Gray Wolf Management with Competing Transboundary Benefits

Background

Wolf behavioral ecology

Tourists & hunters

Bioeconomic model

Conclusion

Modeling annex

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Preview:

A gap exists between how management decisions are made, how we measure ecosystem services and how we model this intersection.

Carpenter et al. (2006; *Science*), Fisher et al. (*2011; ERE*)

This gap can be closed by better modeling jointly-determined economic and ecological systems.

An application of this concept is made to wolf management across jurisdictional boundaries.

Delisting & Active Management:

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Hunting states:

- Alaska
- Idaho
- Minnesota
- Montana
- Wisconsin
- Wyoming

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Non-hunting states:

- Arizona
- Michigan
- New Mexico
- North Carolina

Managing a wildlife population as a renewable resource: Specifying the welfare function.

Fischer et al. (2011; *ERE*) use hunting license revenue and non-consumptive tourism as an increasing function of wildlife population.

Naevdal et al. (2012; *Ecol. Econ*) use harvest quota and differentiate prices for “trophy” value and “meat” value.

Benefits from wolves in Wyoming (2012)

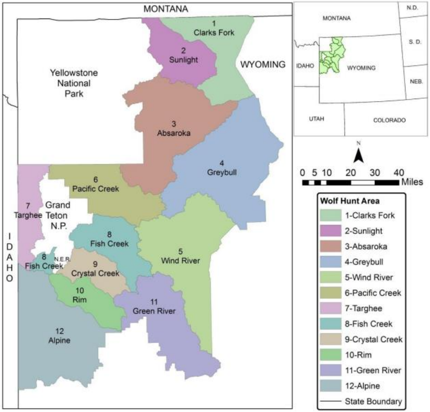
Benefits to hunters:

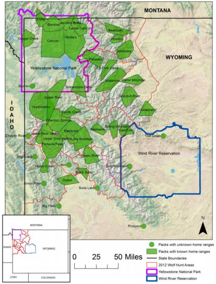
- 3,403 hunters received licenses.
- \$3,273 per-harvested wolf state licensing revenue.
- 25,169 recreation days.
- 599 per-harvested wolf recreation days.
- Contributed to \$132 million in all hunter and angler expenditures.
- Hunter success rate $<2\%$.

Benefits to wildlife viewers:

- 326,170 visitors see a gray wolf in YNP annually (11.6% of visitors).
- Local annual expenditure of \$35 million attributed to wolves.
- 44% of visitors' most preferred species to see when visiting YNP (Duffield 2008).

Wildlife management decisions in Wyoming (2012)





AREA	QUOTA FROM REGS	SEASON DATES GENERAL	HARVEST COUNTED TOWARDS QUOTA *1
1	4	October 1 - December 31	4
2	8		8
3	8		7
4	3		3
5	5		3
6	3		3
7	1		0
8	7		8
9	2		2
10	2		0
11	7		3
12	2	October 15 - December 31	1
Total 2012 Trophy Quota	52	Total 2012 Trophy Harvest	42

Wyoming Game & Fish 2012

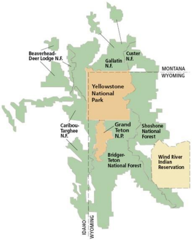
Considerations for active wolf management:

Refuge-seeking behavior

Thurber et al. (1994; *Wildlife Society Bulletin*)

Kenai, Alaska

Greater Yellowstone Area

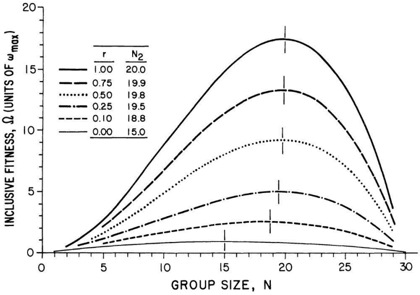


Rocky Mountain National Park

Considerations for active wolf management:

Optimal foraging group size

Rodman (1981; *AmNat*), MacNulty et al. (2011; *Beh. Ecol*)



Considerations for active wolf management:

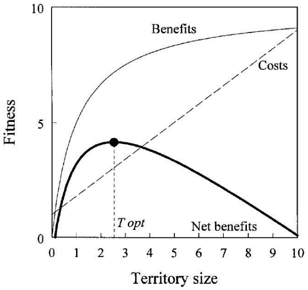
Territoriality and reproductive fitness

Both and Visser (2003; *AmNat*)

The leading non-human source of wolf mortality is interpack aggression. – David Mech (1991)

Harvest to reduce intraspecific strife… intraspecific mortality is a valuable resource consuming itself.

