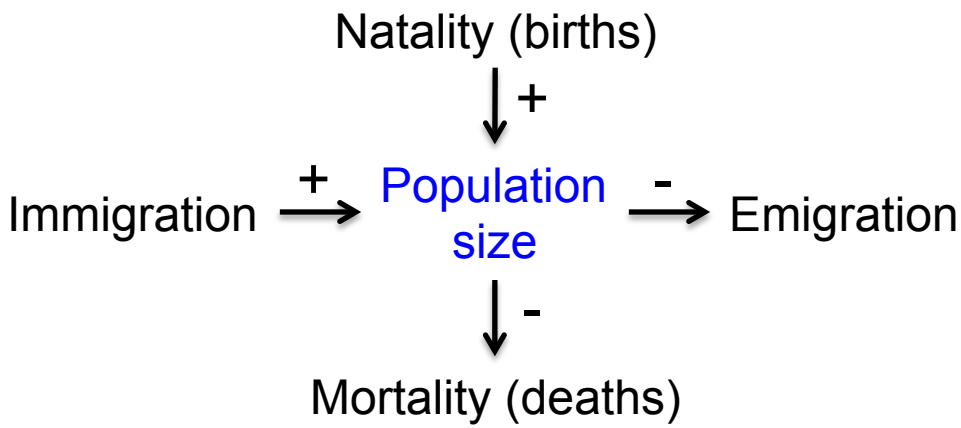
Population Dynamics

- Lecture outline/goals:
  - Population processes: determinants of change
  - Exponential growth
  - Logistic growth
  - Density independence (D.I.)
  - Density dependence (D.D.)
  - Population cycles
  - D.I. – D.D. integration

Population dynamics = study of births, deaths and the movement of organisms

- Critical to:
  - Prediction (spatial and temporal)
  - Management (biological/silvicultural control)
  - Characterization of populations

Population processes: determinants of population change



Population size (N) = Births (B) - Deaths (D) + Immigration (I) - Emigration (E)

$$N_{t+1} = N_t + (B - D + I - E)$$

Population processes: determinants of population change

Change = rate (e.g. deaths per number of individuals)

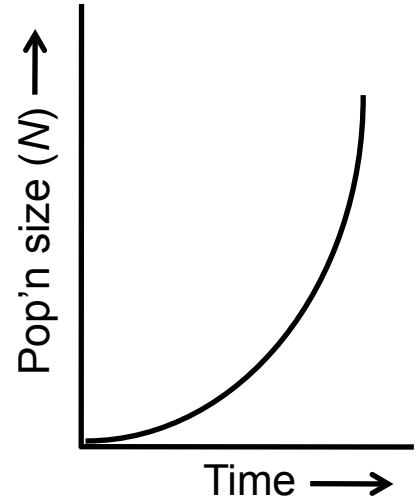
Growth rate (r) = Birth rate (b) - Death rate (d) + Immigration rate (i) - Emigration rate (e)*

$$r = (b - d + i - e)$$

*note: lower case denotes "rate"

