Modeling population fragmentation impacts of solar energy development (UC 614)

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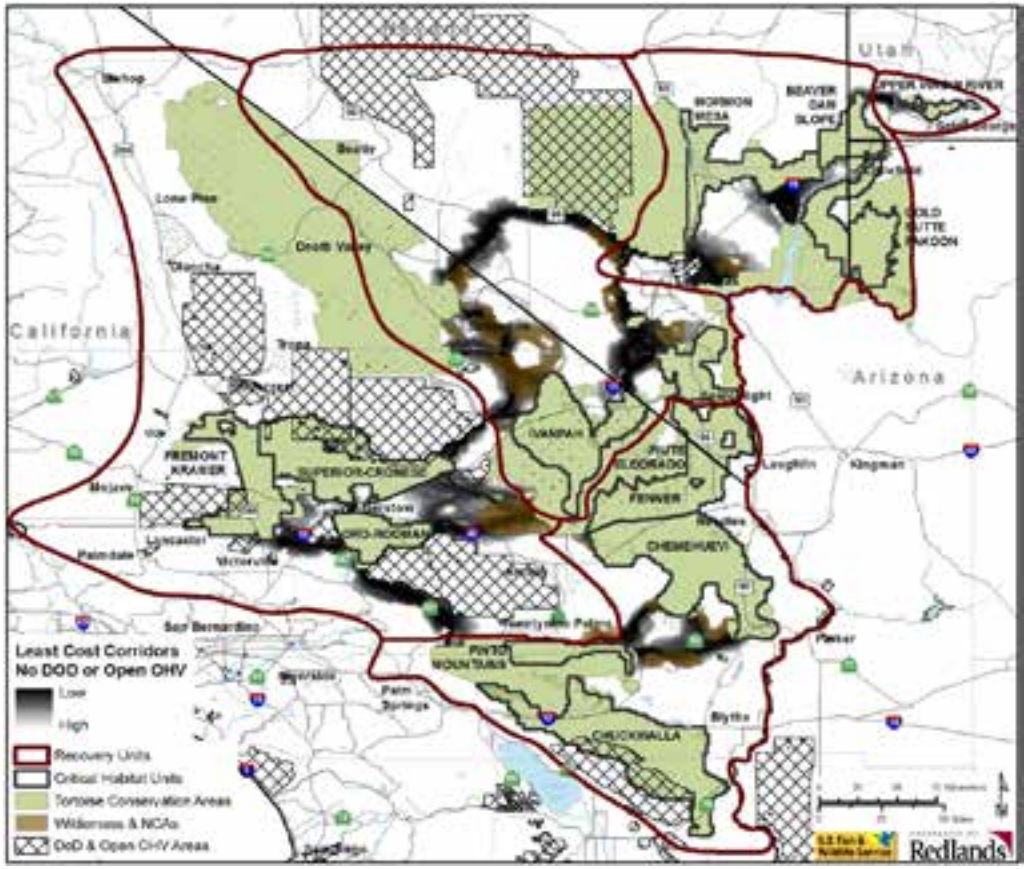
Mojave Desert Tortoise

- Listed as Threatened in 1990
- Observed population declines result from numerous, diverse threats that vary spatially and temporally
- Not all individuals, or even all populations, are affected by every threat
- Most populations likely are affected by several of these threats simultaneously

Desert Tortoise and Population Fragmentation



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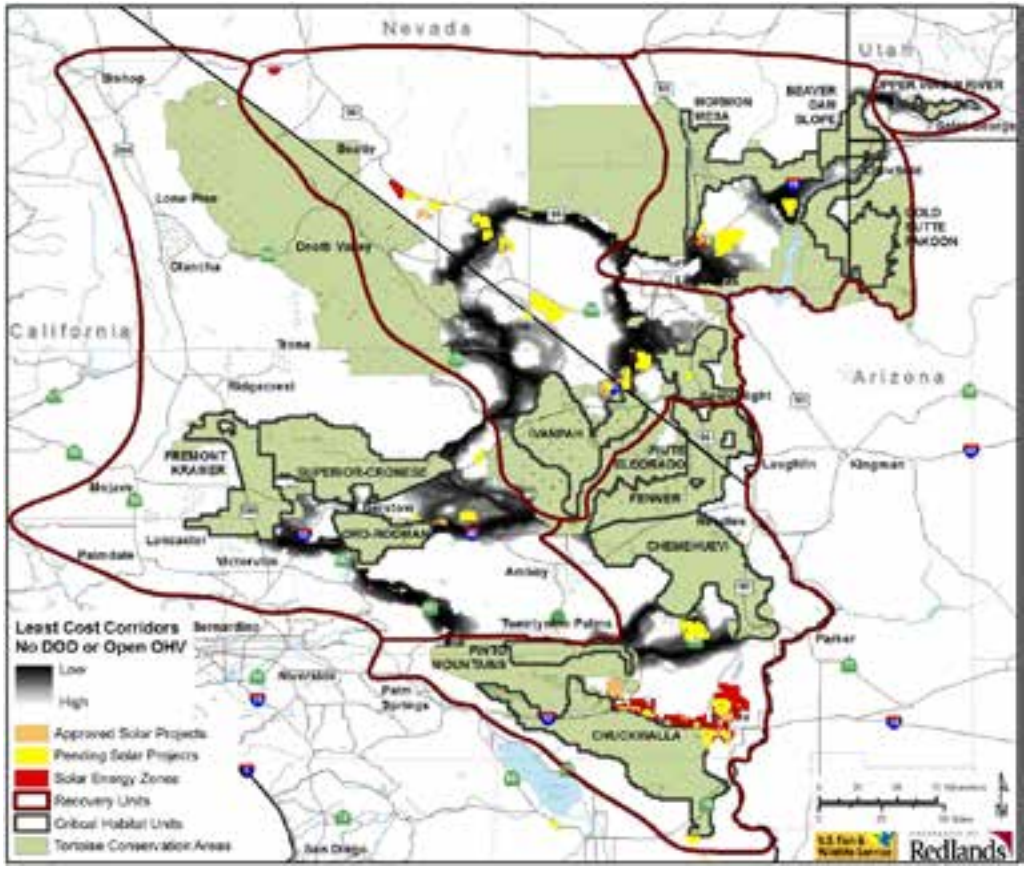

