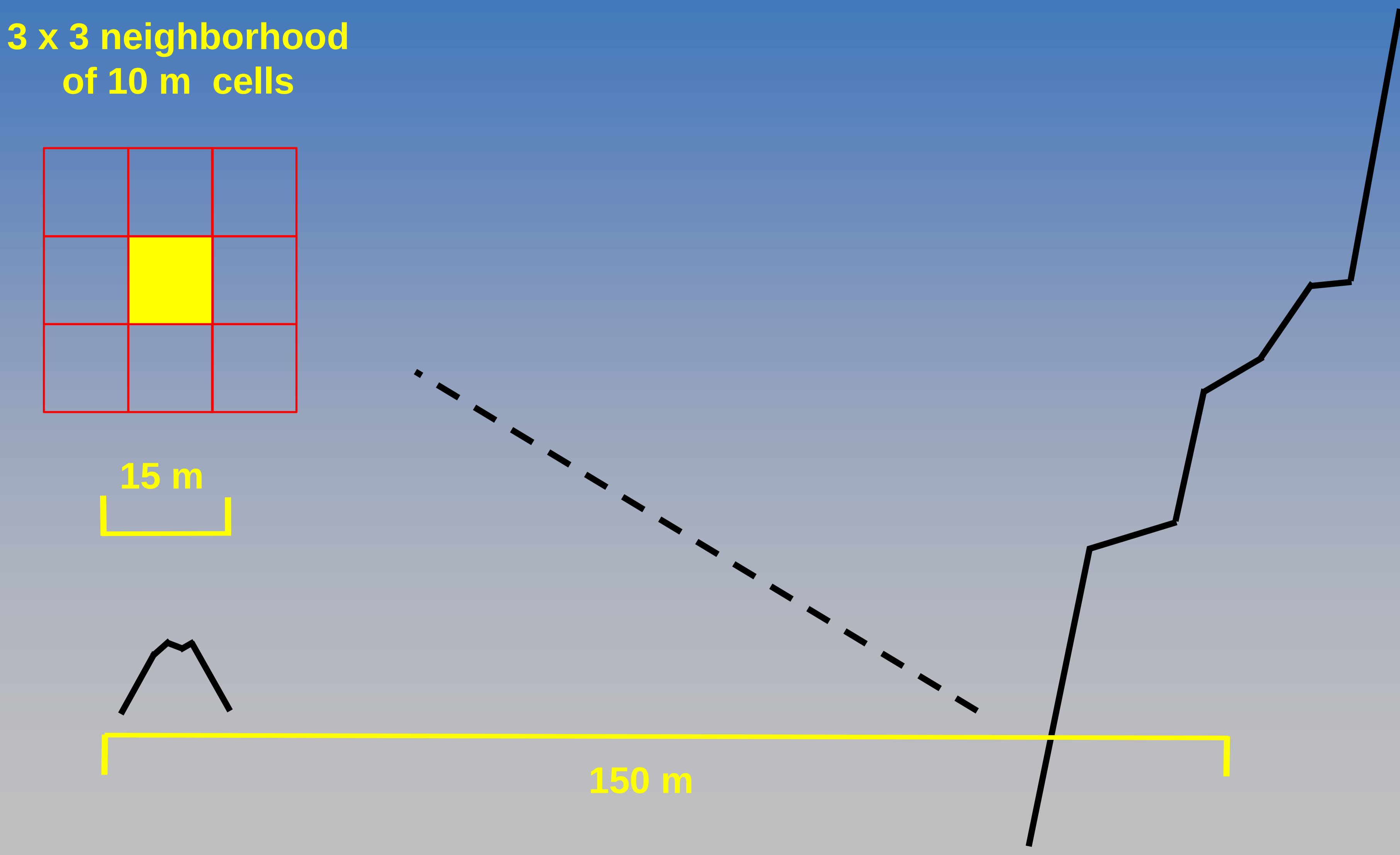
FISH & GAME

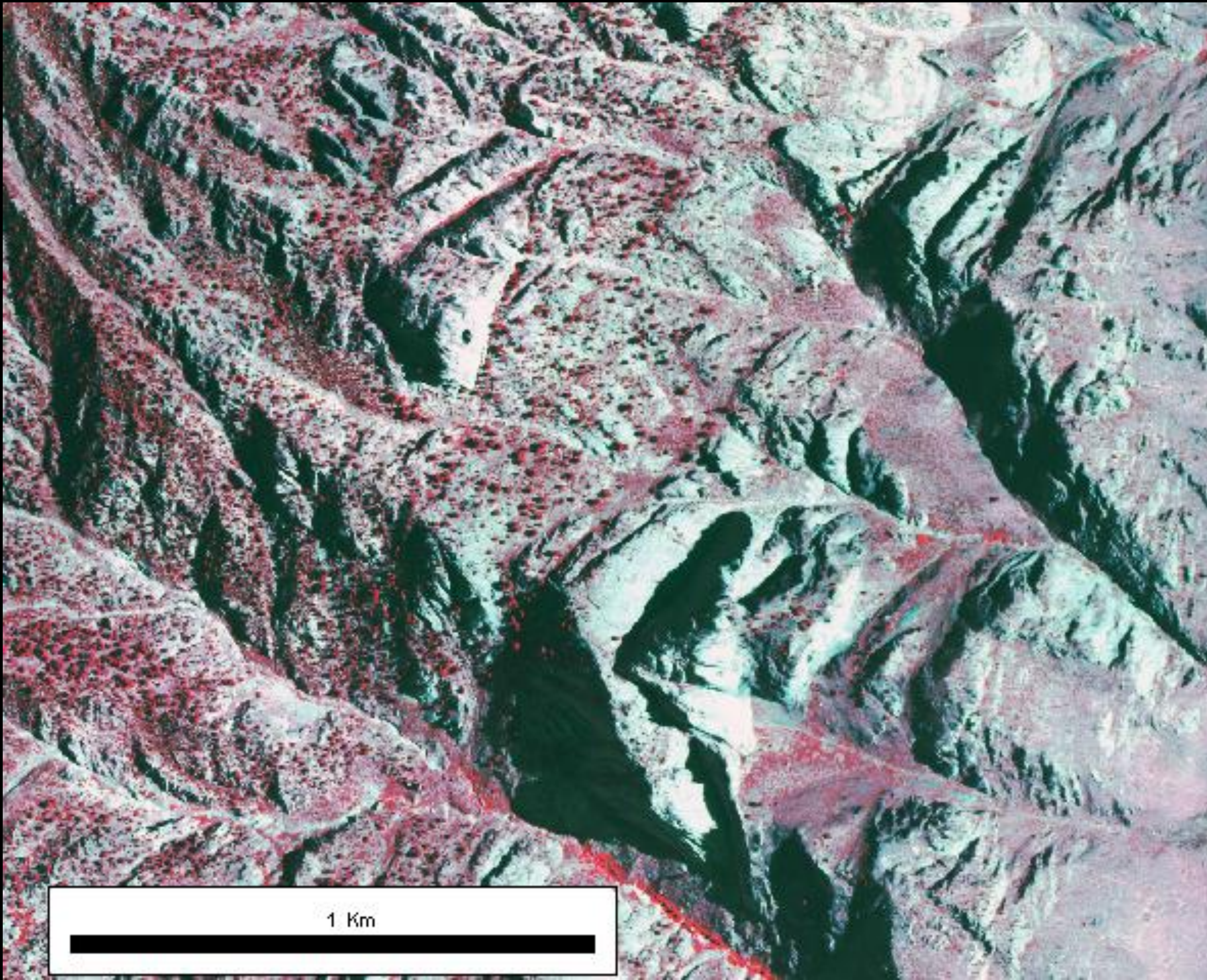

photo by Mark Kiner


Wheeler Ridge
Bishop
6
395
Mt. Baxter
N
100 Kilometers


Wheeler Ridge
Mt. Baxter
Example GPS collar locations
Example 2.4 km availability radii
Composite home ranges
Daily GPS collar locations
10 Km
N

Scale for topographic analysis




1 Km

Spatial analysis

- **Animal home range and movement data**
- **Topographic measures**
- **Remote sensing of land cover**
- **Remote sensing of temporally varying factors: snow and vegetation condition**

Temporally varying Indices

- 57 Cloud-free TM images 1989–1994 and 2002–2009
- Normalized difference snow index
  - NDSI = (Green – SWIR)/(Green + SWIR)
    or (TM2 – TM5)/(TM2 + TM5)
- Normalized difference vegetation index
  - NDVI = (NIR – R)/(NIR + R)
    or (TM4 – TM3)/(TM4 + TM3)

Statistical analysis: RSF

- Candidate variables Pearson correlation <|0.60|
- All possible combinations where univariate $P < 0.25$
- Logistic models for population, conditioned upon the temporal window of each TM image
- Separate models for males and females