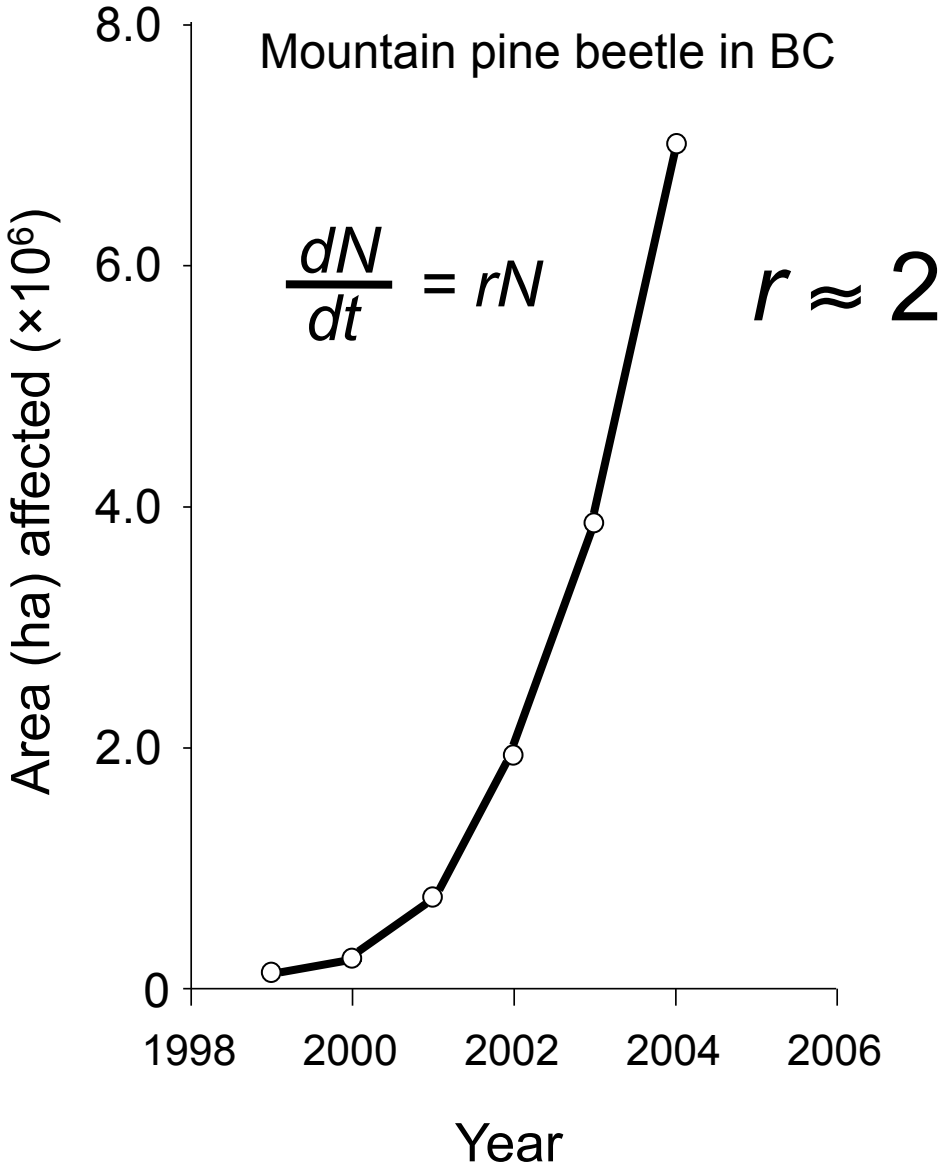
Example: Exponential Growth

$$\frac{dN}{dt} = rN$$



- Populations increase by a constant factor per unit time
- Rare, unsustainable in natural populations

Exponential increase by forest insects?



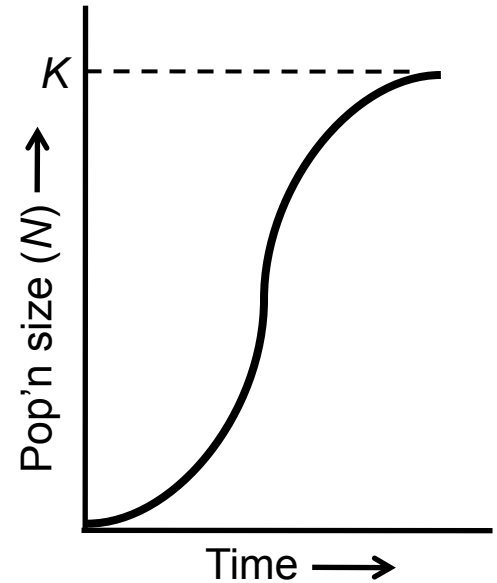
- Occasionally during population eruptions

Example: Logistic Growth

Pop'ns cannot grow at an exponential rate indefinitely due to food/space limitations, or the action of natural enemies

$$\frac{dN}{dt} = rN\frac{K - N}{K}$$

Also known as the Verhulst eq'n



- *K* is carrying capacity; the threshold at which population growth rate (*r*) is zero, negative above (i.e. the maximum sustainable population)
- As the number of individuals (*N*) in the pop'n increases, *b*, *d*, *i* and *e* change due to resource limitation, predation, parasitism, disease, etc.
- Concept critical in determining harvest levels in fishing, hunting, or mgmt of wildlife populations

Factors affecting forest insect population size

<u>Mortality factors</u>

- Climate and weather
- Food quantity/quality
- Host susceptibility, habitat suitability
- Predation, parasitism, disease
- Intraspecific competition (i.e. within species)
- Interspecific competition (i.e. among species)
- Genetic defects

Relative importance varies among populations.