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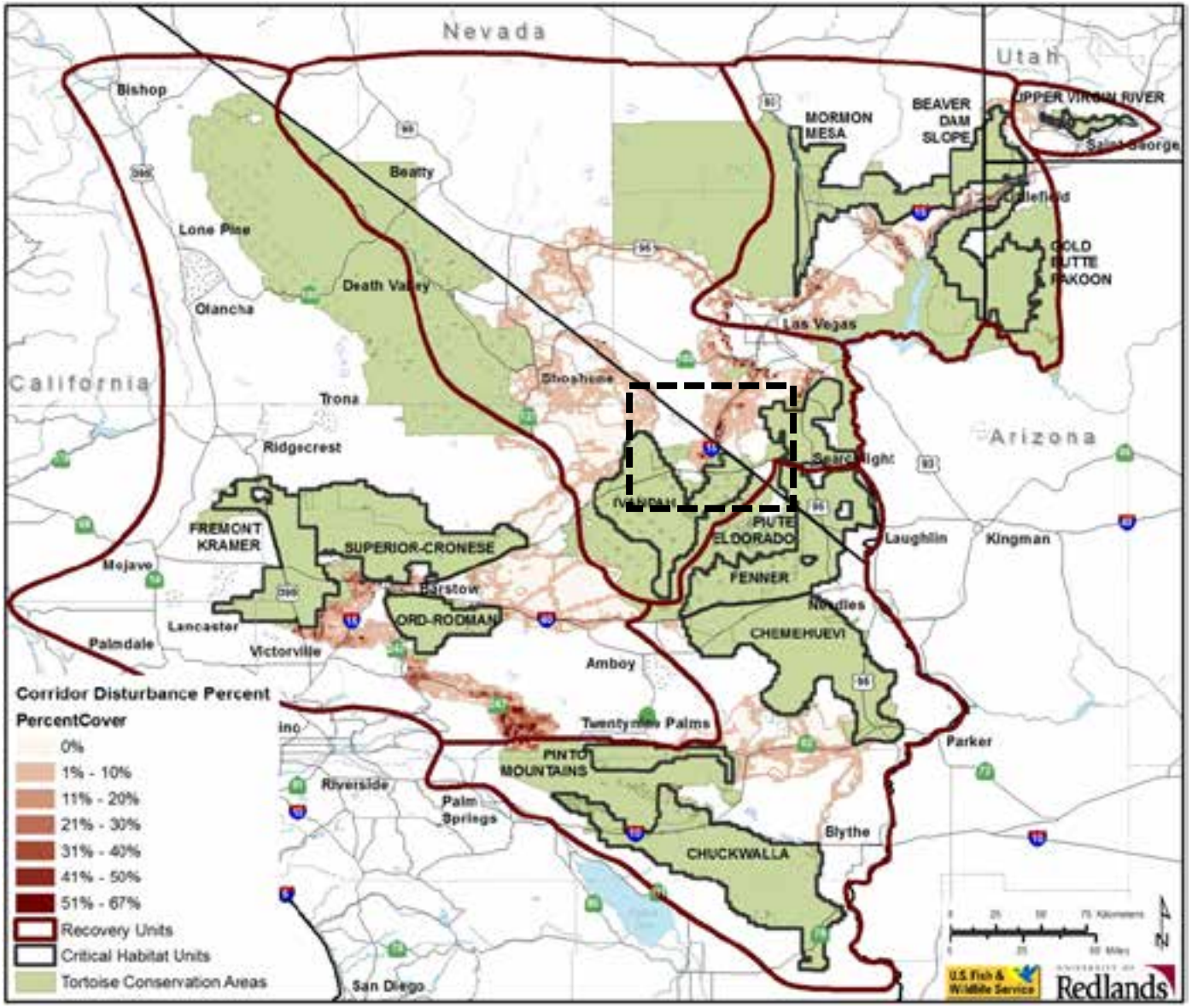
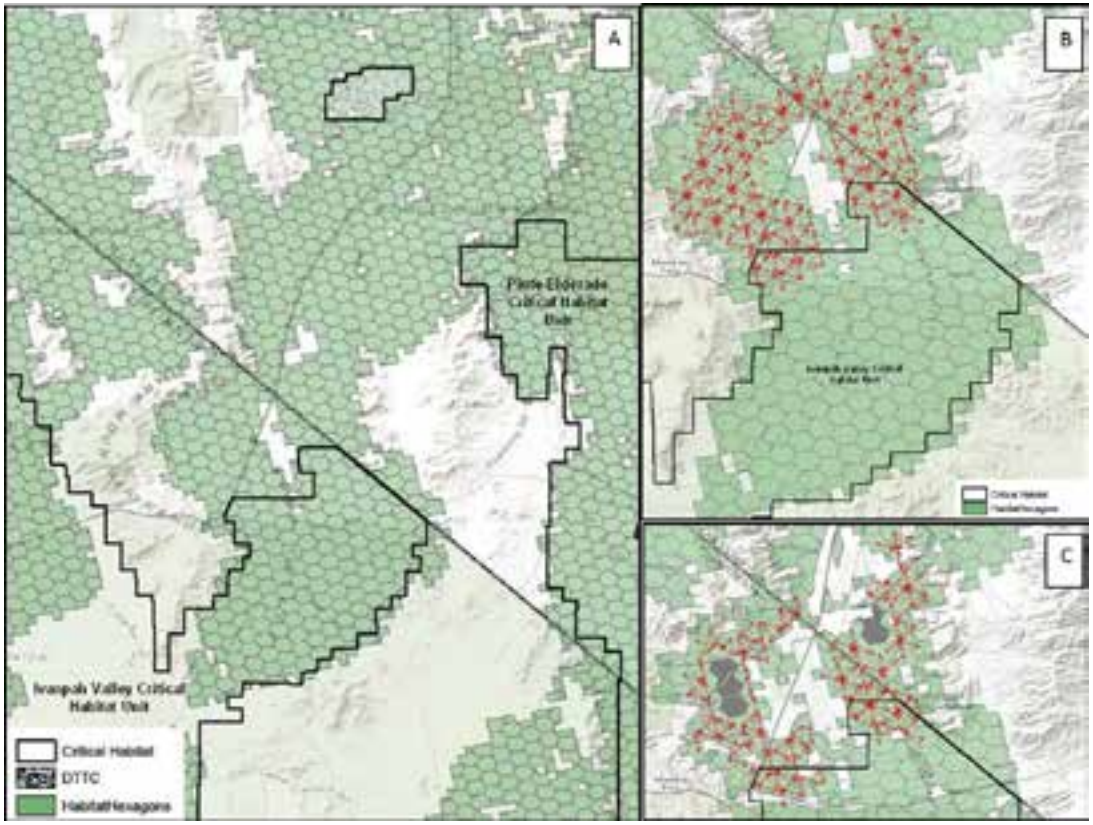


