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Migratory Species' Movement Decisions Should Inform Development and Conservation Actions

University of Wyoming

Policy Question
Economic Question

- Conservation Question: where to site parks to conserve species?
- But also: where to develop to conserve species?

- Spatial economic decisions
- Spatial behavior of species
- Related analyses
  - Many fishery/marine papers: metapopulations of fish across space
  - Bauer et al. (2010): development patterns with amphibians

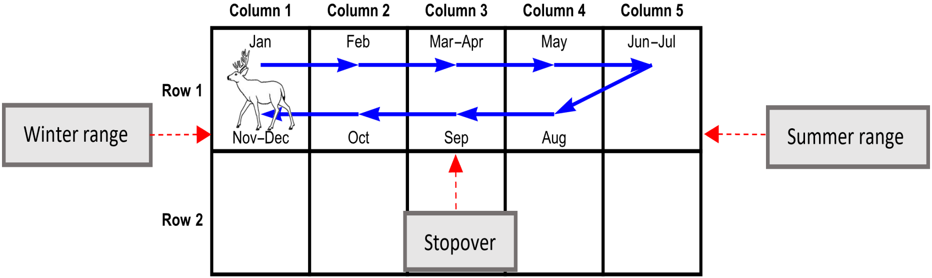
- Siting development
  - Location choices for different levels of development
  - s.t. minimize impact on migratory species

- Conservation actions

Spatial Development or Conservation Decisions Must Reflect How Species Move

- Density Dispersal
  - Fish move "as if" searching for resources
  - Little attention to dispersal matrix
- Migratory species
  - Different types of movement
  - The path matters
- Here: modify density dispersal – "surf the green wave"
- Other factors in movement decisions:
  - **Fidelity** to locations – energy losses
  - **Sensitivity/Tolerance** to development – energy losses
  - Availability and quality of alternative routes

Spatial Representation and Migratory Path

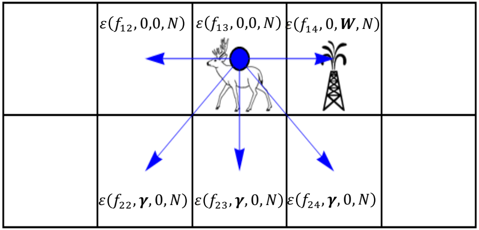


Herd Movement Decision: are net resources higher next door?

move from cell (i_0, j_0) to (i, j) at period t if

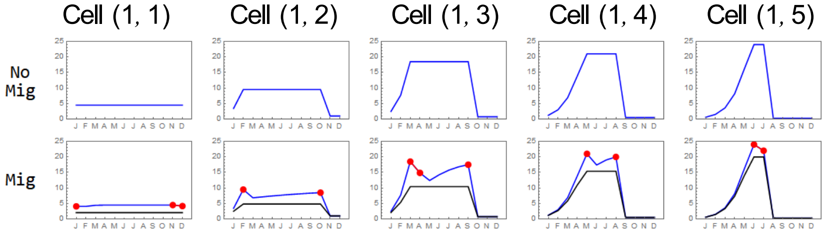
$$\varepsilon_{ij}(t) > \varepsilon_{rc}(t) = \varepsilon\big(f_{rc}(t), \gamma_{rc}(t), w_{rc}, N(t-1)\big)\ \forall (r,c)\ \textit{grid cell}$$

- $\varepsilon_{ij}(t) > \varepsilon_{rc}(t)$: effective consumption
- $f_{rc}(t)$: forage
- $\gamma_{rc}(t)$: fidelity stress
- w_{rc}: develop. sites
- $N(t-1)$: herd location