Functional classification:

- Density independent
- Density dependent

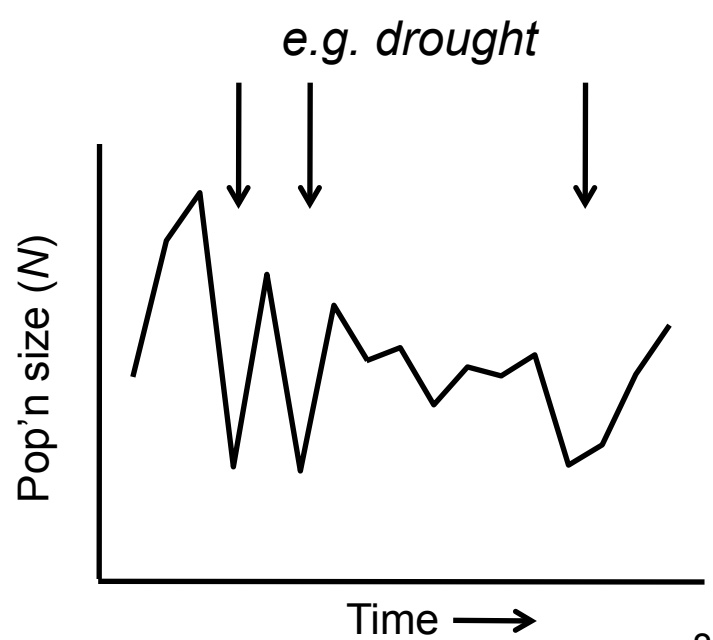
Density-independent factors

Definition: The <u>proportionate</u> effect on population processes (*b, d, i, e*) is **<u>not</u>** related to population density.

Common density-independent factors:

- Site characteristics
  - Elevation, slope, aspect
- Weather
  - Wind, temperature, precipitation
- Biotic factors
  - Browsing, root trampling/compaction

Because the impact of d-i factors on populations is unrelated to population size, the net effect is often dramatic population fluctuations.



Density-independent effects: example 1

- Early frosts in 2002, 2005 and 2007 caused high mortality to a spruce budworm population

Year	Pop'n before frost	Pop'n after frost	Mortality	% Mortality
2002	1000	500	500	50
2003	800	800	0	0
2004	50,000	50,000	0	0
2005	75,000	37,500	37,500	50
2006	100	100	0	0
2007	200	100	100	50

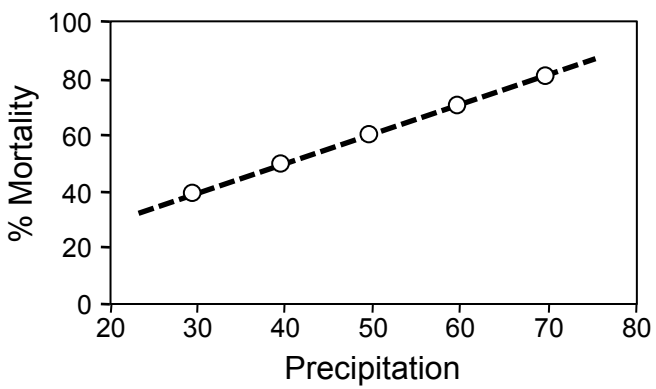
- However, proportionate (%) mortality <u>not</u> related to population density

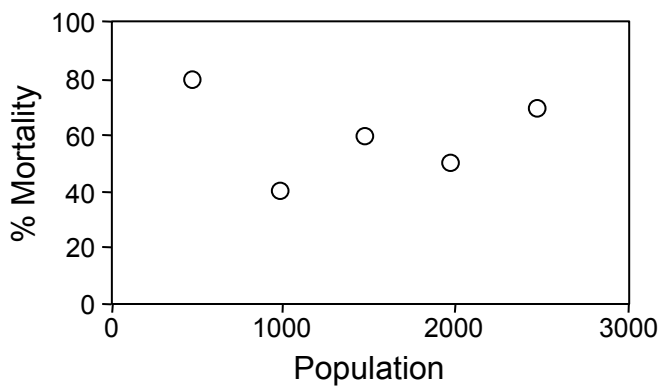
Density-independent effects: example 2

- Mortality and % mortality vary in a population - is it due to precipitation?