Demographic connectivity



General Metric: Probability of Connection

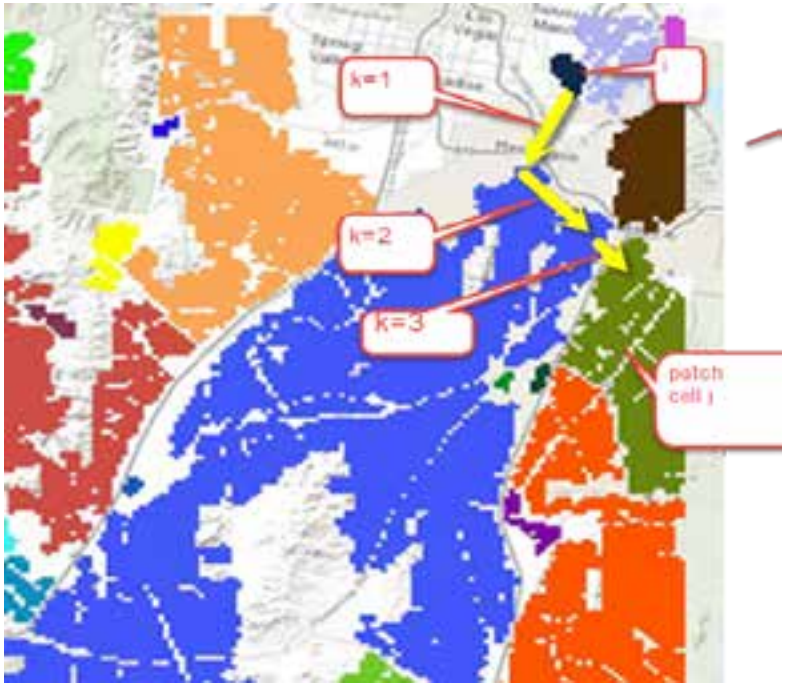
$$PCIndex = \sum_i \sum_j \left(A_i * A_j * pp^*_{ij} \right) / A_L^2$$

Where A_i is a measure of the value of the patch i, is the probability of the most likely path between *i* and *j*, and A_L is the area of the range.

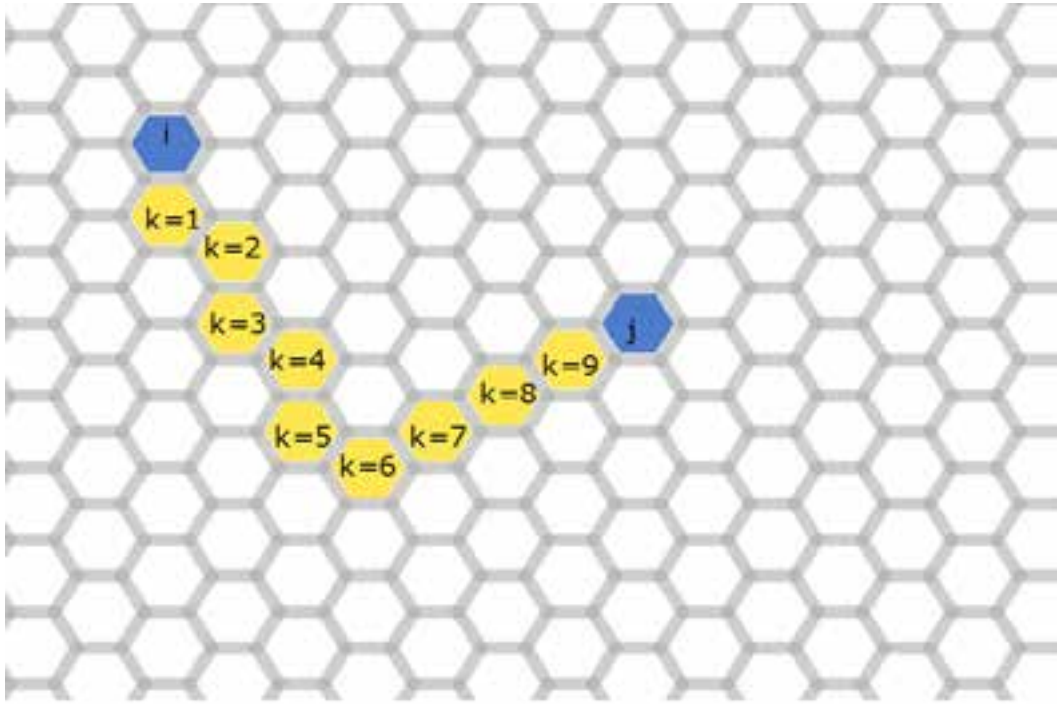
$$\boldsymbol{P_{ij;path}} = \boldsymbol{e}^{-((\sum_{k=0}^{n} \boldsymbol{R_k})/\boldsymbol{L})}$$

and

$$pp^*_{ij} = \max(\boldsymbol{P_{ij;path}})$$



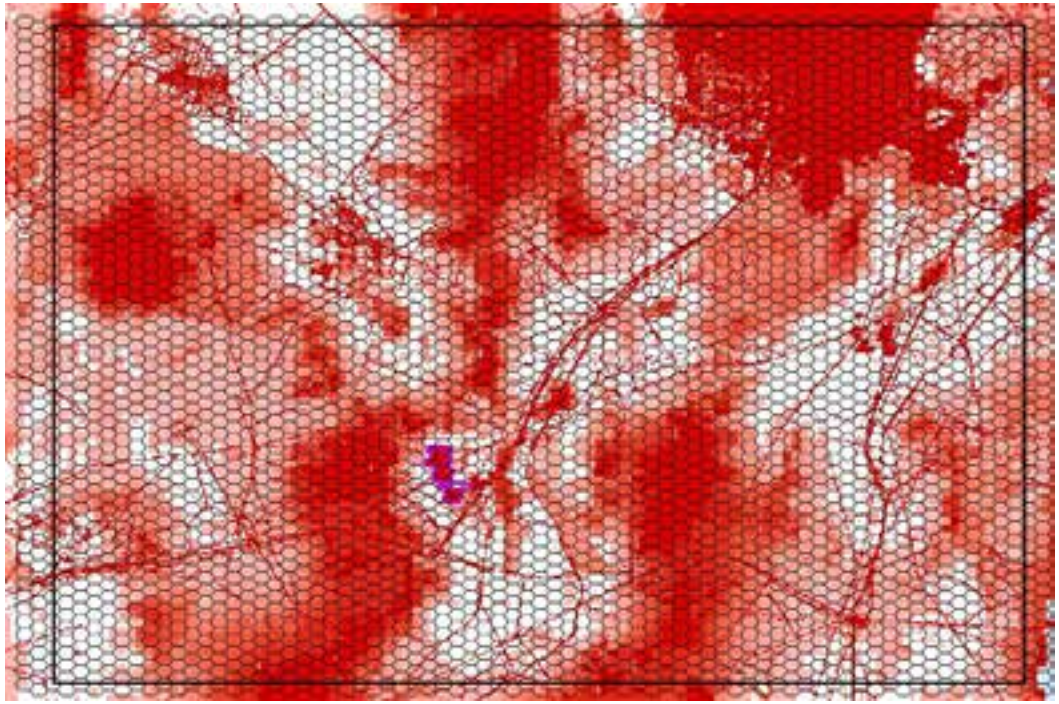
A tiled implementation for the desert tortoise



