Interactions between predators and prey

What is a predator?

Predator – An organism that consumes other organisms and inevitably kills them. Predators attack and kill many different prey individuals over their lifetimes

Brook Trout
Salvelinus fontinalis

Mountain lion
Puma concolor

Masked Shrew
Sorex cinereus

Dragonfly
Diphlebia lestoides

How do predators impact prey populations?

Direct effects

Indirect effects

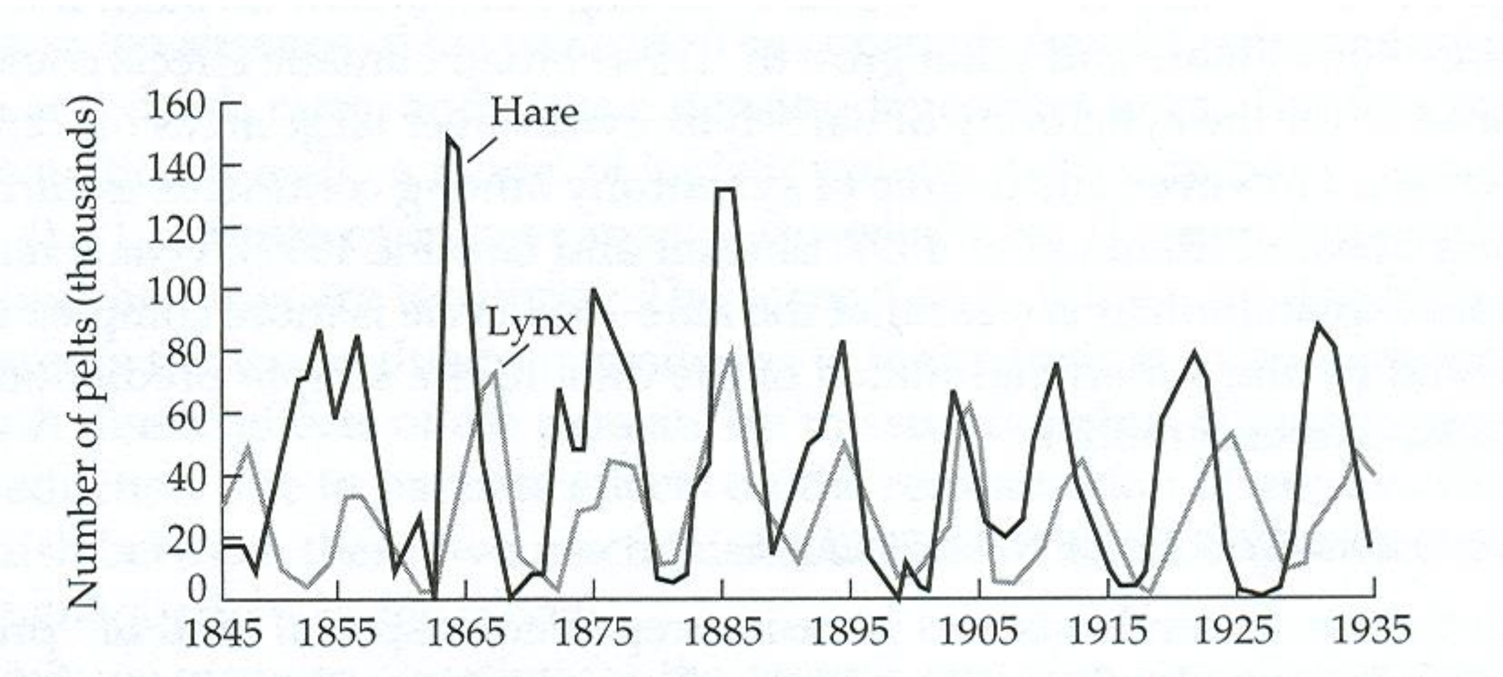
Understanding direct impacts of predation

Lynx canadensis
(Lynx)

Lepus americanus
(Snowshoe hare)

What role does predation play in regulating population densities?

Population cycles of Lynx and Hare



Data from Hudson's Bay Company pelt records

Are these cycles in lynx and hare densities the product of predation?

The Lotka-Volterra Predation Model

Alfred James Lotka
(1880 - 1949)

Vito Volterra
(1860-1940)

The Lotka-Volterra Predation Model

?

The Lotka-Volterra Predation Model

Prey

$$\frac{dN}{dt} = rN - \alpha NP$$

α is the *per capita* impact of the predator on the prey

(-)

Predator

$$\frac{dP}{dt} = \beta NP - qP$$

β is the *per capita* impact of the prey on the predator

(+)

q is the predator death rate (assumes a specialist predator)

What are the equilibria?

Prey

$$0 = rN - \alpha NP$$

$$0 = N(r - \alpha P)$$

Here we see that *N* = 0 is one equilibrium, but there is also another:

$$r = \alpha P$$

$$\hat{P} = \frac{r}{\alpha}$$

Solving for the prey equilibrium actually gives us an answer in terms of the predator!

Predator

$$0 = \beta NP - qP$$

$$0 = P(\beta N - q)$$

Here we see that *P* = 0 is one equilibrium, but there is also another:

$$q = \beta N$$

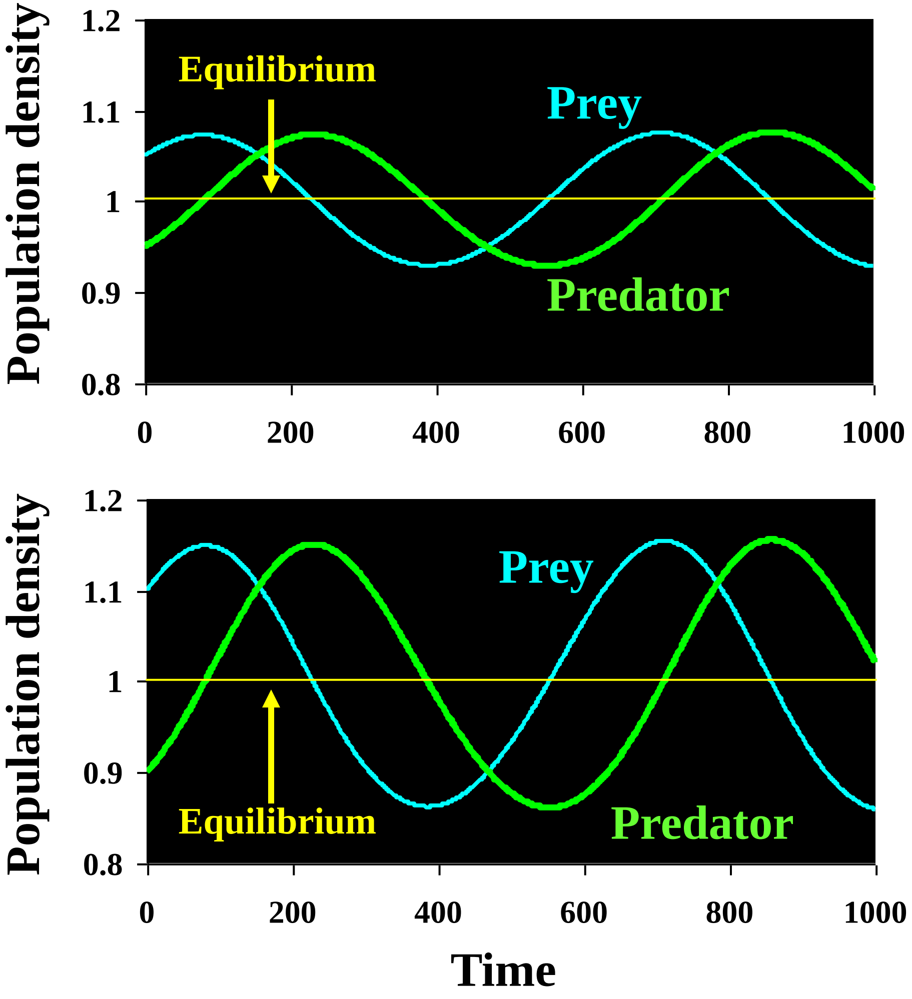
$$\hat{N} = \frac{q}{\beta}$$

Solving for the predator equilibrium actually gives us an answer in terms of the prey!