Year	Precip. (mm)	Population May 1	Population June 1	Mortality	% Mortality
2003	70	500	100	400	80
2004	40	2,000	1,000	1,000	50
2005	50	1,500	600	900	60
2006	30	1,000	600	400	40
2007	60	2,500	800	1750	70

- Proportionate mortality related to precipitation, *but not* density





Density-dependent factors

Definition: The proportionate effect on population processes (*b, d, i, e*) **is** related to population density.

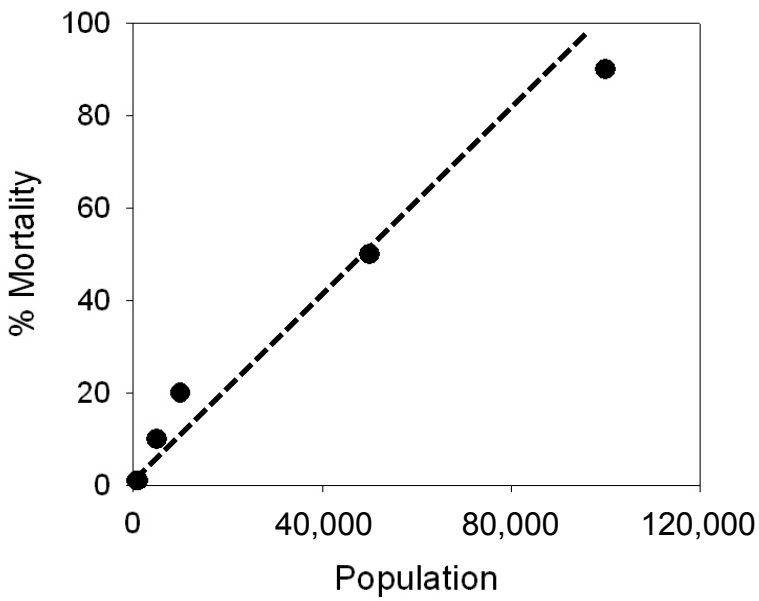
Common density-dependent factors:

- Competition
  - Interference vs. exploitation
  - Effects sometimes non-lethal (i.e. delayed development, reduced fecundity)
- Predation and parasitism
  - Numerical response: predator/parasite population increases when prey/host abundant
  - Functional response: consumption per predator/parasite increases when prey/host are abundant
  - Disease
- Environmental factors?

Density-dependent effects: example 1

- Population levels and mortality due to disease; density dependence?

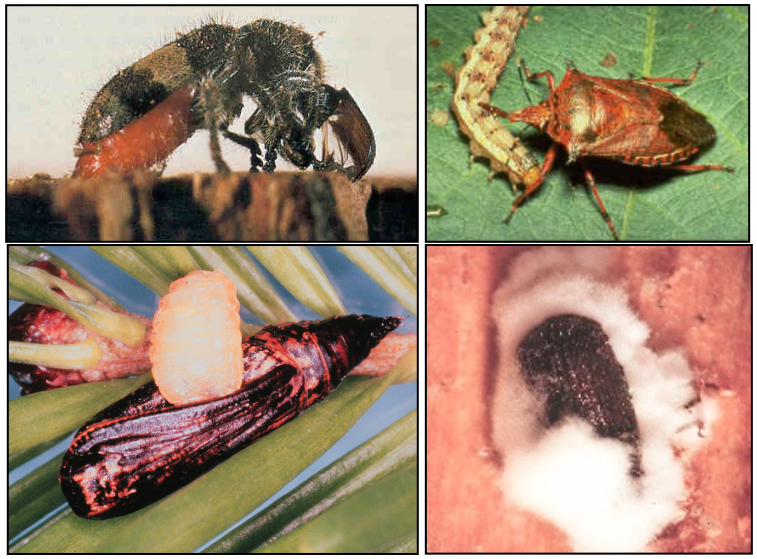
Year	Population	Mortality	% Mortality
2002	1,000	10	1
2003	5,000	500	10
2004	100,000	90,000	90
2005	800	8	1
2006	10,000	2,000	20
2007	50,000	25,000	50