Habitat Potential and Altered Habitat Potential

Fragmentation = decrease in degree to which landscape facilitates individual movement among resource or habitat patches

1. "Habitat potential" captures natural topographic and habitat quality resistances
2. *Alter* habitat potential where anthropogenic landscape change has occurred (AHP)
3. Tiling based on DT home range (1 hexagon = 30 Ha = 1 home range)



Hexagonal tiling of study area (darker red = lower AHP value)

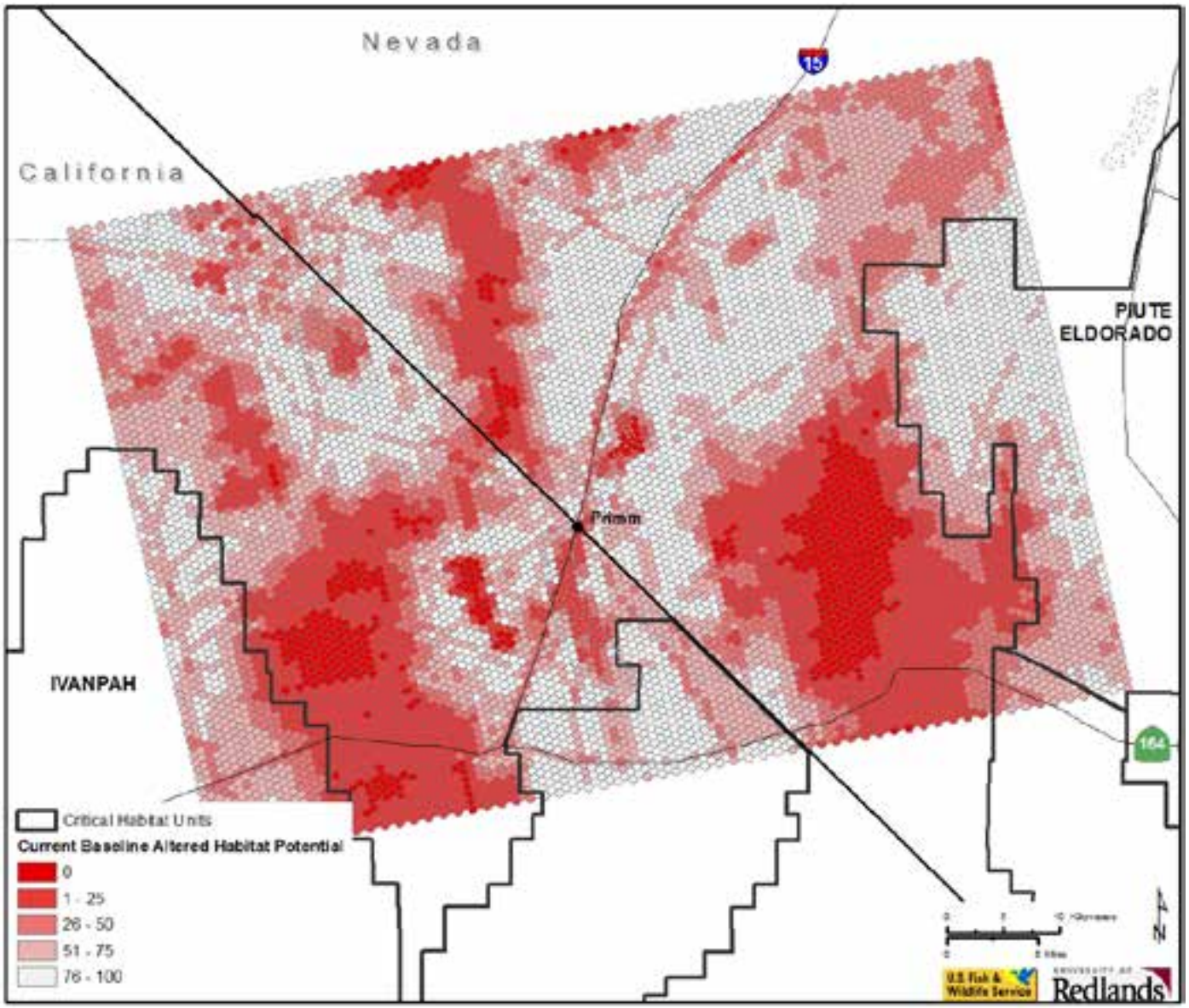
- Area weighted AHP across each hexagon with threshold
- Clip hexagons where AHP = 0

2nd Metric: Population Capacity

Spatial Individual Territory Model

$\frac{dp_i(t)}{dt} = I_i[1 - p_i(t)] - (D_i)p_i(t)$	**Change in probability that a tile (= home range) is occupied. Immigration into empty tiles vs mortality in occupied tiles**
$D_i = (1 - S)\ / A_j \gg (1 - s)\ /\ a_j$	Mortality in an area is 1 – S, survival. S can be identified as s if tile area is home range.
$I_i = \sum_j exp(-d_{ij}/L)A_j\left(Bp_j(t)\right) \gg b\sum_j exp(-d_{ij}/L)a_j p_j(t)$	Immigration depends on births in adjacent, occupied tiles. B can be identified as b if tile area is home range.
$m_{ij} = \exp\left(-d_{ij}/L\right)a_i a_j \quad if\ i \neq j$, 0 if i=j	Population capacity λ_P is principal eigen-value of the connection Matrix M.
$b * m_{ij}[1 - p_i^*] - (1 - s) * p_i^* = 0$	At equilibrium, $\frac{dp_i(t)}{dt} = 0$ yet p_i^* >= 0 all i
$\lambda_P > \tau = \frac{(1 - s)}{b}$	A condition for viability that relates habitat fragmentation to individual rates.