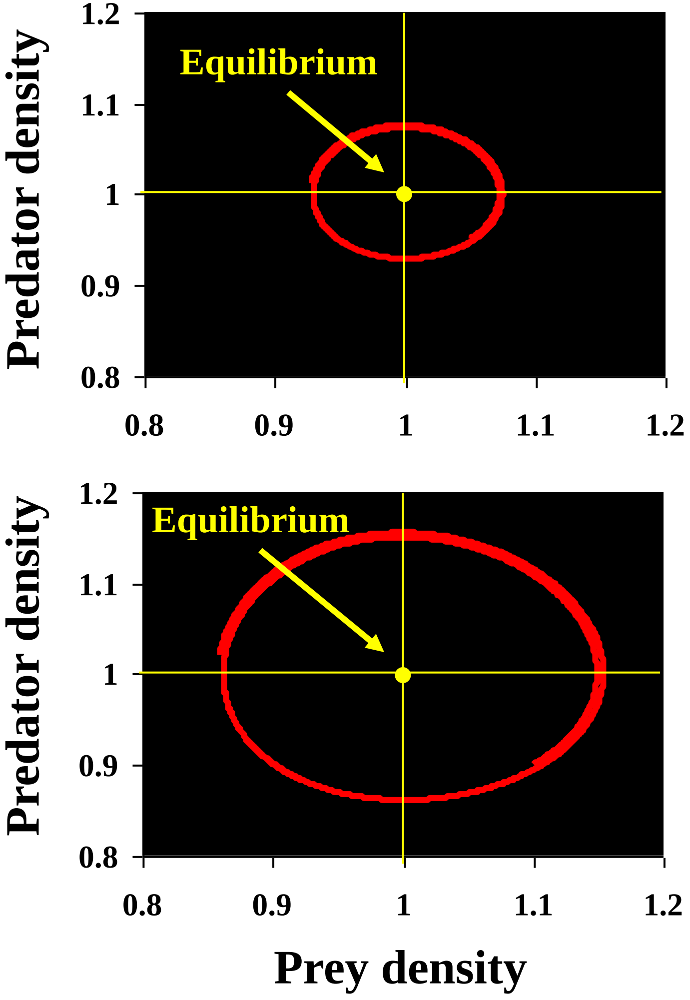
Are these equilibria ever reached?

(in this example, $r = \alpha$ and $q = \beta$)

Time series plots



Phase plots



The model always produces cycles in population densities!

Summary of the Lotka-Volterra predation model

The only possible behavior is population cycles
Stable equilibria are not possible

➔ Direct impacts of predation could explain the lynx-hare cycles

➔ But not other predator-prey interactions that do not cycle

Does our model make important assumptions that limit its generality?

Model assumptions

- **Growth of the prey is limited only by predation (i.e., no *K*)**

- **The predator is a specialist that can persist only in the presence of this single prey item**

- **Individual predators can consume an infinite # of prey**

- **Predator and prey encounter one another at random (N*P terms)**

- **Predation causes additive rather than compensatory mortality**

Now let's modify the model to relax the blue assumptions one at a time

How could we add intraspecific competition?

?

Adding prey density dependence

Prey

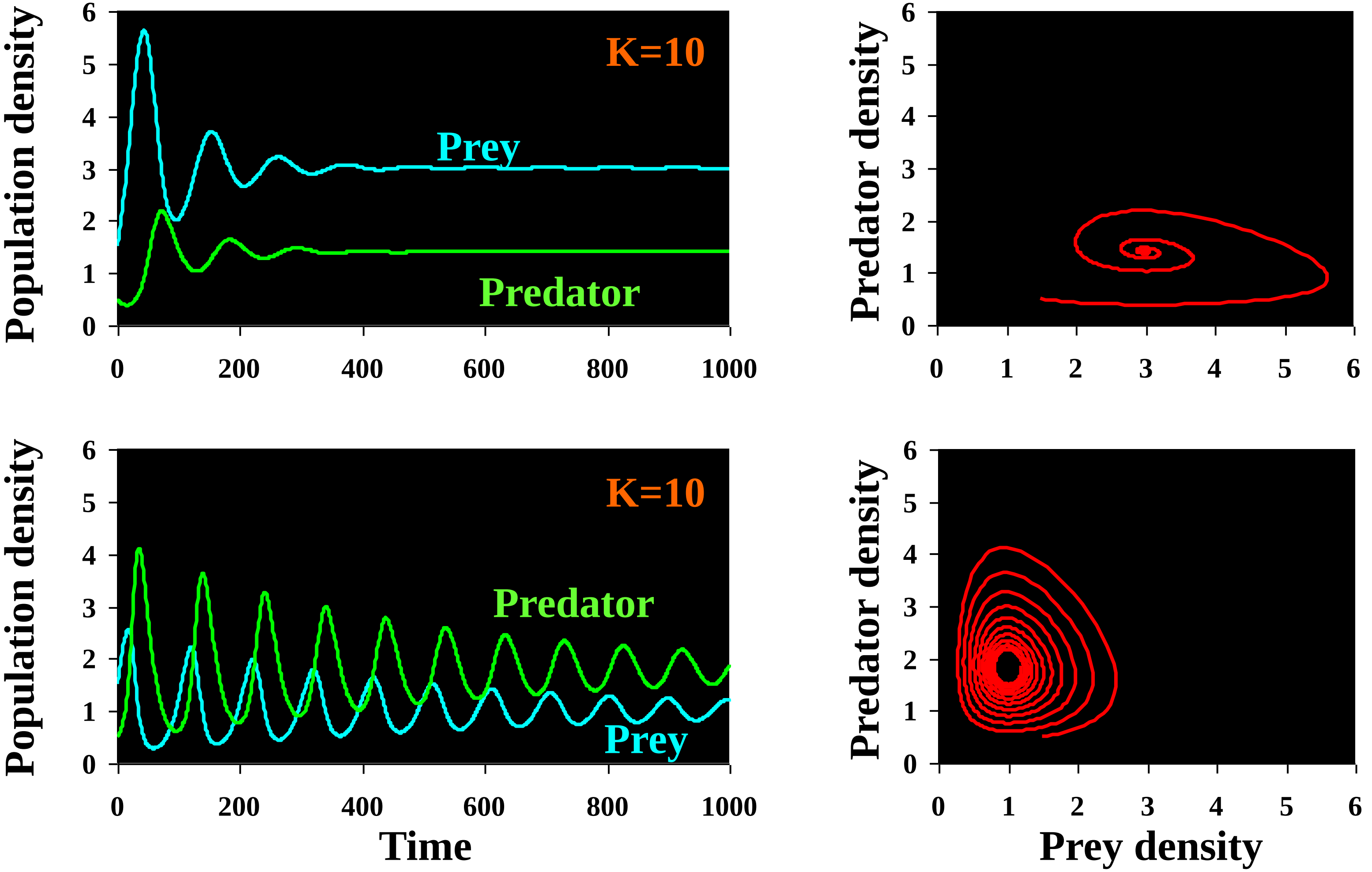
$$\frac{dN}{dt} = rN\boxed{\left(1-\frac{N}{K}\right)} - \alpha NP$$

Prey density dependence

Predator

$$\frac{dP}{dt} = \beta NP - qP$$

What is the effect of incorporating prey *K*?



A stable equilibrium population size is always reached!