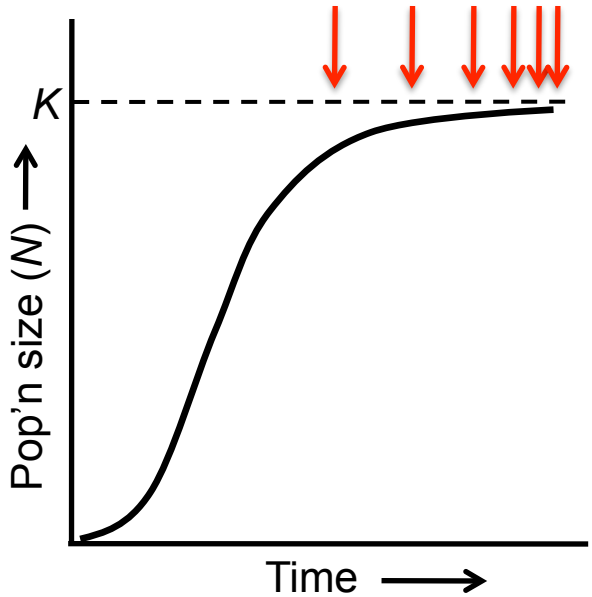


- As the population increases, the % mortality increases, therefore effect of disease is *proportionate* to population density

Density-dependent effects: role in pop'n dynamics

- Population regulation, and therefore persistence, is only possible through action of density-dependent factors
- Density-independent factors often cause large levels of mortality in a pop'n, but without d.d. factors pop'ns will ultimately go to extinction