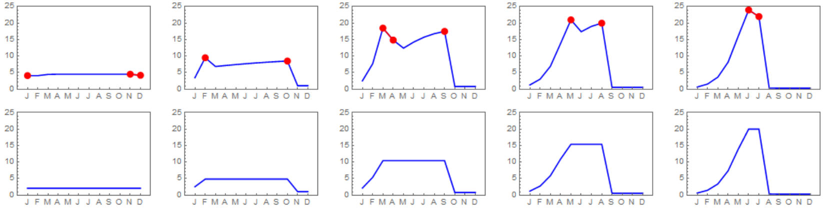


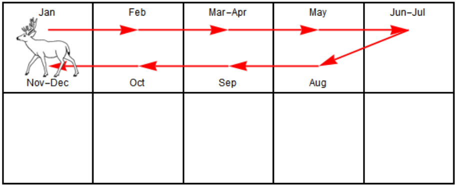
Net resources: energy sources less energy costs

BUT: Forage resources change over the year and with species presence:



Surfing the Green-up of Forage





Effective density dispersal but with intra-temporal resource growth varying across space

Spatial Bioeconomic Model

$$\min_{W} \underbrace{\overbrace{\tilde{N}(t_0)}^{\text{Undisturbed}} - \overbrace{\tilde{N}(t_{SS})}^{\text{Steady State}}}_{\text{Herd Size}} \quad \text{s.t.}$$

- Develop. restrict.
- Forage dynamic
- Herd dynamic
- Herd growth

Spatial Bioeconomic Model

$$\min_{W} \quad \tilde{N}(t_0) - \tilde{N}(t_{SS})$$ s.t.

Develop. restrict.

Development Size

Maximum Concentration

$$\bar{W} = \sum_{(i,j)\in D} \left(w_{ij} \middle| \hat{w} \geq w_{ij} \geq 0 \right)$$

Forage dynamic

Herd dynamic

Herd growth

Spatial Bioeconomic Model

$$\min_{W} \quad \widetilde{N}(t_0) - \widetilde{N}(t_{SS}) \text{ s.t.}$$

Develop. restrict.

Forage dynamic

$$f_{ij}(t) = \hat{f}_{ij}(t-1)\left(1 + \underbrace{\varphi_{ijt}}_{\text{Growing/Decaying Season}}\left(\overbrace{\hat{f}_{ij}(t-1)}^{\text{Post-Grazing Forage}}\right)\right)$$

Herd dynamic

Herd growth

Spatial Bioeconomic Model

$$\min_{W} \quad \tilde{N}(t_0) - \tilde{N}(t_{SS}) \quad \text{s.t.}$$

Develop. restrict.

Forage dynamic

Herd dynamic

$$\varepsilon_{ij}(t) = \varepsilon\left(f_{ij}(t), \gamma_{ij}(t), w_{ij}, N(t-1)\right)$$

- $\varepsilon_{ij}(t)$: Potential effective consumption
- $f_{ij}(t)$: forage
- $\gamma_{ij}(t)$: fidelity stress
- w_{ij}: development sites
- $N(t-1)$: herd location

Herd growth

Spatial Bioeconomic Model

$$\min_{W} \quad \tilde{N}(t_0) - \tilde{N}(t_{SS}) \quad \text{s.t.}$$

- Develop. restrict.
- Forage dynamic
- Herd dynamic
- Herd growth

Population Updating

Growth rate

$$\tilde{N}(t) = \tilde{N}(t-1)\left(1 + \sigma_t\left(\tilde{\varepsilon}(t-1)\right)\right)$$

actual consumption

Spatial Bioeconomic Model

$$\min_{W} \quad \tilde{N}(t_0) - \tilde{N}(t_{SS}) \quad \text{s.t.}$$

Develop. restrict.

$$\bar{W} = \sum_{(i,j)\in D} \left(w_{ij} \middle| \hat{w} \geq w_{ij} \geq 0\right)$$

Forage dynamic

$$f_{ij}(t) = \hat{f}_{ij}(t-1)\left(1 + \varphi_{ijt}\left(\hat{f}_{ij}(t-1)\right)\right)$$

Herd dynamic

$$\varepsilon_{ij}(t) = \varepsilon\left(f_{ij}(t), \gamma_{ij}(t), w_{ij}, N(t-1)\right)$$

Herd growth

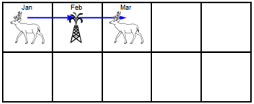
$$\tilde{N}(t) = \tilde{N}(t-1)\left(1 + \sigma_t\left(\tilde{\varepsilon}(t-1)\right)\right)$$

Development

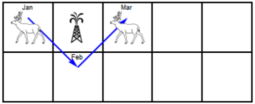
- Development can be separated into w_{ij} sites
- Development value homogeneous
- Production per site is not affected by location nor concentration as long as: $w_{ij} \leq \hat{w}$.