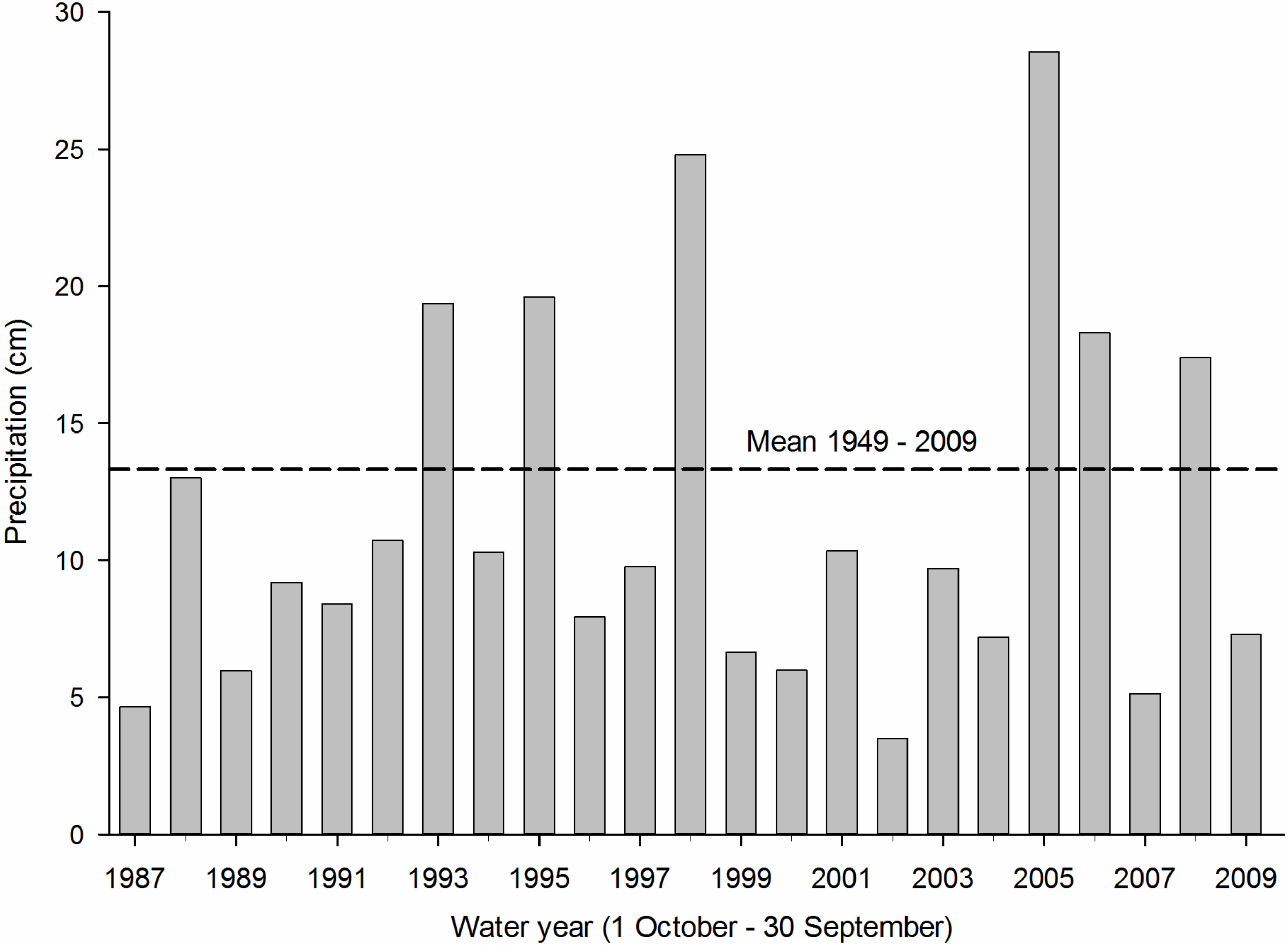
Statistical analyses: Model Selection

- Candidate models ΔAIC_c <4,
- AIC_c used to choose better fit between models differing only in correlated predictors
- Calculated Akaike weights w_i for models
- Importance weight parameter $\Sigma\ w_i$
- Model-averaged βs and SEs