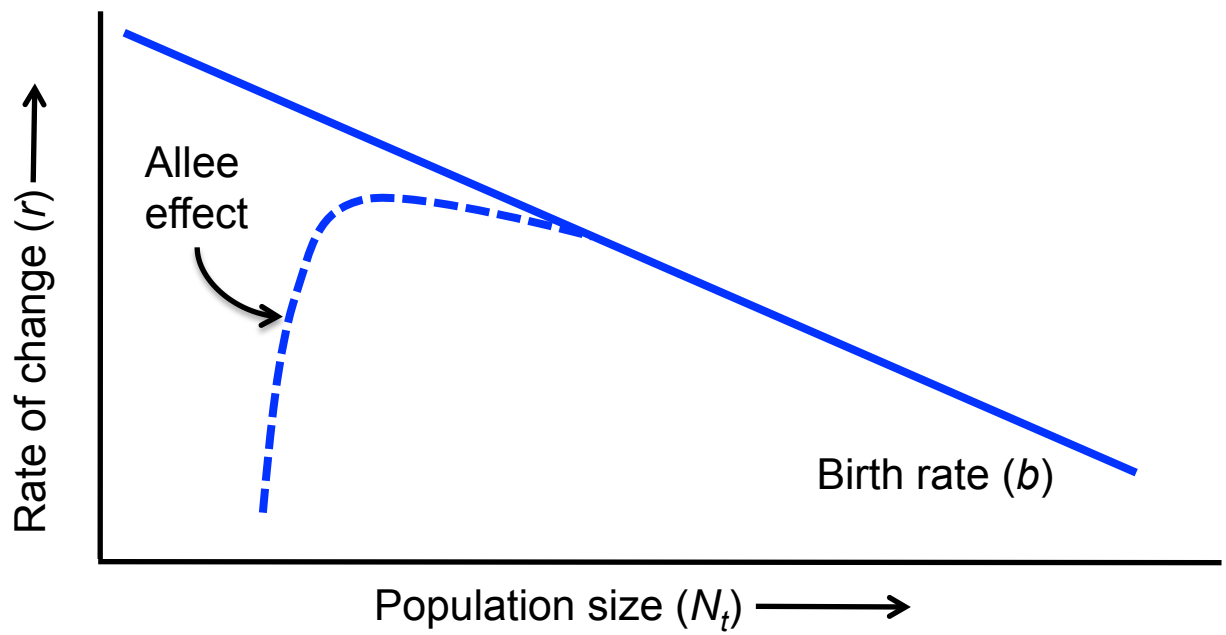




Complex density dependence 1: the curse of small populations

Normally, birth rate (*b*) increases as populations decrease; however, in very small populations, the birth rate may decline due primarily to difficulties in mate location (or inbreeding):
<u>The Allee effect</u>

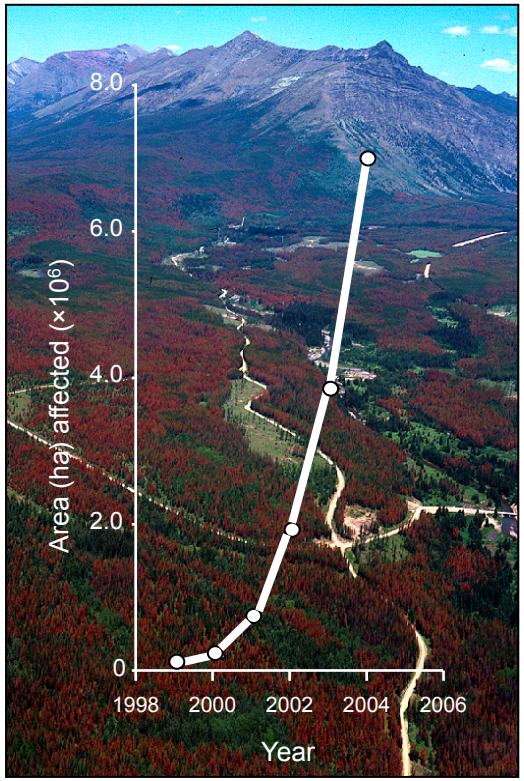
- Implications to endangered species, invasives
  - A threshold population density is required for a species to persist