Hochard and Finnoff (2014; *NRM)*



Attracting wildlife viewers and hunters:

- Viewers visit based on the prospect of seeing a wolf (prior period wolf density).
- Hunters come based on total harvest quota (do not know distribution of wolves across space).

Experience of wildlife viewers and hunters:

- Viewers benefit from seeing a wolf (current period wolf density).
- Hunters benefit not only from tagging a wolf but from experiencing recreation days.

n packs choose territory, $T_{i,t}$, to maximize reproductive fitness

$$\max_{T_{i,t}} F_{i,t} = \overbrace{h \underbrace{\left(\frac{s^{*2} - (s_{i,t} - s^*)^2}{s^{*2}} \right)}_{\text{Deviation from optimal group size penalty}} T_{i,t}}^{\text{Total benefits to fitness}} - \overbrace{[M + \underbrace{\frac{\sum_{i=1}^{n} s_{i,t}}{\bar{T} - \sum_{i=1}^{n} T_{i,t}}}_{\text{Population to vacant territory ratio}} \frac{1}{D_i} T_{i,t}]}^{\text{Total cost to fitness}}$$

h = translates territory quality into reproductive fitness.

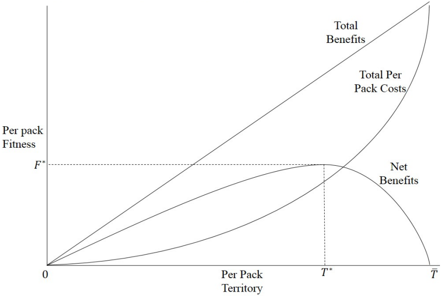
$s_{i,t}$= size pack i in time *t.*

s^* = optimal group size.

M = fixed maintenance cost.

$\bar{T}$ = Available territory.

D_i = Pack-specific defendability



Analogous to Both and Visser (2003; AmNat) critiqued by Adams (2001; Ann. Rev. Ecol. Sys.)

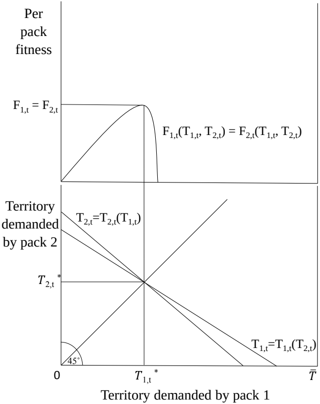
Addressing Adams (2001) critique using strategic Cournot-territory choice

$$\max_{T_{i,t}} F_{i,t} = \overbrace{h \underbrace{\left(\frac{s^{*2} - (s_{i,t} - s^*)^2}{s^{*2}} \right)}_{\substack{\text{Deviation from optimal} \\ \text{group size penalty}}} T_{i,t}}^{\text{Total benefits to fitness}} - \overbrace{[M + \underbrace{\frac{\sum_{i=1}^{n} s_{i,t}}{\bar{T} - \sum_{i=1}^{n} T_{i,t}}}_{\substack{\text{Population to vacant} \\ \text{territory ratio}}} \frac{1}{D_i} T_{i,t}]}^{\text{Total cost to fitness}}$$

$$MB_{i,t} = h \left(\frac{s^{*2} - (s_{i,t} - s^*)^2}{s^{*2}} \right)$$

$$MC_{i,t} = \frac{1}{D_i} \left[\frac{\sum_{i=1}^{n} s_{i,t}}{\bar{T} - \sum_{i=1}^{n} T_{i,t}} + T_{i,t} \frac{\sum_{i=1}^{n} s_{i,t}}{(\bar{T} - \sum_{i=1}^{n} T_{i,t})^2} \right]$$

First-order conditions, $MB_{i,t} = MC_{i,t}$ for all $i = 1, 2, ..., n$ govern a set of n territory-choice reaction functions.