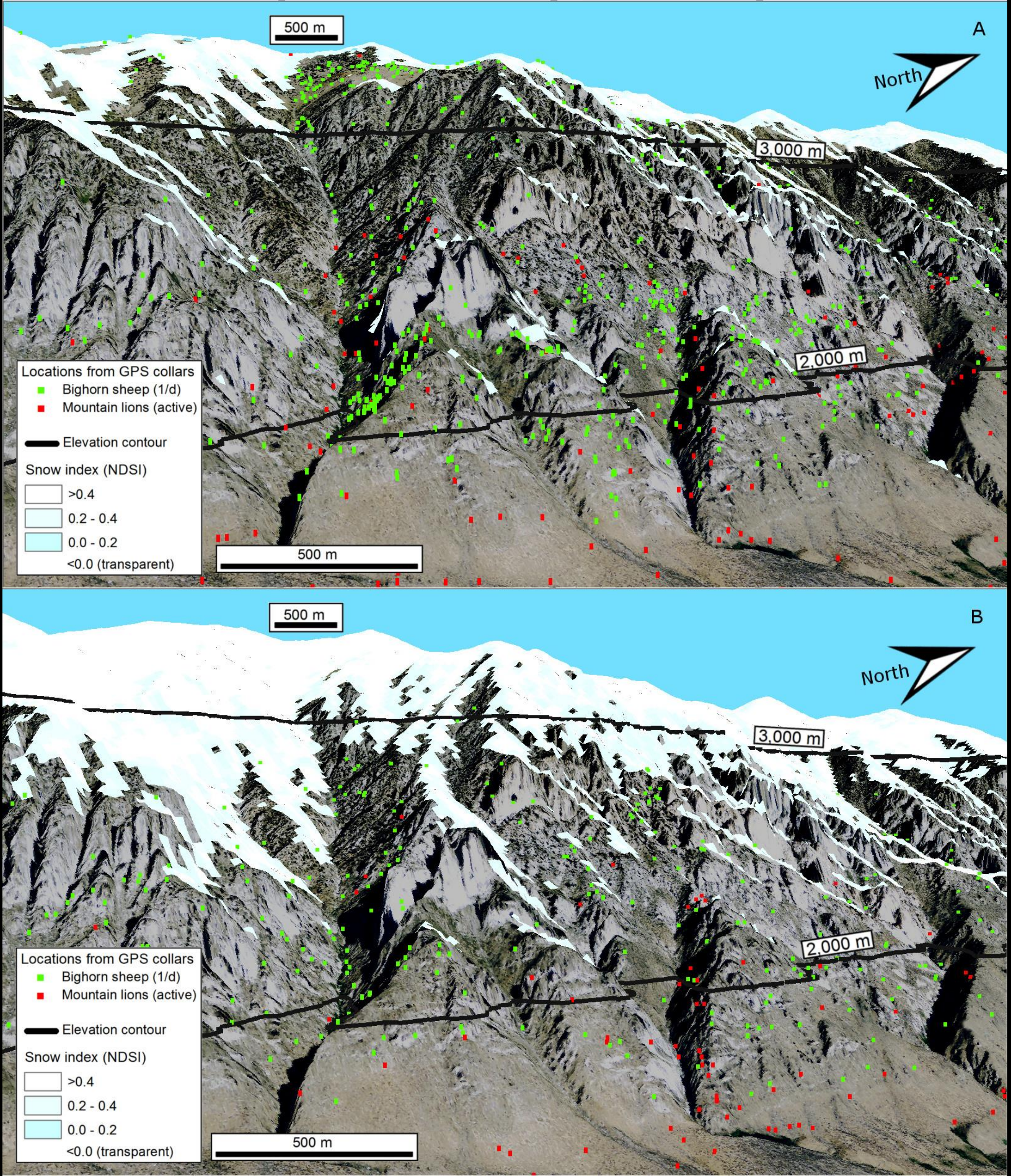
Forage (NDVI) tradeoff

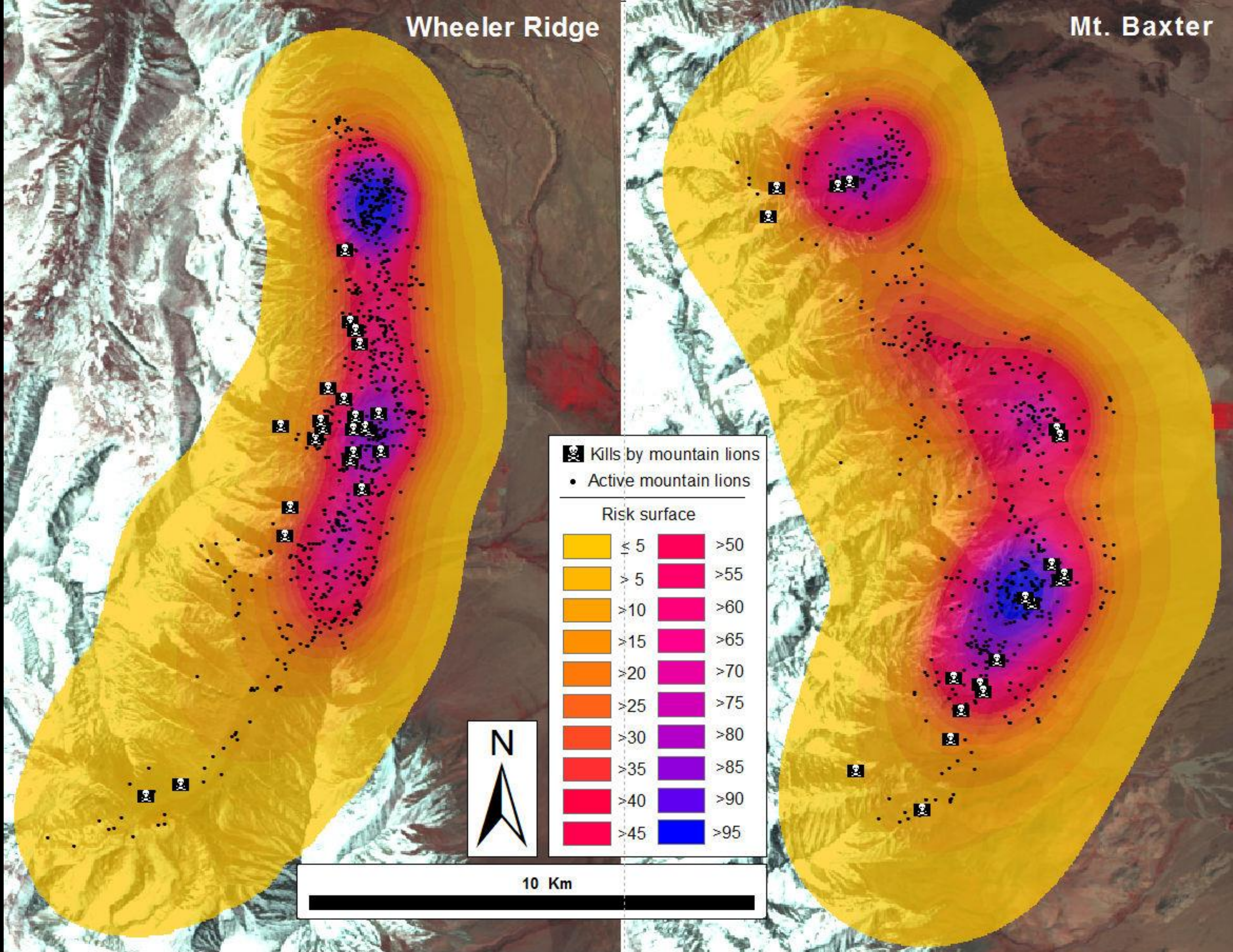
- GPS locations (3-D, DOP < 10) used by bighorn sheep in winters 2002–2007 at >3,000 m and <2,000 m
- No Tree-shrub or Rock cover
- ≥10 snow-free pixels (NDSI > 0.2)
- Calculate Mean NDVI <2,000 m and >3,000 m
- NDVI Tradeoff = NDVI @ <2,000 m – NDVI @ >3,000 m