Potential Herd Responses

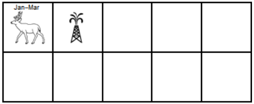
Maintain



Deviate

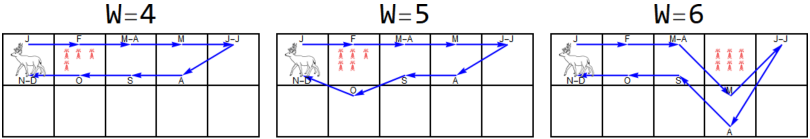


Overstay



- Maintain migration path: losses due to development stress
- Deviate: Less forage, losses due to fidelity stress.
- Overstay: Forage in already grazed region, no stress losses. (truncated migration)

Baseline Results: 3 levels of development (W)



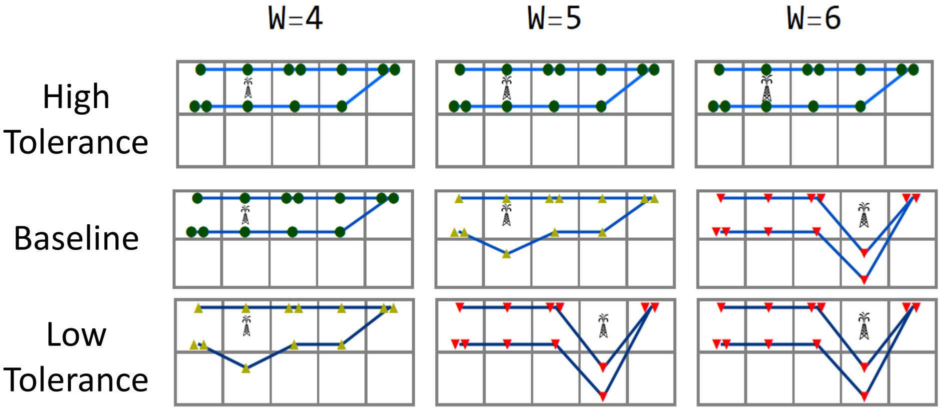
Cluster development

- Contain energy losses to one area

Where? Minimize energy loss

- Development level determines herd response
- Maintain migration path or deviate once:
  - Near winter range – low forage
- Double deviation from migratory path:
  - Near summer range – abundant forage on alt. path

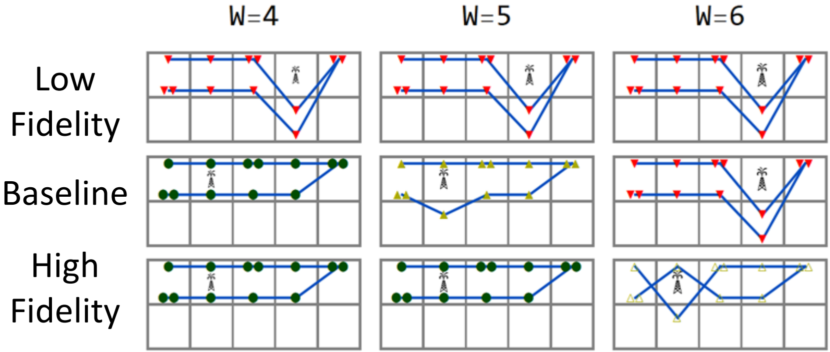
Shift of Tipping Point: Development Size vs. Tolerance