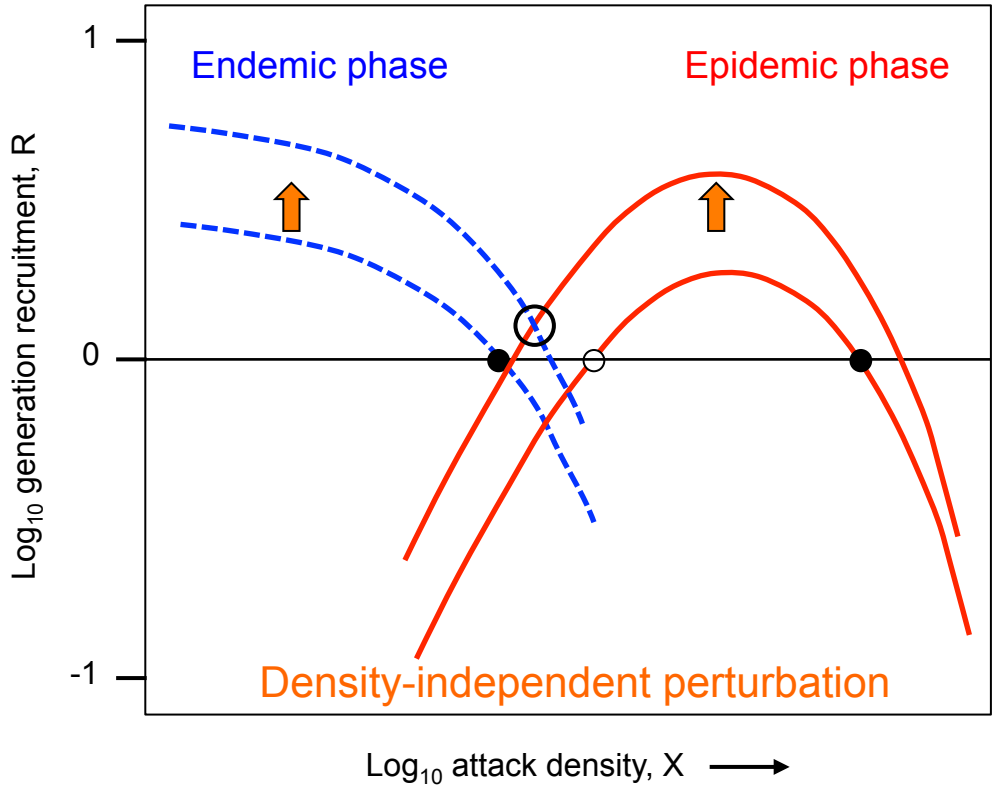


Complex density dependence 2: population eruptions

<u>Eruptive species</u> are characterized by distinct population phases – *endemic* (sub-outbreak) where negative feedbacks predominate, and *epidemic* (outbreak) where positive feedbacks facilitate rapid population growth/spread until negative feedbacks reassert themselves

- The mountain pine beetle as an example
  - Density-independent perturbations shift endemic-epidemic curves so that they intersect above R=0, allowing endemic populations to enter the epidemic phase and achieve positive feedbacks for a short time.