Results…

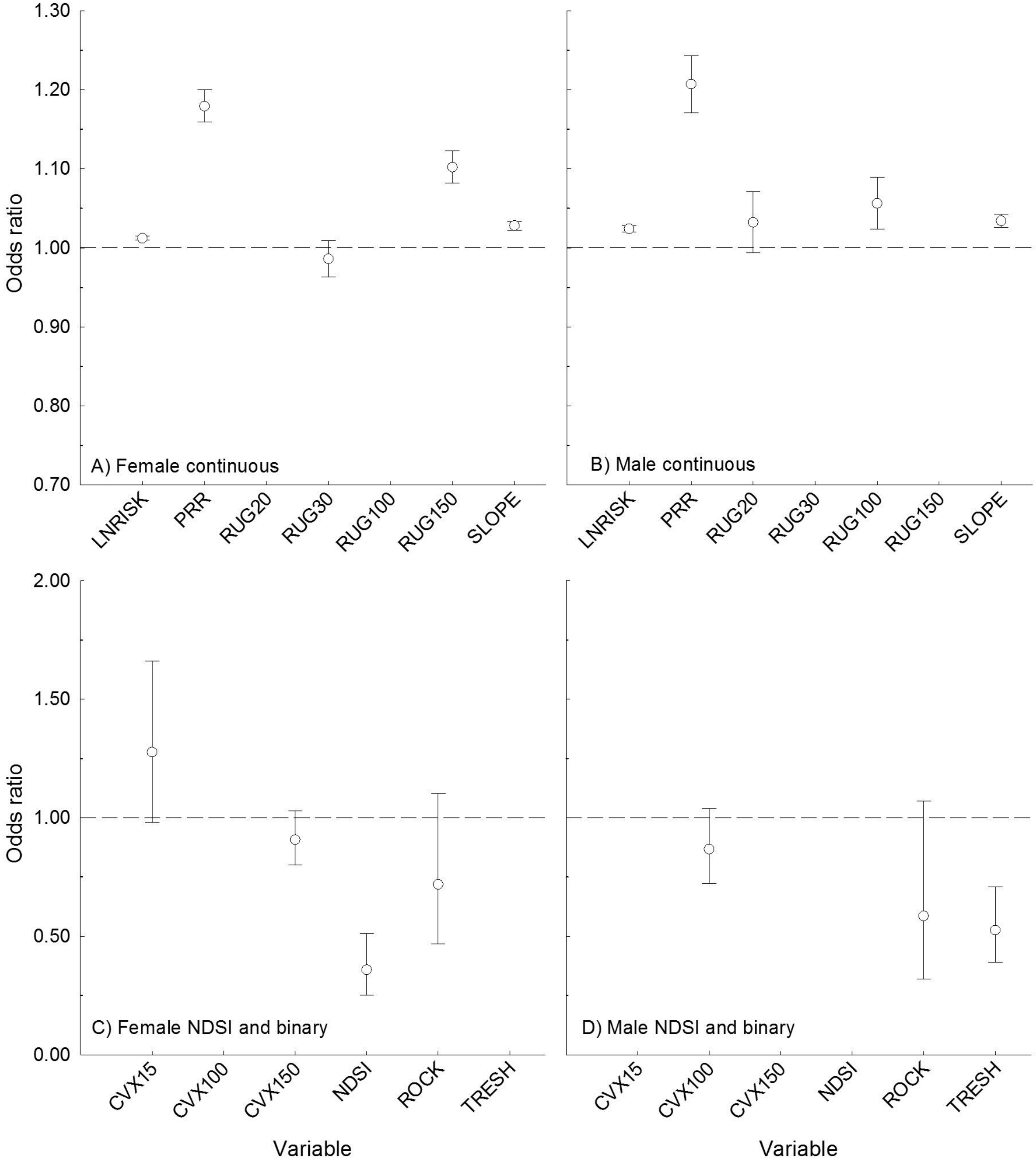


Precipitation (cm)
30
25
20
15
10
5
0
Mean 1949 - 2009
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
Water year (1 October - 30 September)