Implementation: rescue, habitat quality and resistance



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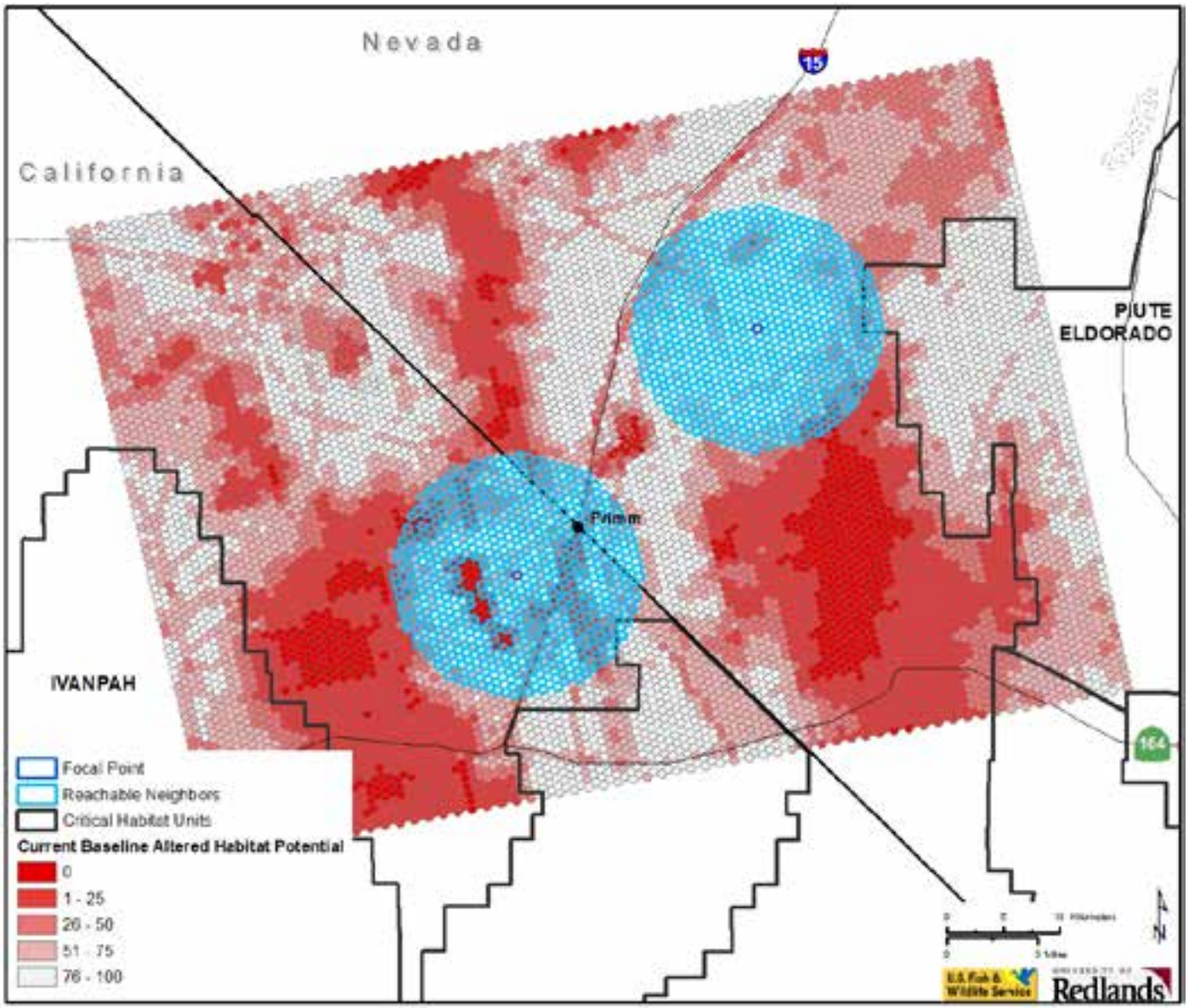
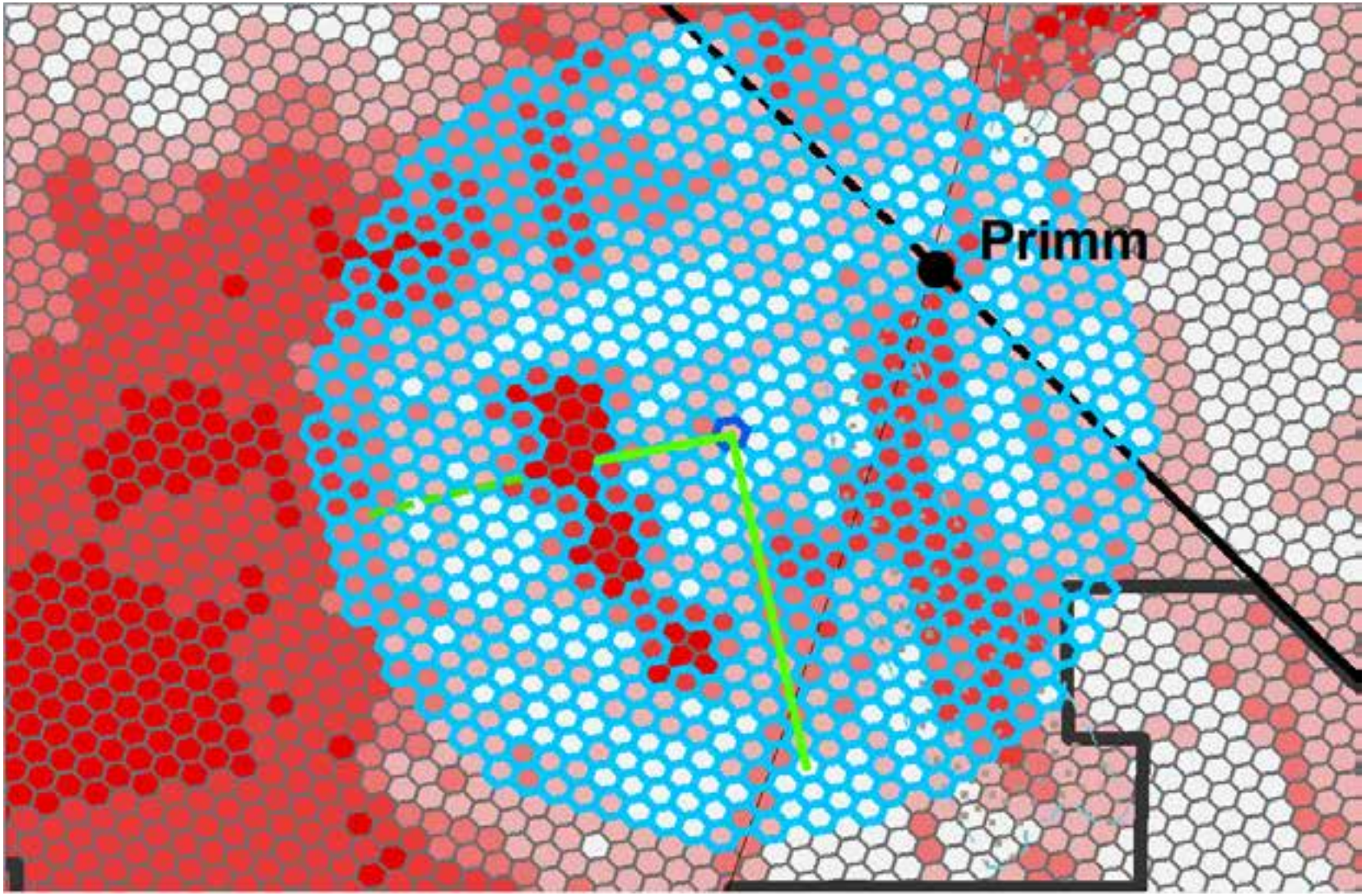