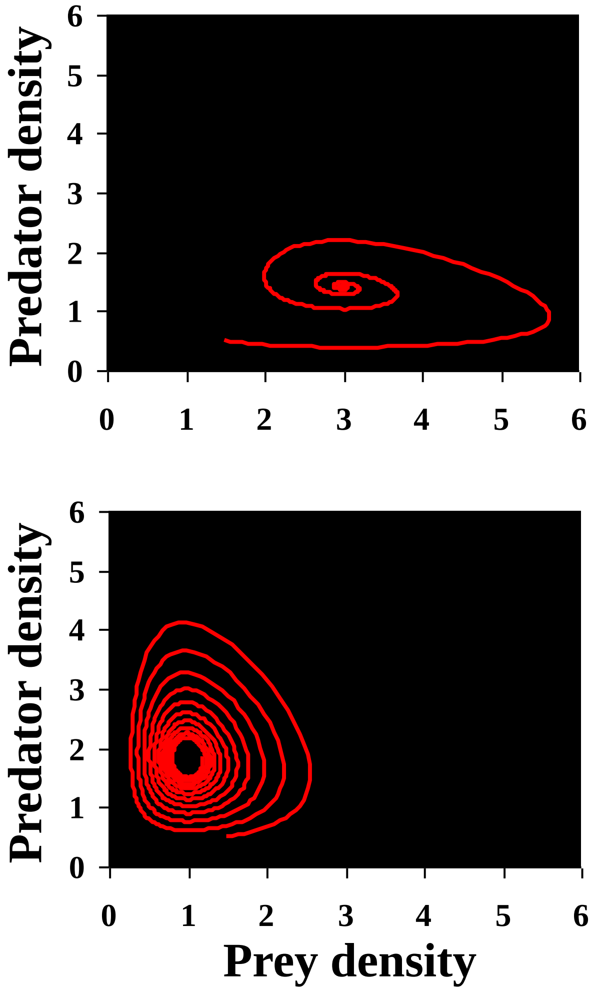
Results of adding prey density dependence

- Population cycles are no longer neutrally stable

- Populations always evolve to a single stable equilibrium

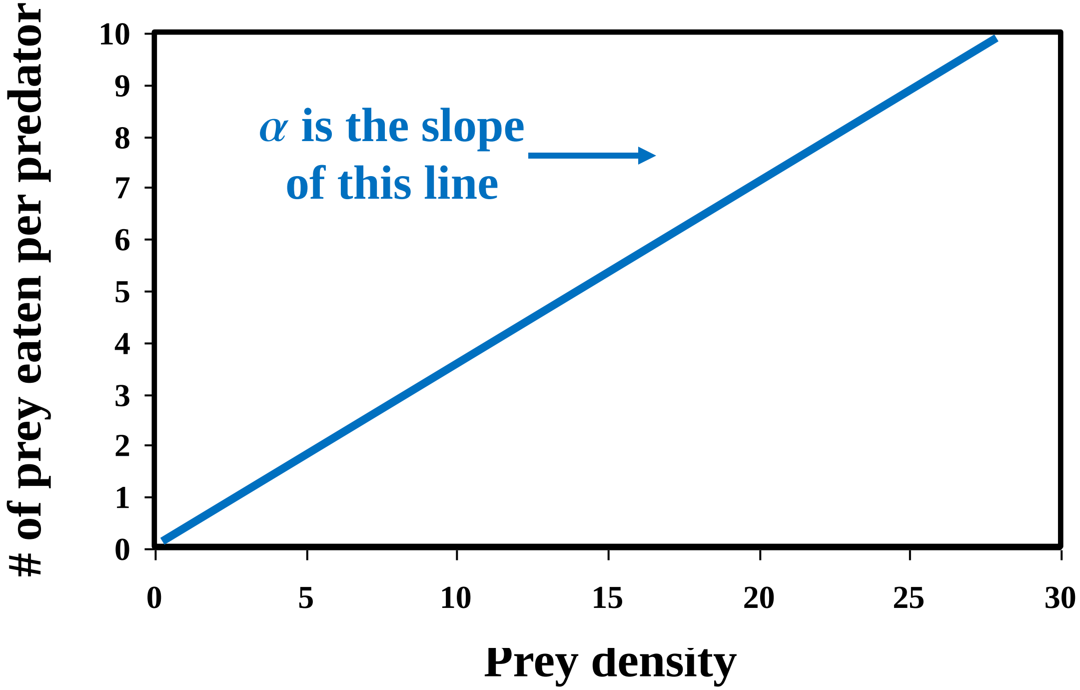
- This equilibrium is characterized by a prey population density well below carrying capacity

- Suggests that predators could be effective at regulating prey density



Adding limits to predator consumption

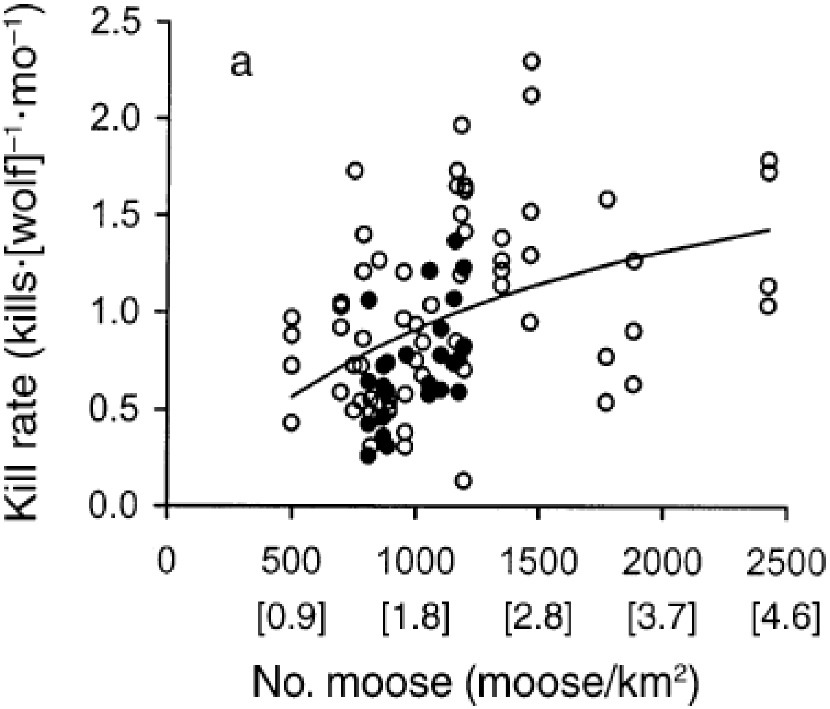
The original Lotka-Volterra model assumes a ‘Type I Functional Response’



This assumes each predator can potentially consume an infinite # of prey!

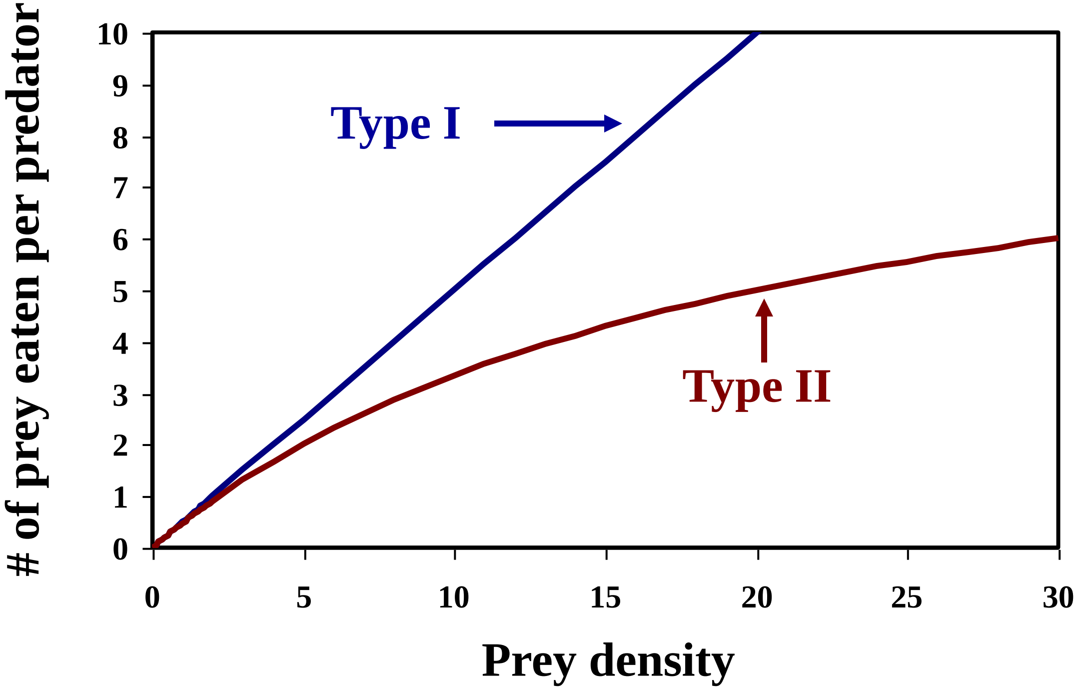
Wolves and Moose on Isle Royal

Vucetich et al. (2002)