500 m
A
North
3,000 m
2,000 m
Locations from GPS collars
Bighorn sheep (1/d)
Mountain lions (active)
Elevation contour
Snow index (NDSI)
>0.4
0.2 - 0.4
0.0 - 0.2
<0.0 (transparent)
500 m
500 m
B
North
3,000 m
2,000 m
Locations from GPS collars
Bighorn sheep (1/d)
Mountain lions (active)
Elevation contour
Snow index (NDSI)
>0.4
0.2 - 0.4
0.0 - 0.2
<0.0 (transparent)
500 m



Wheeler Ridge
Mt. Baxter
Kills by mountain lions
Active mountain lions
Risk surface
≤ 5
> 5
>10
>15
>20
>25
>30
>35
>40
>45
>50
>55
>60
>65
>70
>75
>80
>85
>90
>95
N
10 Km



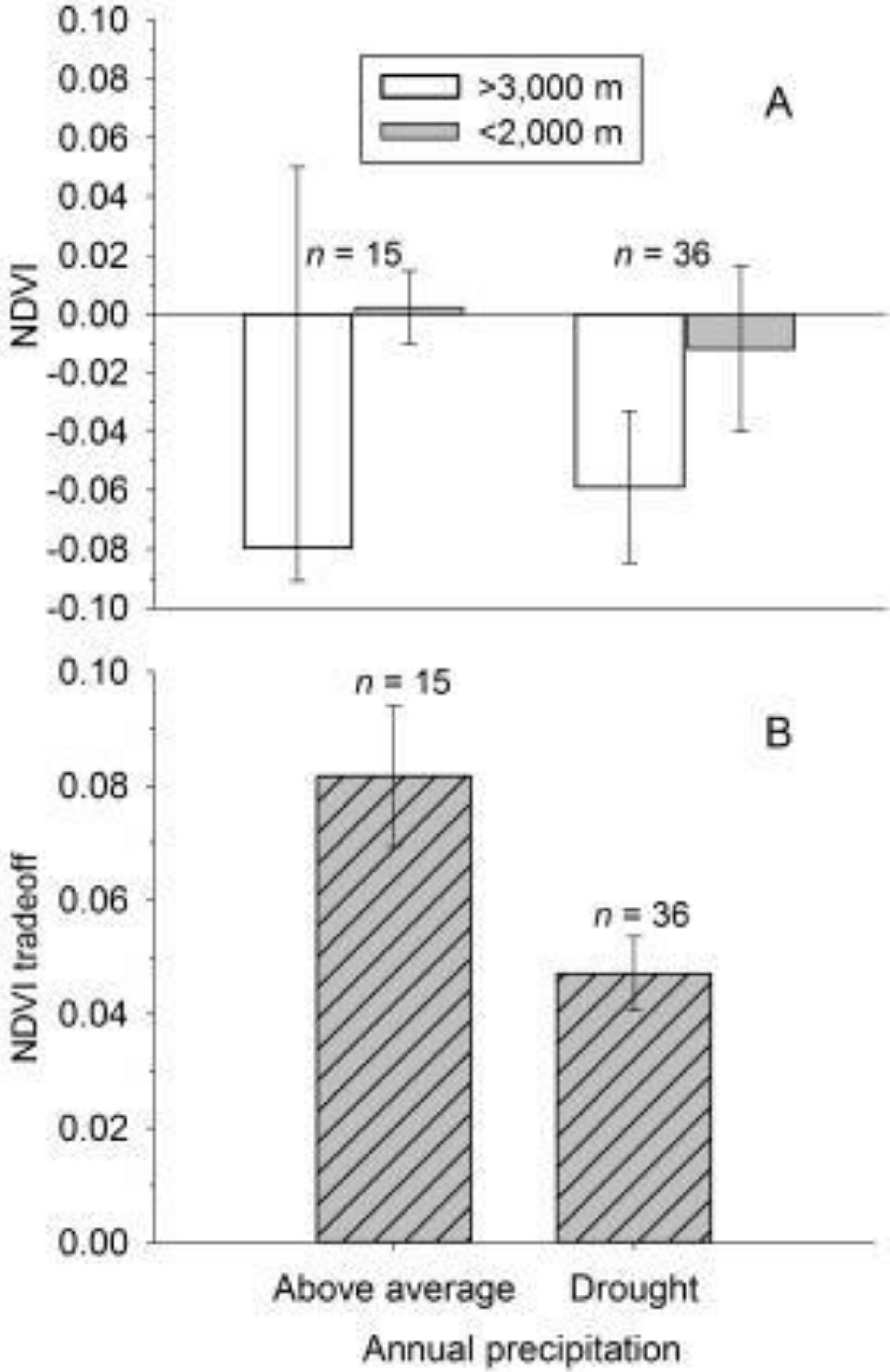
Odds ratio
1.30
1.20
1.10
1.00
0.90
0.80
0.70
A) Female continuous
B) Male continuous
LNRISK
PRR
RUG20
RUG30
RUG100
RUG150
SLOPE
2.00
1.50
1.00
0.50
0.00
C) Female NDSI and binary
D) Male NDSI and binary
CVX15
CVX100
CVX150
NDSI
ROCK
TRESH
Variable