Implementation: rescue, habitat quality and resistance



Two Metrics: Two Connection Matrices

Probability of Connection Index:

$$PC = \sum_i \sum_j (\widehat{\boldsymbol{M}}_{\boldsymbol{ij}})/A_L^2$$

where the connection Matrix

$$\widehat{\boldsymbol{M}}_{\boldsymbol{ij}} = A_i * AHP_i * A_j * AHP_j * \boldsymbol{max}(\boldsymbol{e}^{-((\sum_{\boldsymbol{k=0}}^{\boldsymbol{n}} \boldsymbol{D_k/AHP_k})/\boldsymbol{L})}) \textit{ for all i,j}$$

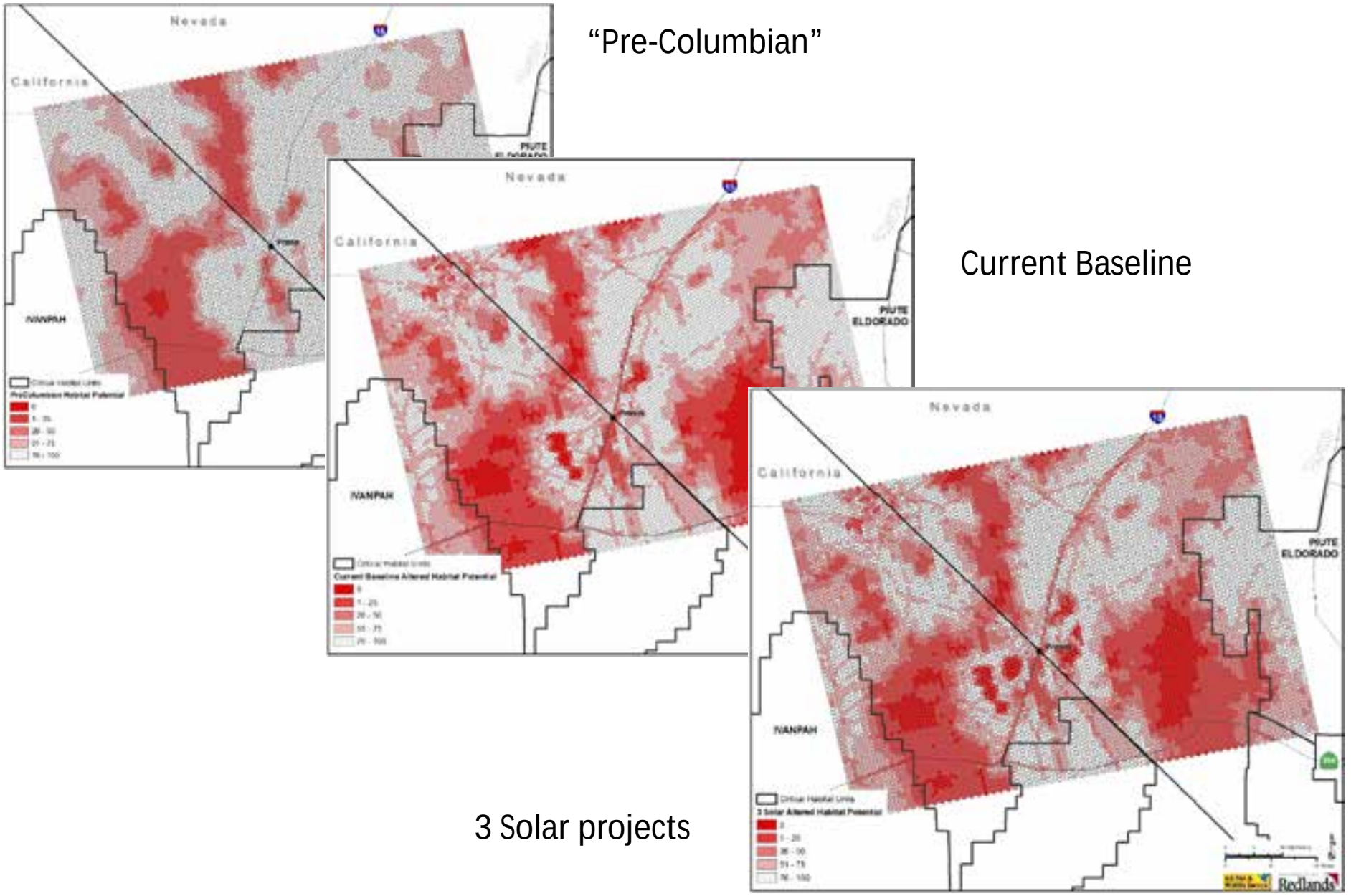
Population Capacity metric:

λ_{PC} = principal (largest positive) eigen-value of connection matrix $\boldsymbol{M}$

$$\boldsymbol{M}_{\boldsymbol{ij}} = A_i * AHP_i * A_j * AHP_j * \boldsymbol{exp}(-((\sum_{\boldsymbol{k=0}}^{\boldsymbol{n}} \boldsymbol{D_k/AHP_k})/\boldsymbol{L})) \quad if \quad i \neq j$$