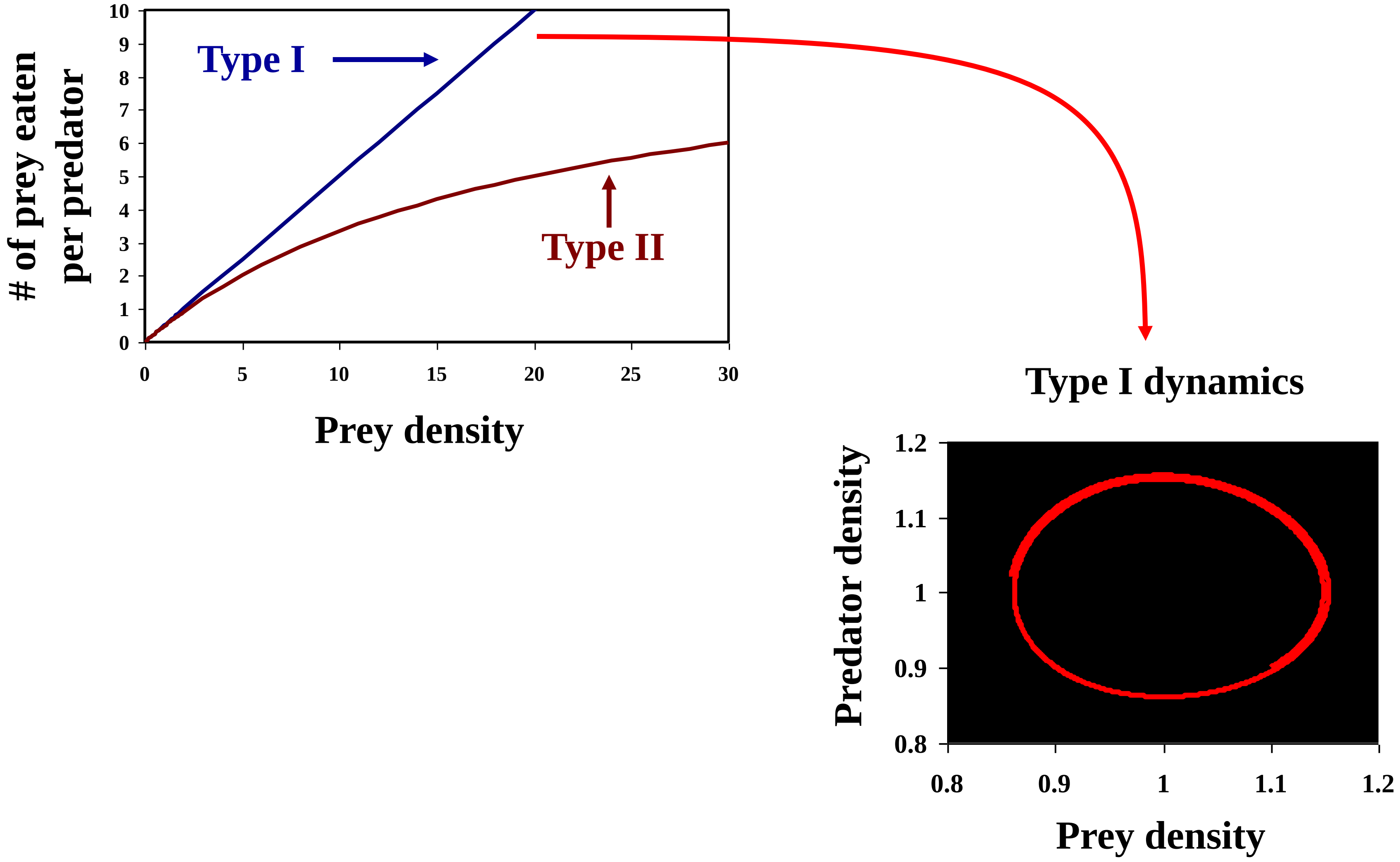
Wolf predation rate does not increase linearly with moose population size

Suggests a Type II Functional Response

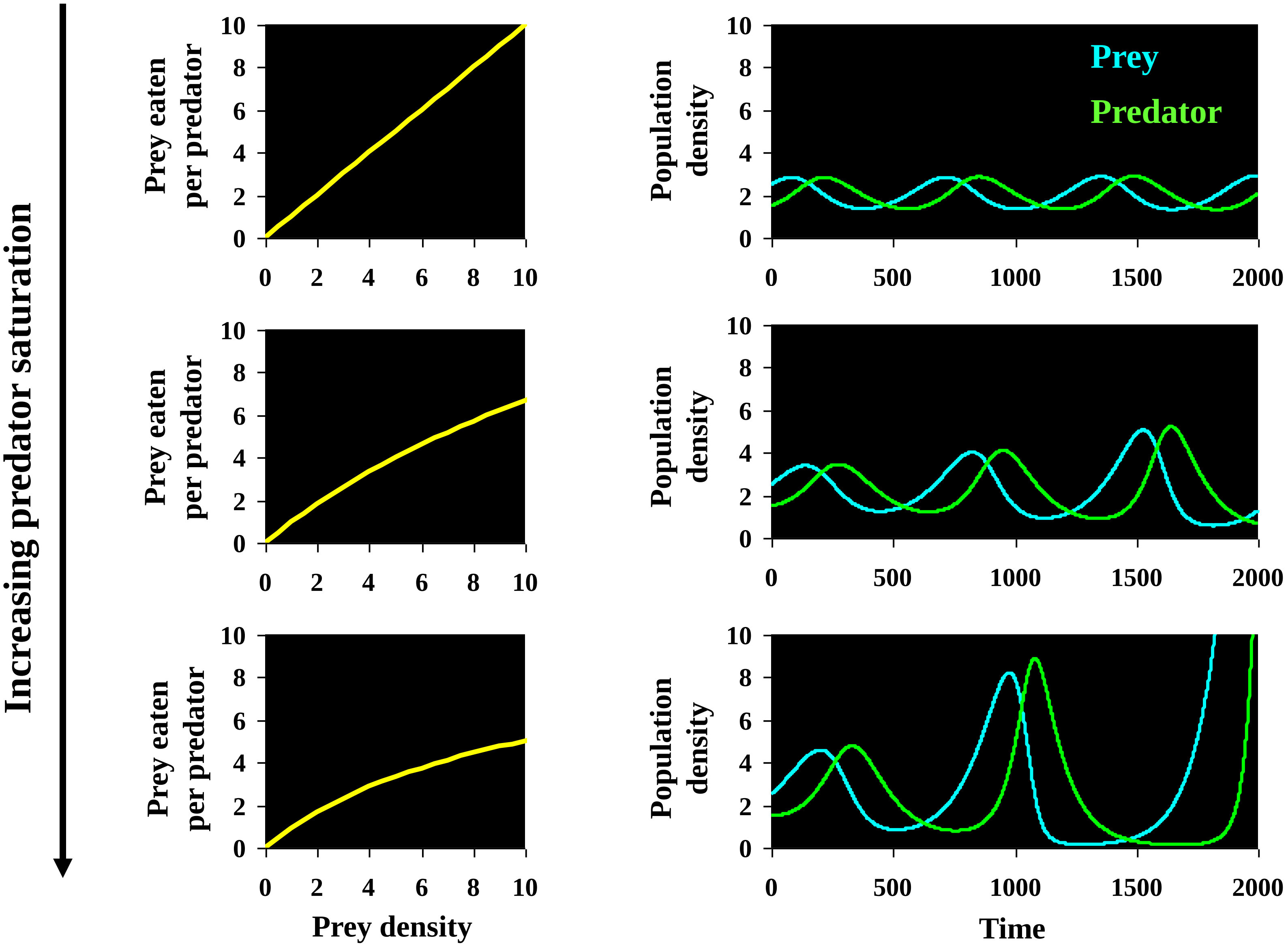


The Type II Functional Response assumes that predators get full!