Tolerant ungulates respond by maintain migration despite large W

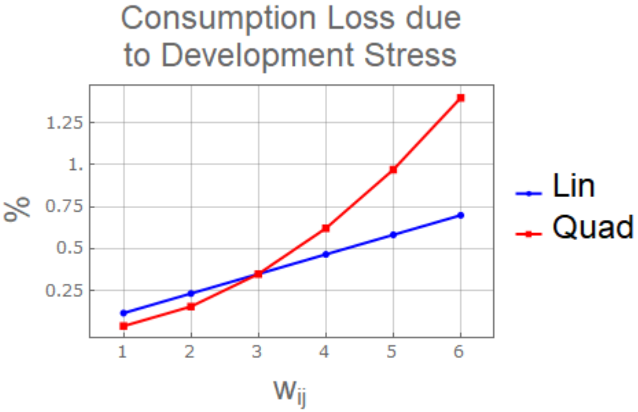
Intolerant ungulates deviate even at small W

Migratory Path Fidelity

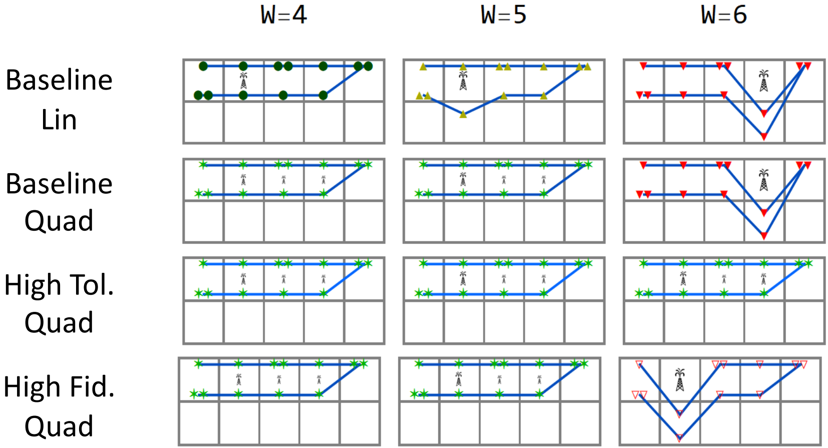


- Low fidelity species easily deviate
  - Optimal location: induce deviation near summer range
- High fidelity species maintain migratory path
  - Optimal location: Induce deviation near winter range/low forage

Functional Form of Tolerance to Development Stress



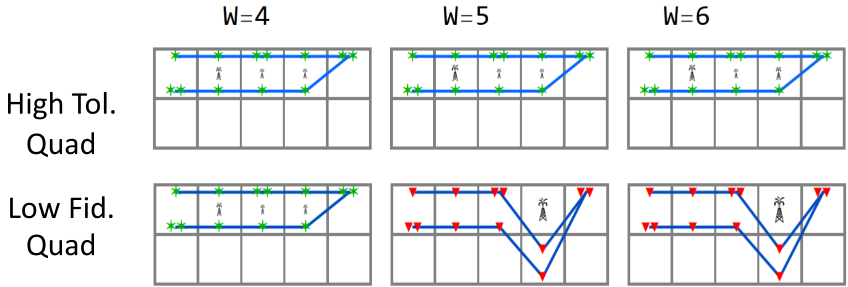
Tolerance Functional Form: Impact on Development Locations



Increasing marginal stress from development in one location:

- Optimal to distribute development
- High development: induce deviation by clustering

Tolerance Functional Form



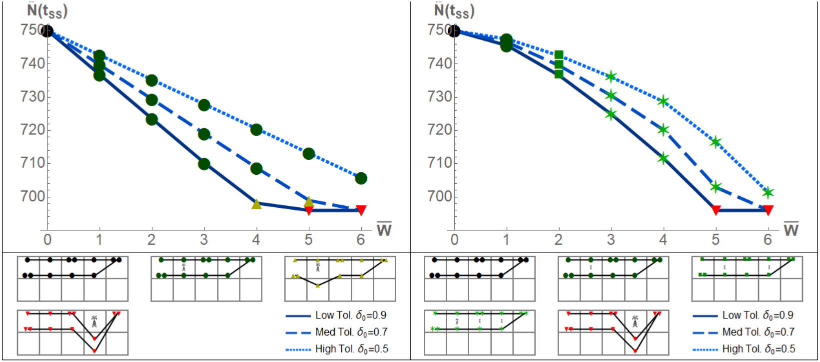
High tolerance species: spread development, herd maintains

Low fidelity species:

- Low development: spread development, herd maintains
- High development: cluster, induce deviation

Tradeoffs: Development levels and Species Populations

Linear	Nonlinear



- Deviation induced, no additional species losses
- Marginal species losses differ across tolerance form

Optimal Tradeoffs? What is the Objective?