$$= 0 \; if \quad i = j$$

Sensitivity to habitat loss: AHP for three Scenarios



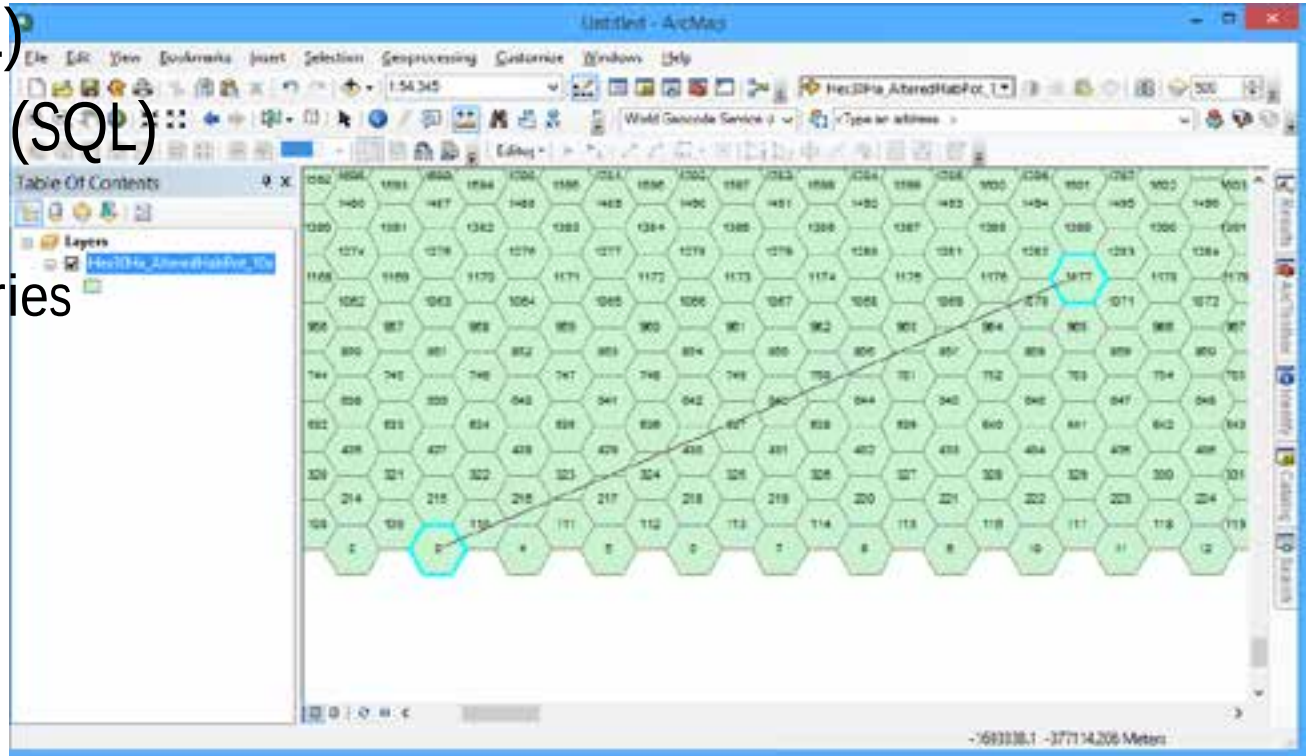
"Pre-Columbian"

Current Baseline

3 Solar projects

Computation Workflow

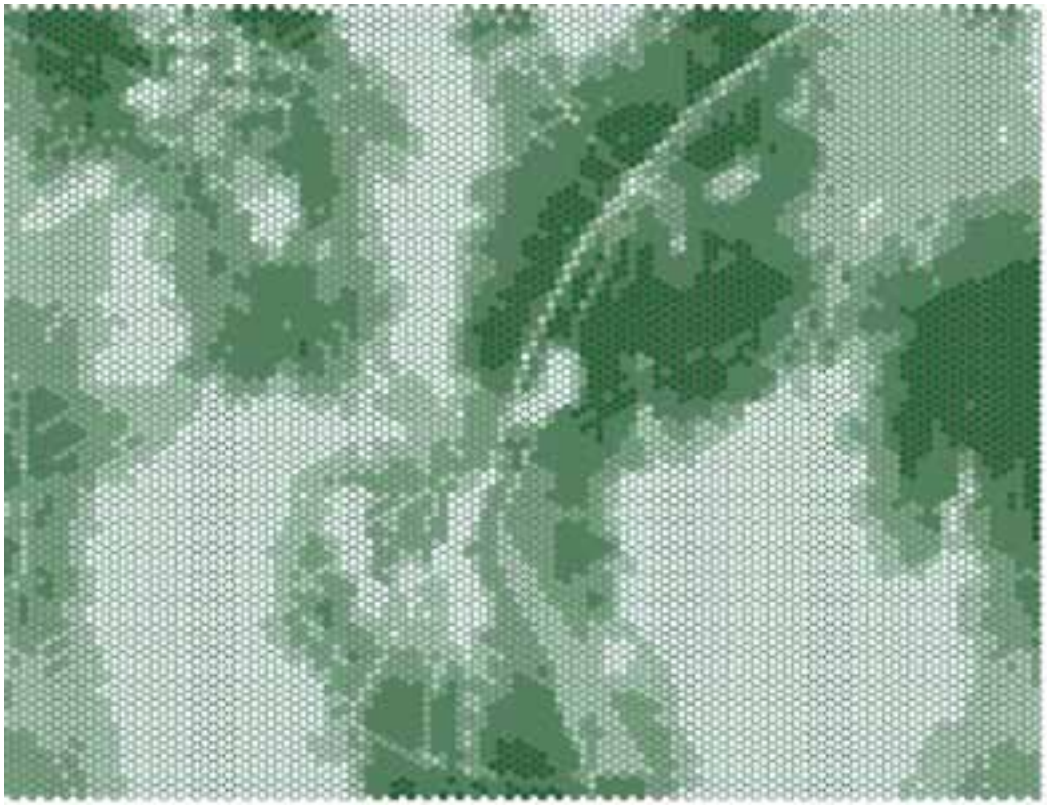
- Create Hexagon tiling for study area (33 thousand hexs)
- Calculate area weighted AHP for each hex for each scenario
- Calculate the Effective Distance between each pair
  - but with distance < 10km, the life time travel distance
  - produces > 30million pairs
- Calculate Mij (SQL)
- Calculate PCIndex (SQL)
- Calculate λ_{PC}
  - M has billion entries
  - Use SciPy



Metric 2.x: Resilience

Resilience of a territory:

$$R_i = \sum_{i \neq j} (\boldsymbol{M_{ij}}) / A_{Hex}^2 (N_R - 1)$$



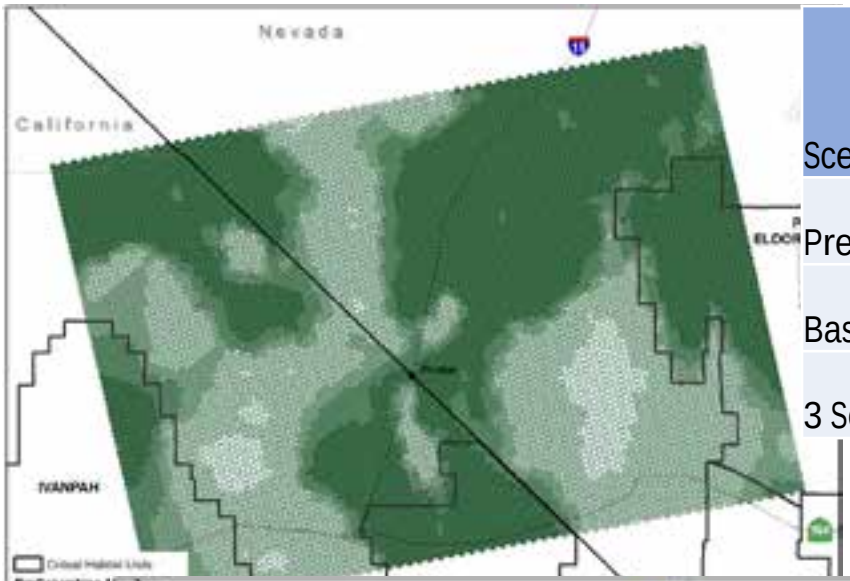
For uniform tiling:

$$PC^* = \sum_i \sum_j (\widehat{\boldsymbol{M}}_{\boldsymbol{ij}}) / A_L^2$$

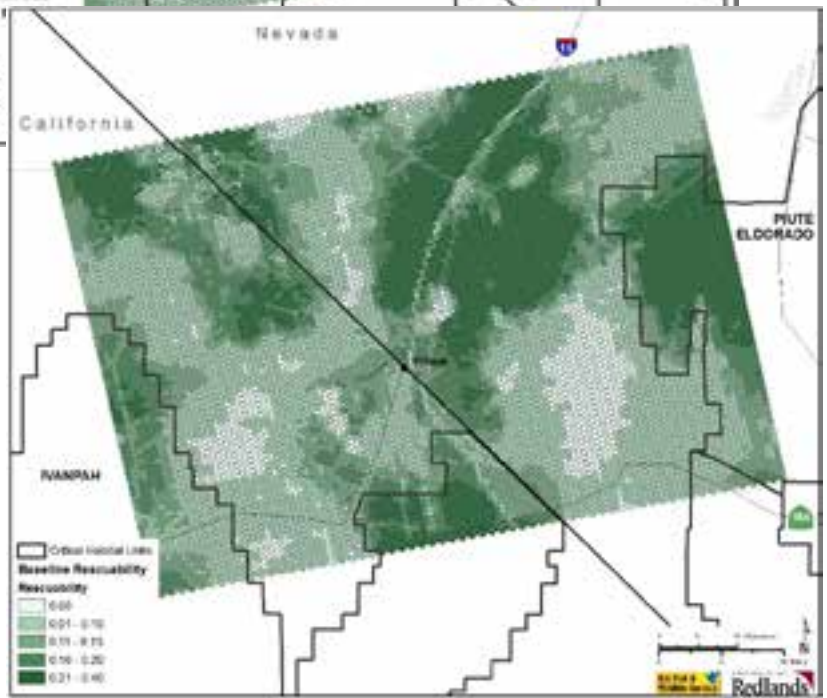
$$PC^* = \frac{E(AHP^2)}{N} + E(Resilience) * (N_R - 1)/N$$

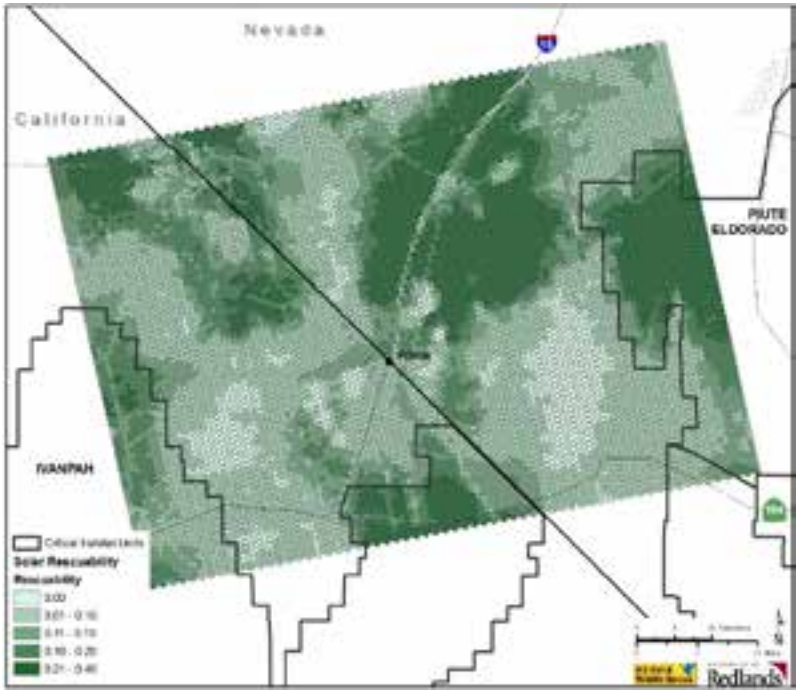
= (0.4% + 99.6%) * 0.0096

Results: 2.x metrics, 3 scenarios



Scenario	PC^* Index	%Change	λ_{PC}	%Change
Pre-Columbian	0.0141359	100.0%	2315839.7	100.0%
Baseline	0.0096343	68.2%	1794341.2	77.5%
3 Solar	0.0093072	65.8%	1790398.4	77.3%





Analysis of metrics

- PC Index
  - Fast to calculate (summation) if not least cost path
  - Change in local habitat can be calculated locally
  - BUT – what is the threshold for population collapse?
- Population Capacity (λ_{PC})
  - Directly related to a threshold for collapse
  - Local changes require global recalculation(?)
  - Not very sensitive to major habitat loss (3 solar)

$$\boldsymbol{\lambda_P} > \boldsymbol{\tau} = \frac{\boldsymbol{(1-s)}}{\boldsymbol{b}}$$

- Resilience
  - One component of PC Index
  - Directly and visually captures concept of rescue
  - Local change computed locally
  - Appears to suggest when a linkage is lost
  - BUT issues of scale and interpretation

Next Steps

- Ivanpah Valley Study Area
  - Add disturbance to scenarios
  - Create Least cost path surface
  - Calculate at different scales
- Investigate thresholds for habitat fragmentation
  - Scale $\boldsymbol{\lambda_P}$ vs survival rate s and reproduction rate b
- Scale to Range and recalculate all metrics
  - 10 times size of Ivanpah Valley study area
  - Current calculations on order of days
- Incorporate in Spatial Decision Support System
  - Asynchronous calculations
  - geodesign calculations

Questions for you

- Iterative eigenvalue calculations
  - If AHP changes in a local area, do you have method that allows the system to update the eigenvalue without a range wide recalculation?
  - Do you have a method that uses “black box” method for Mij? (avoid creating a trillion element matrix in memory)
- More efficient method for identifying hex segments of paths than intersect method?

Thank you!

- Philip Murphy Ph.D. philip_murphy@Redlands.edu
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