Spatial dynamics & harvest:

Packs choose in-refuge or out-of-refuge territory...
out-of-refuge packs are susceptible to harvest.

In-refuge equilibrium condition

$$h^r \left(\frac{s^{*r2} - (s_{i,t} - s^{*r})^2}{s^{*r2}} \right) = \frac{1}{D_i} \left[\frac{\sum_{i=1}^{n_t^r} s_{i,t}}{\bar{T}^r - \sum_{i=1}^{n_t^r} T_{i,t}} + T_{i,t} \frac{\sum_{i=1}^{n_t^r} s_{i,t}}{(\bar{T}^r - \sum_{i=1}^{n_t^r} T_{i,t})^2} \right]$$

Out-of-refuge equilibrium condition

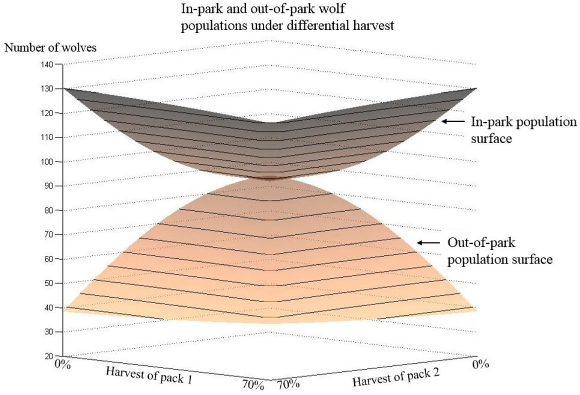
$$h^{nr} \underbrace{\left(\frac{s^{*nr2} - (s_{j,t} - h_{j,t} - s^{*nr})^2}{s^{*nr2}} \right)}_{\substack{\text{Harvest reduces pack foraging efficiency} \\ \text{(technical efficiency)}}} = \frac{1}{D_j} \left[\frac{\sum_{j=1}^{n-n_t^r} s_{j,t}}{\bar{T}^{nr} - \sum_{j=1}^{n-n_t^r} T_{j,t}} + T_{j,t} \frac{\sum_{j=1}^{n_t^{n-n_t^r}} s_{j,t}}{(\bar{T}^{nr} - \sum_{j=1}^{n_t^{n-n_t^r}} T_{j,t})^2} \right]$$

r superscripts in-refuge parameters, nr superscripts out-of-refuge parameters. $i = 1, 2, \ldots, n_t^r$ in-refuge and $j = 1, 2, \ldots, n - n_t^r$ packs out-of-refuge.

In-refuge & out-of-refuge migration equilibrium:

$$Min(F^*_{j,t}|_{n^{*r}_t}) \ \forall\ j = F^*_{i,t}|_{n^{*r}_t}$$

Hunted packs retreat in-refuge until intraspecific forces in-refuge equal the worst-off harvested-pack's fitness out-of-refuge.



Symmetric in-park/out-of-park parameters and $d_i = d_j = 0.1 \ \forall\ i, j$.

Temporal dynamics & population updating:

- Background
- Wolf behavioral ecology
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- **Bioeconomic model**
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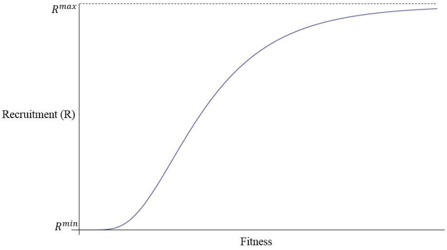
Each pack transforms reproductive fitness into recruitment following a lognormal CDF.