Maximize development value s.t. min impact on species population level

- Heterogeneous development net values?

Max net social benefits

- Assign value to species populations
- Assign value to migration itself?
- Assign value to species in particular locations?

Conservation Policy: Resources

- Resource Enrichment in Path
  - Offsets energy losses for high fidelity species
  - Can avoid deviation for low fidelity and low tolerance species
  - Can truncate or slow the migration
- Resource Enrichment on Public Land (alternative path)
  - Can induce deviation away from development for low fidelity and low tolerance species
  - Can truncate or slow migration

EITHER WAY: Can disrupt the migration

Conservation Policy: Pop-up

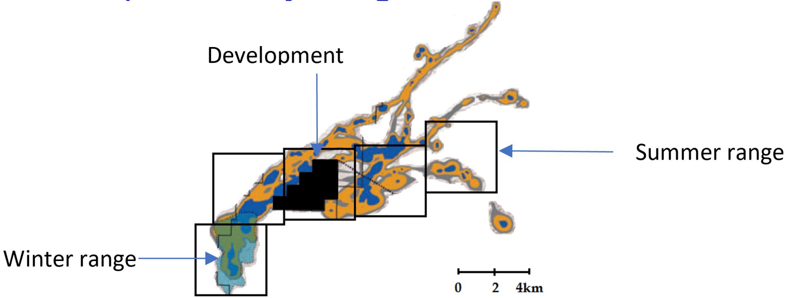
- Temporary reduction of activities
  - No activities during species use of site
  - Costs a portion of development profits
  - Gains higher ss species populations
- In stopover
  - Costs more due to 3 months of species use
  - Benefits species more
- Partial reductions in stressors
  - Costs less
  - Shifts development-population tradeoff curves

Conservation Policy: Corridors; Bridges over Barriers

- Corridors
  - Functional connectivity issues
  - Will the species use it?

- Physical barriers to movement
  - How do herds adjust? What info do they use?
  - Do they move through with high mortality?
  - Do they truncate the migration?
- Wildlife Bridges
  - What aspects of the species' decisions addressed?

Stylized Example from Wyoming



- High development value in stopover
- Herds: Speeding up in stopover due to development
- Policy? Diagonal drilling, fencing/bridges to induce deviation, payments for pop-up

Further development in the stopover?

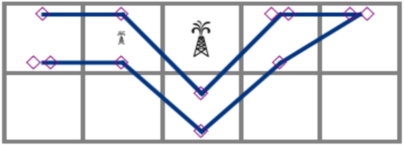
Our parameters:

- never see optimal development in the stopover
- development there is costly in 3 months

With larger development (W>6):

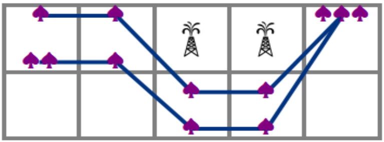
The herd can change the stopover location (deviate)

W=7



Or arrive earlier to the summer range

W=12



Conclusions: Relationship to Literature

- Species' spatial decisions to generate migration
  - Integrate forage growth with energy-based movement
- Species' characteristics inform species decisions
  - fidelity; tolerance
- Beyond density dispersal
  - More than pure resource-based decisions

Conclusions: Development Siting

- Species' spatial decisions influence development patterns
  - Do not focus only on endpoints
  - High fidelity and low tolerance: cluster development near winter range
  - Low fidelity and high tolerance: induce deviation near summer range
- Know your species:
  - Assume perfect fidelity when low? Place development in the wrong location

Conclusions: Conservation

- Resource enrichment can backfire
- Functional connectivity – species' choices
    - "if you build it, they will come"??
- Pop-up allows for lower development costs than permanent
- Corridors and bridges
    - Work with herd decisions to make effective

Questions and comments?