Dynamics with non-linear functional responses



Type II Dynamics



Impacts of saturating functional response

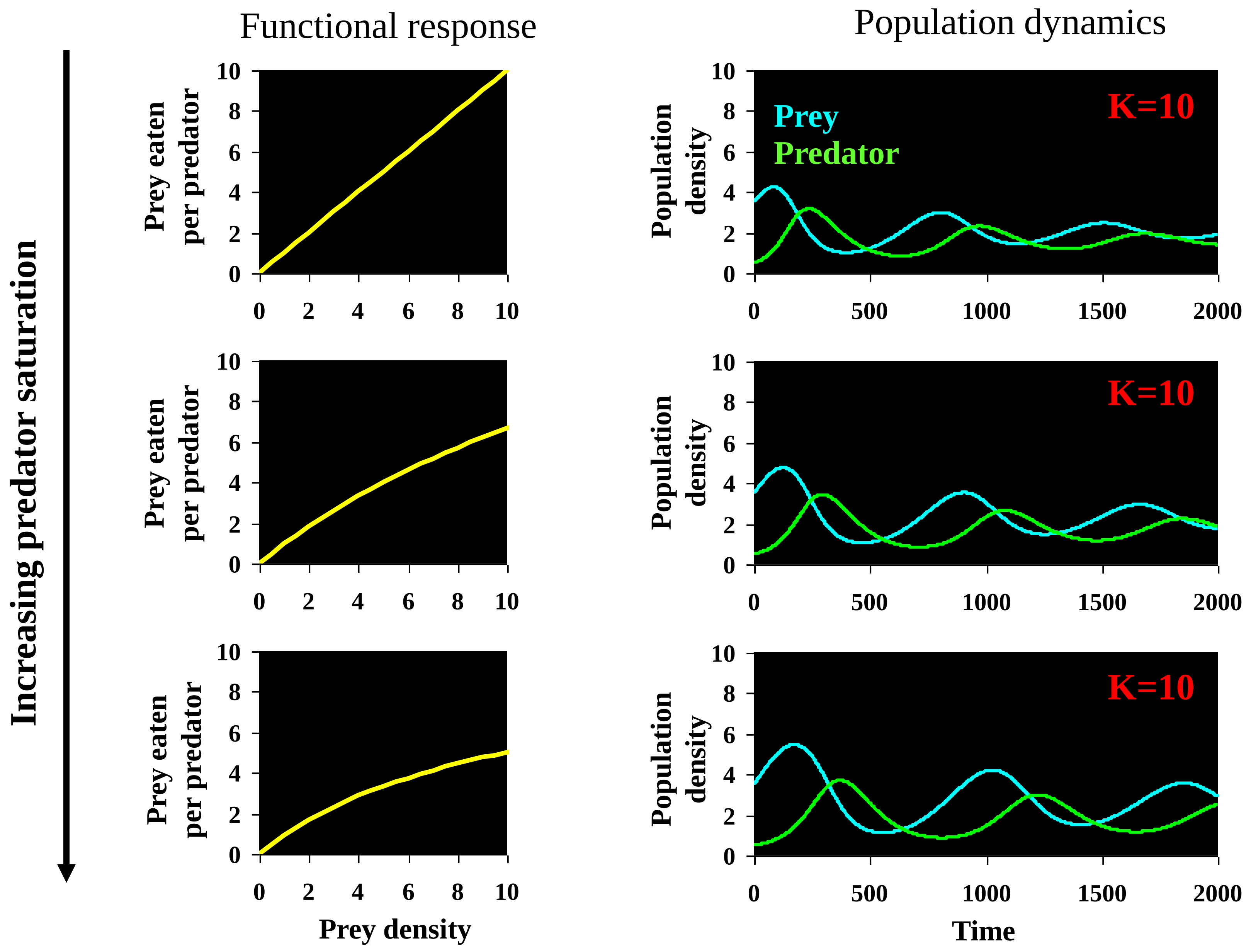
- **Decreases the predators ability to effectively control the prey population**

- **Leads to periodic 'outbreaks' in prey population density**

- **Prey outbreaks lead to predator outbreaks**

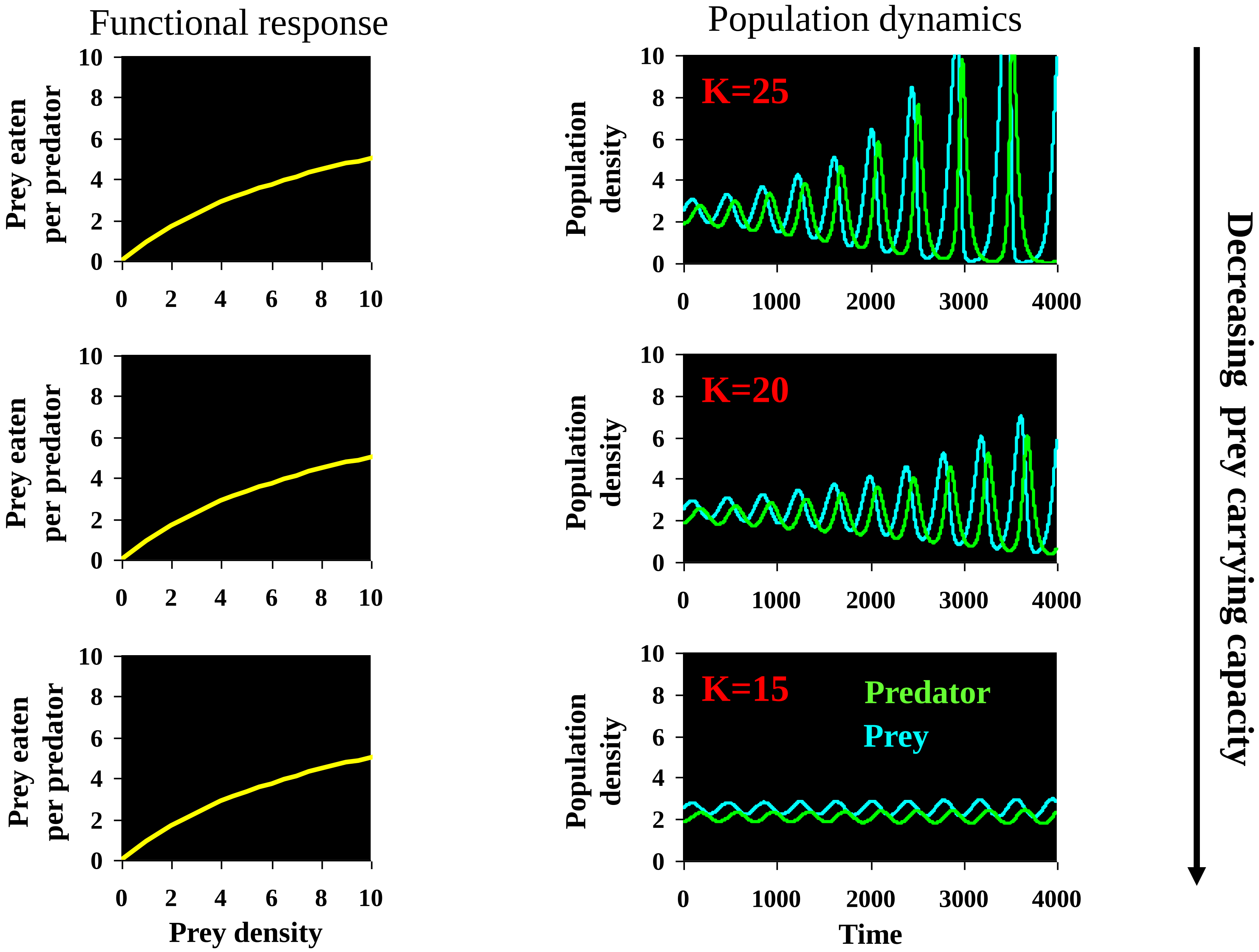
- **The result can be repeated population outbreaks and crashes, ultimately leading to the extinction of both species**