Higgins et al. (1997; *AmNat*), Latham et al. (2011; *JWM*)

Pack-size recruitment



Pack-size updating

$$s_{i,t+1} - s_{i,t} = \frac{1}{2\delta}\left[1 + Erf\,\frac{Log\left(\frac{F_{i,t}}{\rho}\right) - \mu}{\sqrt{2\sigma}}\right]$$

$$\delta = natural\ mortality\ rate$$

Temporal dynamics & population updating:

Recruitment pushes packs above their optimal foraging group size, remainder wolves disperse and form new packs at the optimal group size.

$$n_{t+1} = \frac{\overbrace{\sum_{i=1}^{n_t^r} s_i + \sum_{j=1}^{n_t - n_t^r} s_j}^{\text{Total wolf population}}}{s^*(n_t \epsilon)}$$

$n_t\epsilon$ =density-dependent intraspecific aggression penalty
Cubaynes (2014; *J. Animal Ecology*)

Benefits to viewers in-refuge

The number of viewers, τ_t, is concavely increasing function in prior period wolf density

$$\tau_t\left(\frac{s^{*r} n^r_{t-1}}{\bar{T}^r}\right).$$

Probability a viewer sees a wolf, p^v_t is an increasing function of current wolf density

$$p^v_t\left(\frac{s^{*r} n^r_t}{\bar{T}^r}\right).$$

Number of wolf views in time t is $\tau_t(\frac{s^{*r} n^r_{t-1}}{\bar{T}^r}) p^v_t(\frac{s^{*r} n^r_t}{\bar{T}^r})$.

Benefits to hunters out-of-refuge

The number of hunters, η_t, is concavely increasing function of total harvest across all out-of-refuge packs

$$\eta_t(\sum_{j=1}^{n_t - nr_t} h_{j,t}).$$

Number of harvested packs, z, is vector subspace of total out-of-refuge packs ($z_t \subset n_t - nr_t$).

Harvest distribution and territory-choice responses allows us to determine average density of wolves across hunted space throughout hunting season

$$(z_t - 1)\frac{\sum_{j=1}^{z_t} \frac{h_{j,t}}{T_{j,t}}}{\sum_{j=1}^{z_t}(1 - h_{j,t})}.$$

Benefits to hunters out-of-refuge

The probability, throughout a season, a hunter records a tag on a given day, p_t^k, is an increasing function of average hunting density

$$\overbrace{p_t^k\left((z_t-1)\frac{\sum_{j=1}^{z_t}\frac{h_{j,t}}{T_{j,t}}}{\sum_{j=1}^{z_t}(1-h_{j,t})}\right)}^{\text{Measure of hunter success}}$$

combined with number of hunters

$$\overbrace{\eta_t\left(\sum_{j=1}^{n_t-nr_t}h_{j,t}\right)p_t^k\left((z_t-1)\frac{\sum_{j=1}^{z_t}\frac{h_{j,t}}{T_{j,t}}}{\sum_{j=1}^{z_t}(1-h_{j,t})}\right)}^{\text{Number of wolf tags per day.}}.$$

Benefits to hunters out-of-refuge

$$\overbrace{\frac{\text{total season harvest}}{\text{harvest rate (per day)}}}^{\text{Harvest season length (days)}} =$$

$$\frac{\sum_{j=1}^{z_t}(1-h_{j,t}s^{*nr})}{\eta_t(\sum_{j=1}^{n-nr_t} h_{j,t})p_t^k\left((z_t-1)\frac{\sum_{j=1}^{z_t}\frac{h_{j,t}}{T_{j,t}}}{\sum_{j=1}^{z_t}(1-h_{j,t})}\right)}$$

$$\overbrace{\text{Number of hunters X season length}}^{\text{Number of recreation days}} =$$

$$\frac{\sum_{j=1}^{z_t}(1-h_{j,t}s^{*nr}}{p_t^k\left((z_t-1)\frac{\sum_{j=1}^{z_t}\frac{h_{j,t}}{T_{j,t}}}{\sum_{j=1}^{z_t}(1-h_{j,t})}\right)}$$

WOLF HUNTER HARVEST SUMMARY 2013 — **1/2/2014 3:00 PM**

Note: Hunt Areas in red indicate total harvest is at or above quota.