Lion risk vs. Elevation

Model	AICc	ΔAICc
Female		
CVX15 CVX150 **LNRISK** NDSI PRR ROCK RUG30 RUG150 SLOPE	7147.0	0
CVX15 CVX150 **ELEV** NDSI PRR ROCK RUG30 RUG150 SLOPE	7220.7	**73.7**
Male		
CVX100 **LNRISK** PRR ROCK RUG20 RUG100 SLOPE TRESH	3296.9	0
CVX100 **ELEV** PRR ROCK RUG20 RUG100 SLOPE TRESH	3421.0	**124.1**

k-fold cross-validation

Model	Slope	r^2	r_s
Female	0.19	0.95	0.96
Male	0.05	0.81	0.92



0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
NDVI
>3,000 m
<2,000 m
A
n = 15
n = 36
0.10
0.08
0.06
0.04
0.02
0.00
NDVI tradeoff
B
n = 15
n = 36
Above average
Drought
Annual precipitation

Summary

H$_o$ **Resource selection by Sierra Nevada bighorn sheep is strongly influenced by**

Direct risk of predation **REJECT**
Indirect risk of predation **SUPPORT**

H$_o$ Resource selection by Sierra Nevada bighorn sheep is strongly influenced by forage availability

INCONCLUSIVE

H$_o$ Benefit of migration to low elevations in drought years is lower than in normal years

SUPPORT

Hindawi Publishing Corporation
Advances in Ecology
Article ID 357080

Research Article

Resource Selection by an Endangered Ungulate: A Test of Predator-Induced Range Abandonment

Jeffrey T. Villepique,[1,2,3] Becky M. Pierce,[1,2] Vernon C. Bleich,[1,2] Aleksandra Andic,[4] and R. Terry Bowyer[1]

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We investigated influences of risk of predation by mountain lions (*Puma concolor*), topographic metrics at multiple scales, and vegetation, land, and snow cover on resource selection by Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), an endangered taxon, during winters 2002–2007, in the Sierra Nevada, California, USA. We hypothesized that those mountain ungulates would trade off rewards accrued from using critical low-elevation habitat in winter for the safety of areas with reduced risk of predation. We also compared the tradeoff between forage and risk of predation in years of drought versus wet years. We tested the prediction that differences in quality of forage at low elevations versus high elevations were less in years of below-average precipitation than in wet years, yielding a reduced benefit of migration to low elevations during drought, compared with years of above-average precipitation. Sierra Nevada bighorn sheep did not trade off benefits of forage for reduced risk of predation but selected areas of high solar radiation, where risk of predation by mountain lions was greatest, while mitigating indirect risk of predation by selecting for steep, rugged terrain. Bighorn sheep selected more strongly for areas where mountain lions were active, than for low-elevation habitat in winter, likely because mountain lions were most active in those areas of bighorn sheep winter ranges overlapping ranges of mule deer (*Odocoileus hemionus*), where both ungulates accrued forage benefits. We demonstrated reduced benefit of migration to low elevation during drought years, when the difference in quality of forage was significantly less than in years of above-average precipitation, providing an alternative explanation to the predator-induced abandonment hypothesis for the disuse of low-elevation winter range observed during drought years.

1. Introduction

Animals living in temperate or arctic environments, where a seasonal abundance of forage coincides with increased nutrient demands of late gestation and lactation [1–3], must balance the need to acquire nutrients against constraints from risk of predation [4–6]. Many populations of ungulates migrate between discrete seasonal ranges [7–13], with those occupying montane environments obtaining high-quality resources by selecting among elevations that enable exploitation of new growth in forage [11, 14]. Benefits of migration to areas of high-quality forage must outweigh increased risk of predation to comprise an evolutionarily stable strategy [15]. Populations of mountain sheep occupying montane environments may migrate between high-elevation summer ranges and lower-elevation winter ranges, corresponding to the progression of new growth in grasses, forbs, and shrubs [16–18]. Variation in temperature, precipitation, and vegetation phenology, however, may alter behavior and habitat selection by mountain sheep [13, 19, 20].