Combining prey *K* with the Type II functional response


Functional response

Population dynamics

Combining prey *K* with the Type II functional response



Summarizing the interaction between prey *K* and saturating predator functional response

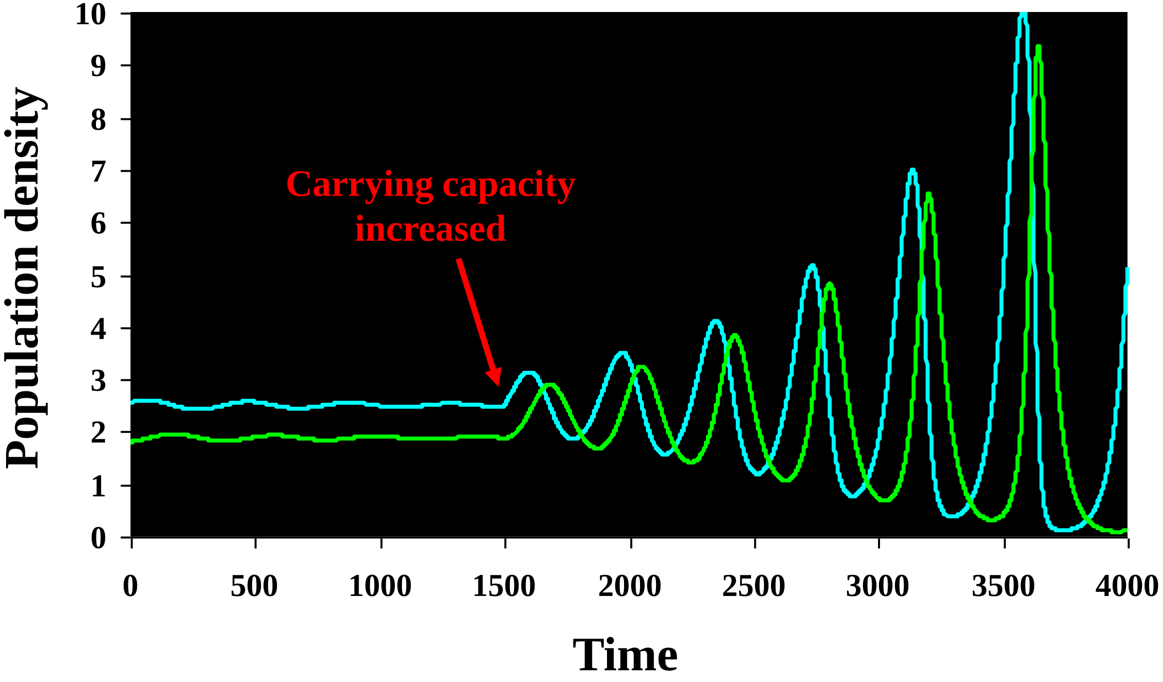
- **Rapidly saturating predator functional responses destabilize population densities**

- **Prey density dependence stabilizes population densities**

- **Whether predator-prey interactions are stable depends on the relative strengths of:**

  - **Prey density dependence**
  - **Predator saturating response**

The “paradox of enrichment” results from the interaction of prey *K* and a saturating predator functional response



Carrying capacity increased

Increasing the carrying capacity of the prey, say through winter feeding, actually destabilizes the system!

Summarizing direct impacts of predators

- **Predators can control prey population densities**

- **Population dynamics are stabilized by strong prey density dependence**

- **Population dynamics are destabilized by saturating functional responses**

Practice problem

Site	Wolves Present	Coyotes/km^2
Lamar River	0	0.499
Lamar River	0	0.636
Lamar River	0	0.694
Lamar River	0	0.726
Antelope Flats	0	0.345
Antelope Flats	0	0.479
Antelope Flats	0	0.394
Lamar River	1	0.477
Lamar River	1	0.332
Lamar River	1	0.477
Lamar River	1	0.270
Elk Ranch	1	0.279
Elk Ranch	1	0.308
Elk Ranch	1	0.215
Gros Ventre	1	0.312
Gros Ventre	1	0.247
Northern Madison	1	0.194

Does this data support the hypothesis of ecological release in Coyotes?

Mean in absence of Wolves: 0.539
Mean in presence of Wolves: 0.311

Sample variance in absence of Wolves: 0.02204
Sample variance in presence of Wolves: 0.00947