HUNT AREA	QUOTA FROM REGS	SEASON DATES GENERAL	HARVEST COUNTED TOWARDS QUOTA *1	AREA STATUS	DATE/TIME AREA CLOSED
1	2	Oct 1 - Dec 31	2	CLOSED	11/10/2013 @ 11:00 AM
2	4		5	CLOSED	10/13/2013 @ 1:30PM
3	3		3	CLOSED	10/20/2013 @ 12:15 PM
4	2		2	CLOSED	10/27/13 @ 2:30 PM
5	3		3	CLOSED	10/8/2013 @ 11:50 AM
6	3		3	CLOSED	12/22/13 @ 7:20 PM
7	0		0	CLOSED	Closed in 2013
8	4		4	CLOSED	12/26/2013 @ 1030
9	1		0	CLOSED	12/31/13 per regulations
10	1		1	CLOSED	10/1/2013 @ 11:35 AM
11	2		1	CLOSED	12/31/13 per regulations
12	1	Oct 15 - Dec 31	0	CLOSED	12/31/13 per regulations

Closing the gap: specifying welfare functions

A more sophisticated bioeconomic model enables *us to better specify welfare effects from management schemes.*

- Refuge-seeking behavior.
- Optimal foraging group size.
- Territoriality and reproductive fitness.
- Humans respond to ecological conditions based on partial information.

- Number of viewers.
- Number of views.
- Percentage of views.
- Number of tags.
- Number of hunters.
- Harvest success rates.
- Length of hunting season.
- Number of recreation days.

Exploits the fact that wildlife managers set harvest across both time and space.

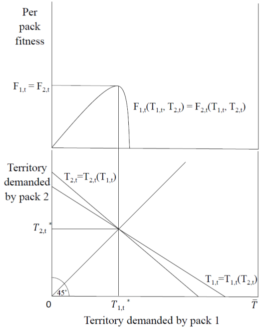
Relies on functional forms estimable with human and ecological data.

n packs choose territory, $T_{i,t}$, strategically: Cournot-territory competition best-response curve

$$T^*_{i,t} = \bar{T} - \left(\frac{\sum_{i=1}^{n} s_{i,t} \left(\bar{T} - \sum_{j=1}^{n-1} T_{j,t} \right)}{hD_i \left(\frac{{s^*}^2 - (s_{i,t} - s^*)^2}{{s^*}^2} \right)} - \left(\sum_{j}^{n-1} T_{j,t} \right)^2 \right)^{0.5} \quad i = 1, 2, ..., n \;\; i \neq j$$

Territory choice reaction curves:

$$T_{i,t} = T_{i,t}(T_{q,t})$$



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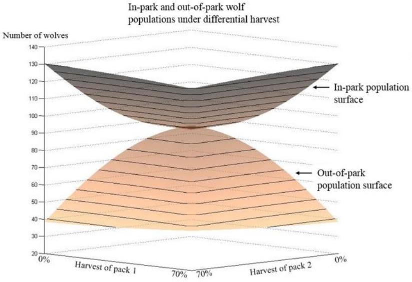
$$Min(F^*_{j,t}|_{n^{*r}_t})\ \forall\ j = F^*_{i,t}|_{n^{*r}_t}$$

Hunted packs retreat in-refuge until intraspecific forces in-refuge equal the worst-off harvested-pack's fitness out-of-refuge.

Harvest management and pack defensibility



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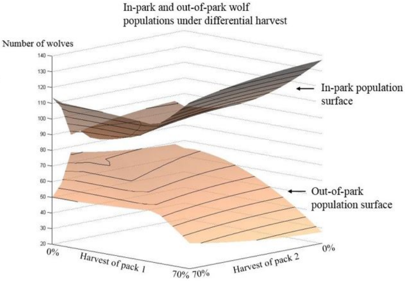

Symmetric in-park/out-of-park parameters and $d_1 = 0.1, d_2 = 0.3$.