Predator avoidance operates through both indirect mechanisms that affect the likelihood of encountering, detecting, or eluding a predator, as well as through direct means by

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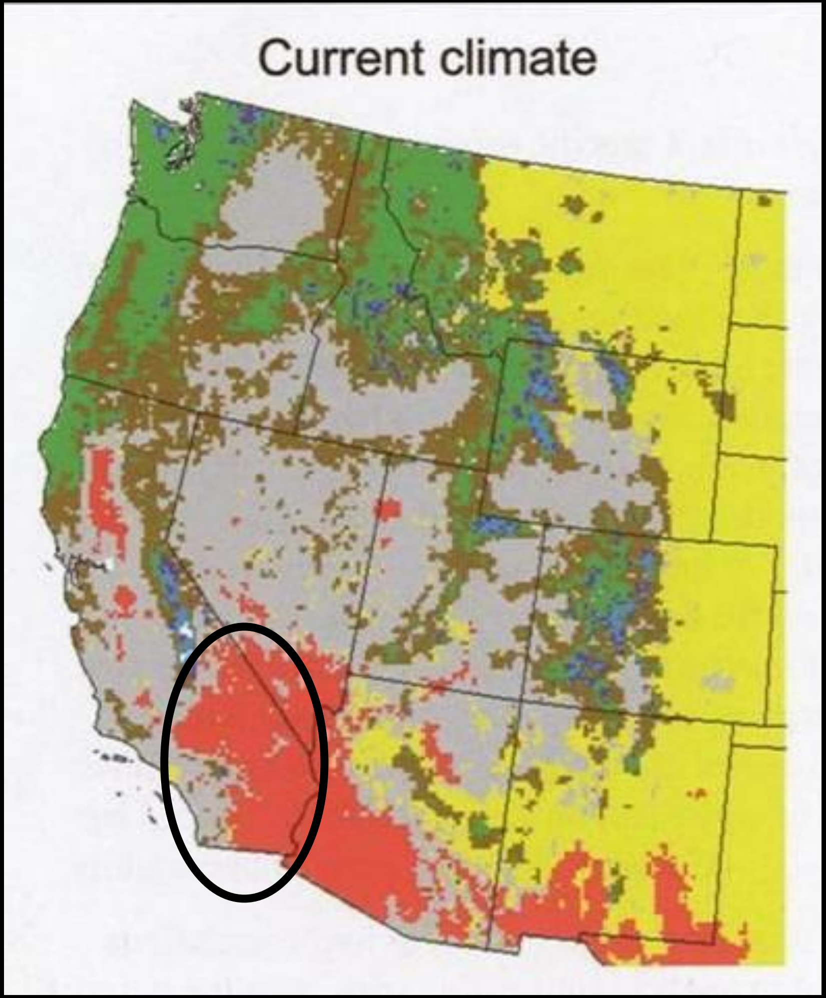
Thank you!
photo © Tim Glenner


24.53 inHg
4°C
10/12/09 02:53 PM
CALDOT3209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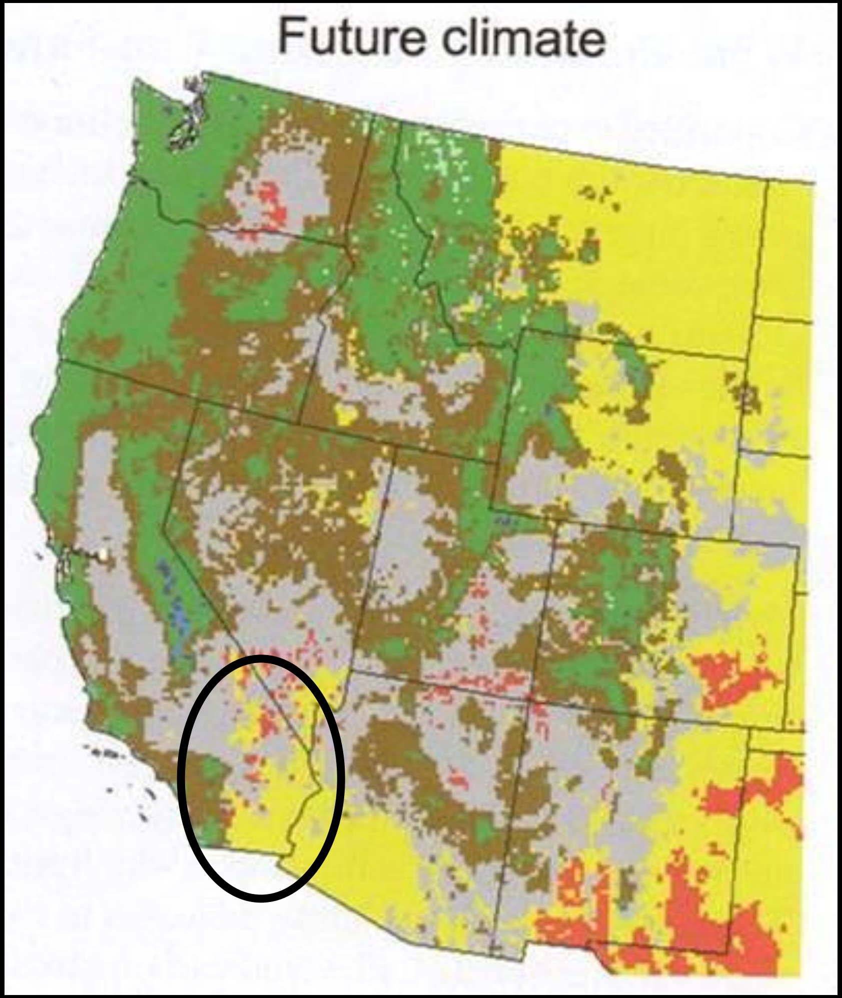
Future climate