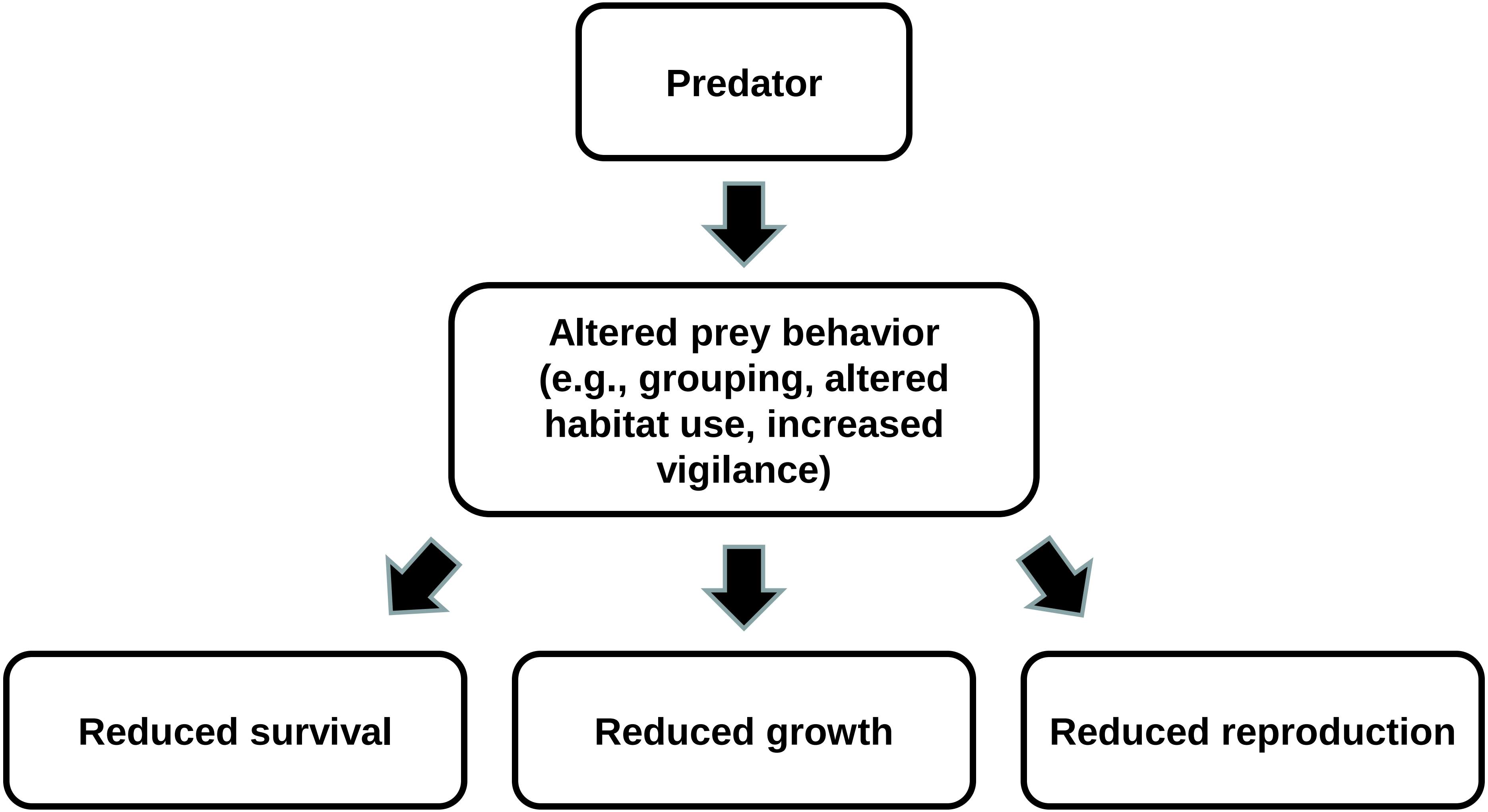
$t = 3.8402$

$t_{.025,15} = 2.131$

Because the value of our test statistic, 3.8402, exceeds the critical value from the table, 2.131, we can reject the null hypothesis that coyote density is equal in the presence and absence of wolves.

This supports ecological release in coyotes since it appears the density of coyotes increases in the absence of wolves

Understanding indirect impacts of predation



Predator

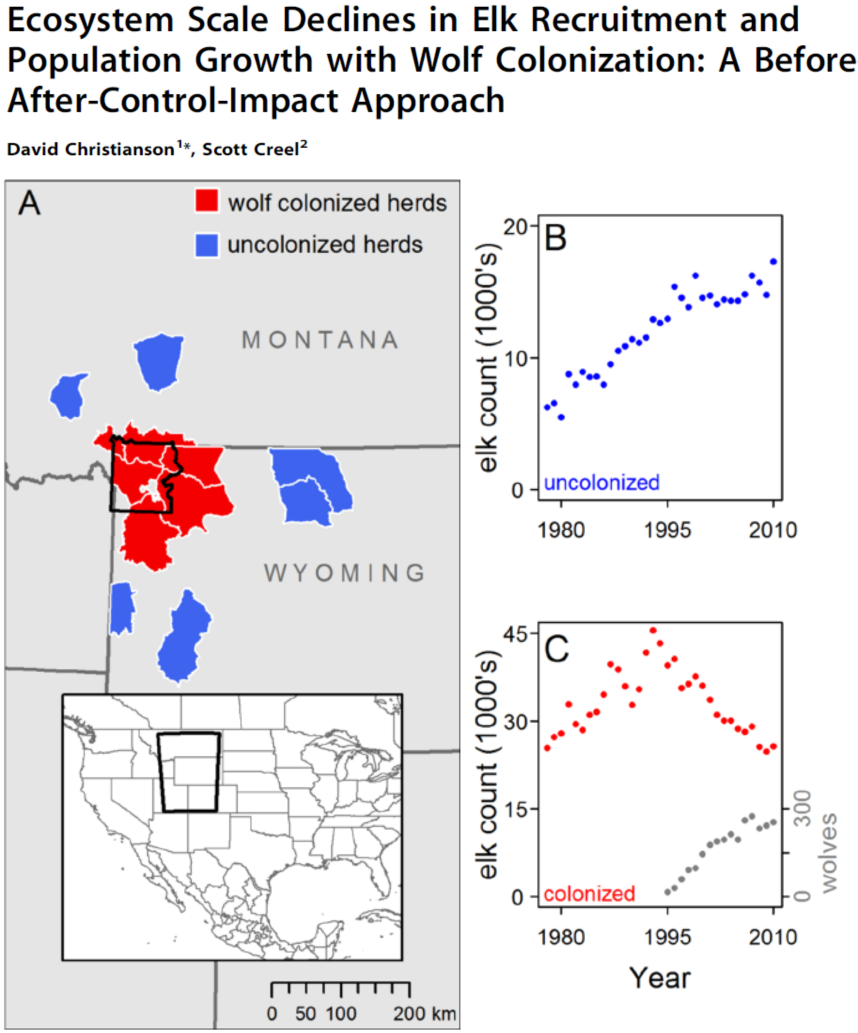
Altered prey behavior (e.g., grouping, altered habitat use, increased vigilance)

Reduced survival

Reduced growth

Reduced reproduction

Indirect impacts of wolf predation



Ecosystem Scale Declines in Elk Recruitment and Population Growth with Wolf Colonization: A Before-After-Control-Impact Approach

David Christianson[1]*, Scott Creel[2]

- Since wolf reintroduction elk populations have declined

- This is strange because:

    1. Wolf predation is largely compensatory due to focus on individuals with low reproductive value

    2. Even if wolf predation were perfectly additive, it can explain at most 52% of the decline in elk populations

Indirect impacts of wolf predation

Ecosystem Scale Declines in Elk Recruitment and Population Growth with Wolf Colonization: A Before-After-Control-Impact Approach

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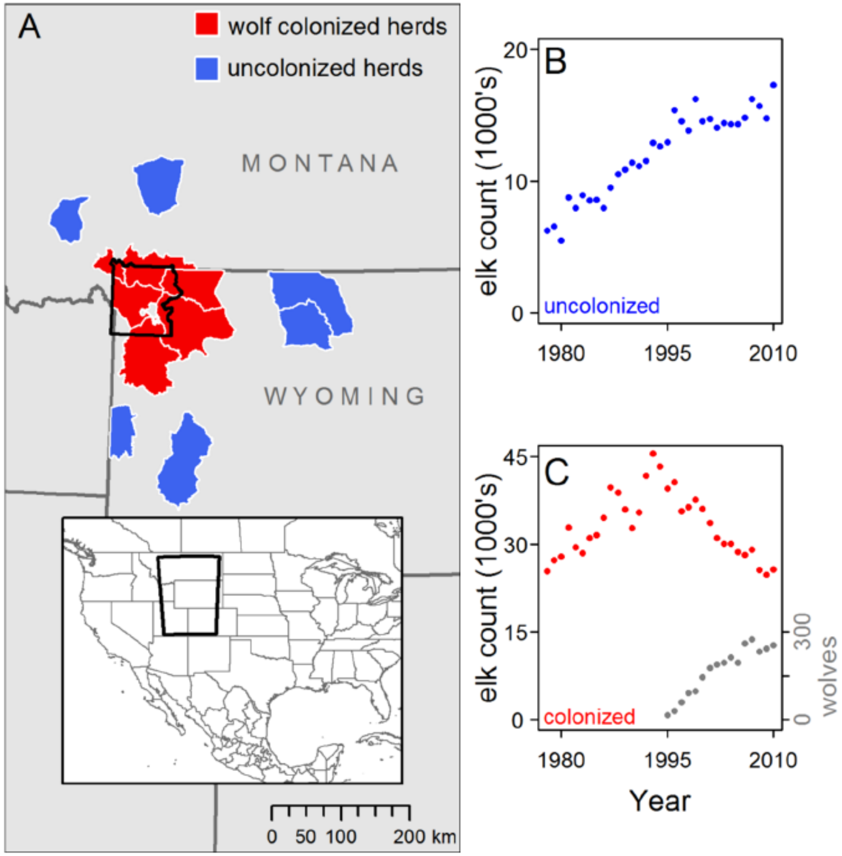
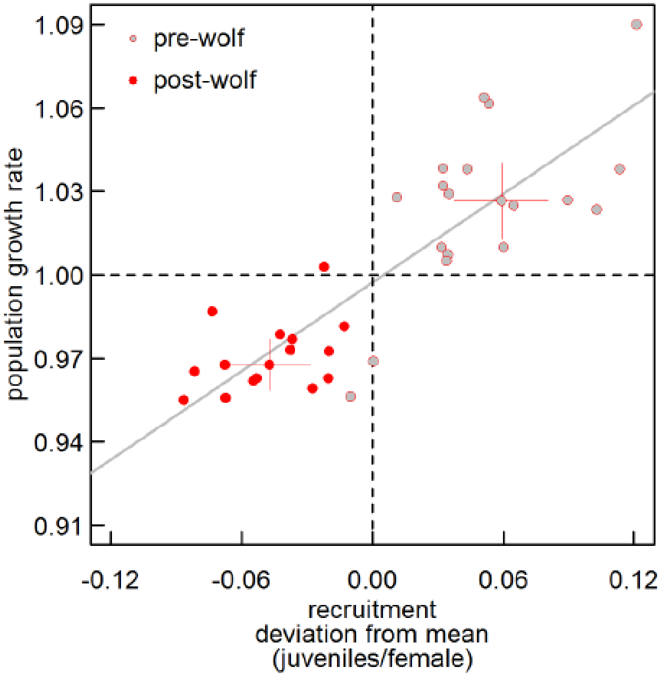
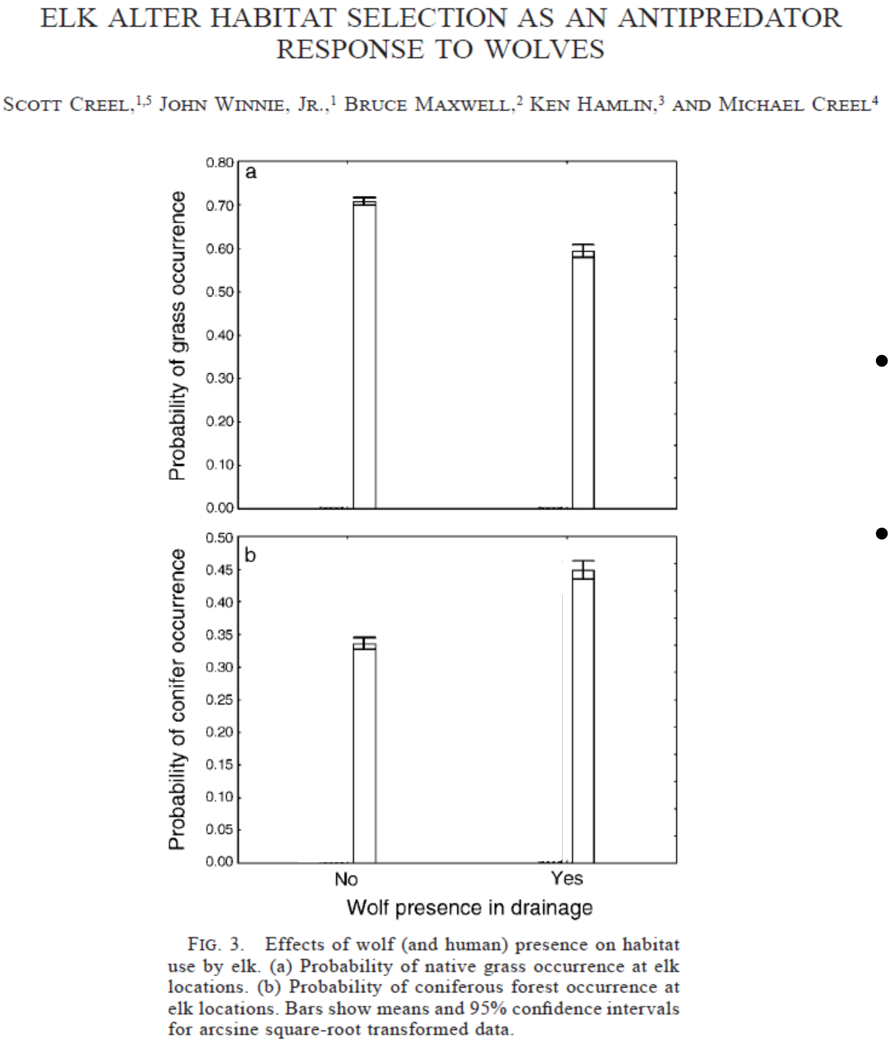


It appears that wolves reduce elk fertility



Why might this be the case?

Indirect impacts of wolf predation



ELK ALTER HABITAT SELECTION AS AN ANTIPREDATOR RESPONSE TO WOLVES

Scott Creel,[1,5] John Winnie, Jr.,[1] Bruce Maxwell,[2] Ken Hamlin,[3] and Michael Creel[4]

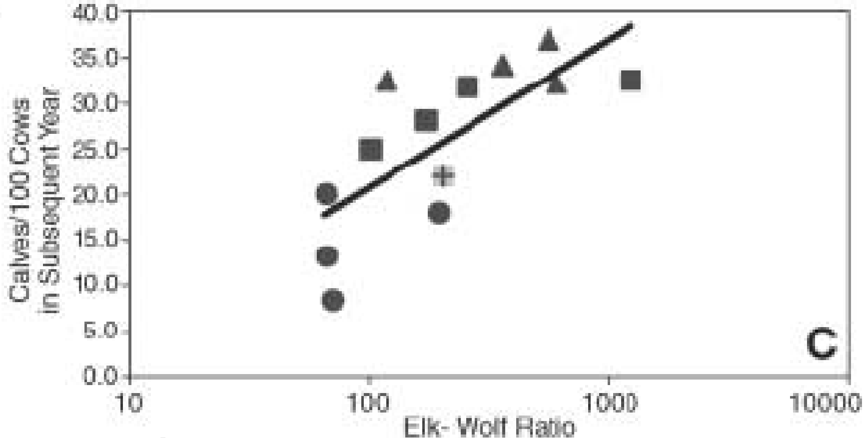
Fig. 3. Effects of wolf (and human) presence on habitat use by elk. (a) Probability of native grass occurrence at elk locations. (b) Probability of coniferous forest occurrence at elk locations. Bars show means and 95% confidence intervals for arcsine square-root transformed data.

- **Studied elk habitat selection in the presence and absence of wolves**
- **When wolves are present elk prefer coniferous forest to grass**

Indirect impacts of wolf predation

Predation Risk Affects Reproductive Physiology and Demography of Elk

Scott Creel,* David Christianson, Stewart Liley, John A. Winnie Jr.



High predation risk

Low predation risk

- Subsequent work revealed this anti-predator behavior is costly

- The greater the risk of wolf predation, the lower rates of elk reproduction

Indirect impacts are common

Studied how proximity of lions influenced zebra diet quality in Hwange National Park Zimbabwe

- Just having lions nearby reduced protein consumption

Diet quality in a wild grazer declines under the threat of an ambush predator

Florian Barnier[1], Marion Valeix[2,3], Patrick Duncan[1], Simon Chamaillé-Jammes[4], Philippe Barre[5], Andrew J. Loveridge[2], David W. Macdonald[2] and Hervé Fritz[3]

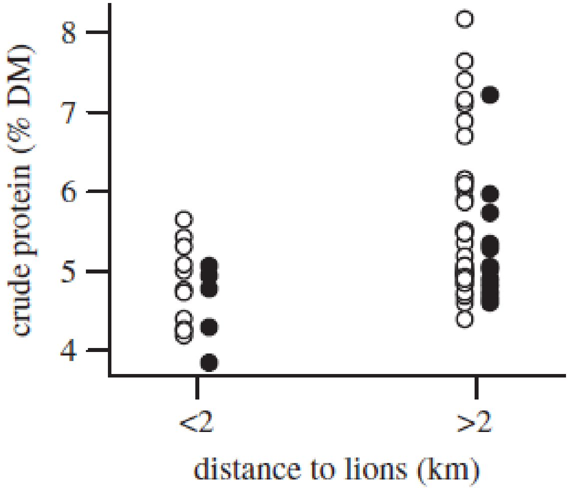


Figure 1. Effects of the distance to lions in the previous nights (see Methods) on the crude protein content of the faeces (a good index of diet quality) of plains zebras in Hwange National Park, Zimbabwe. Empty and filled circles represent females and males, respectively. DM, dry matter.

Summary of Predation

- Predators can regulate prey population densities

- This may occur through direct or indirect effects