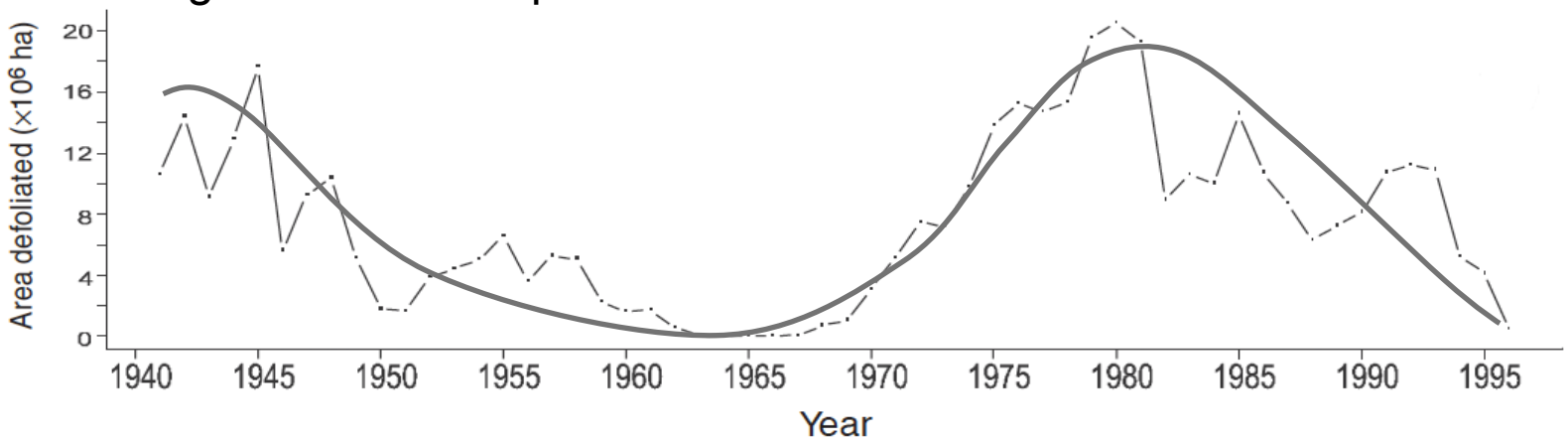




From: Cooke and Carroll 2017

The relative roles of density-dependent and density-independent factors

e.g. The eastern spruce budworm

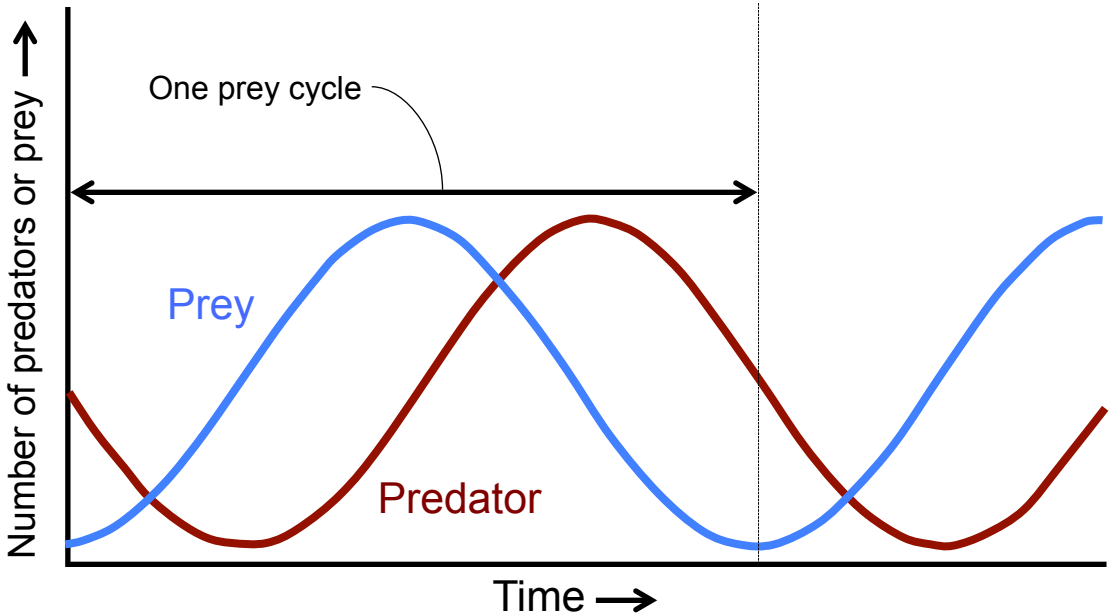


Adapted from Royama 1992

- Considerable population fluctuations – d.i. factors
- Detectable population cycle, 30 – 40 years
- What causes populations to cycle?
- Role of d.d. factors?

Population cycles: predator-prey interactions and lags 1

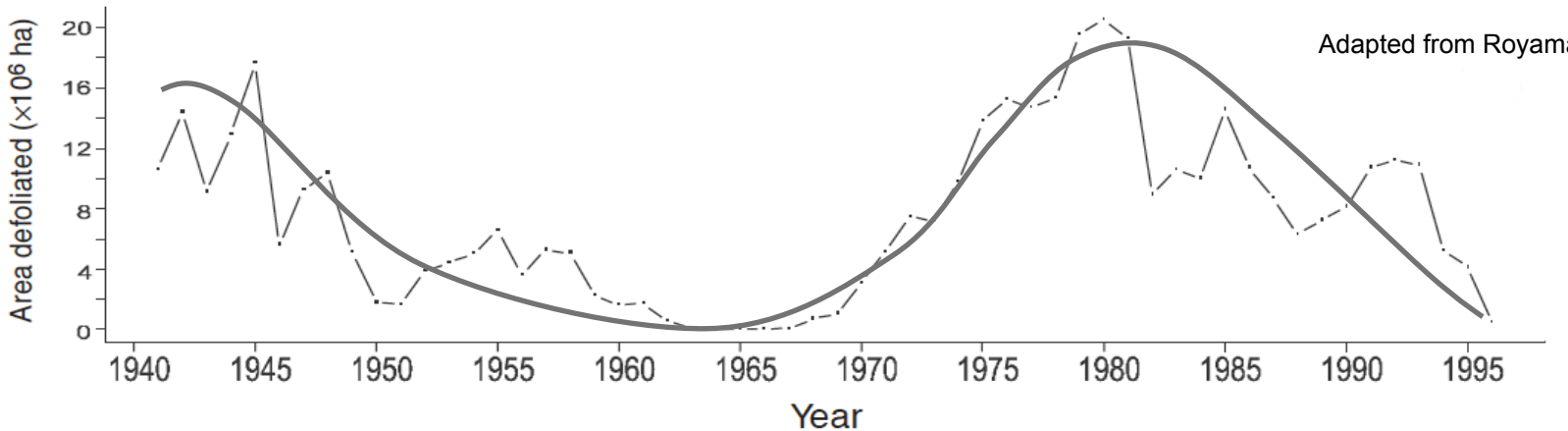
The Lotka-Volterra model (without the math!)



- Insect (i.e. prey) pop'n increases toward *K* (remember logistic growth), *r* declines
- Approaching *K*, d.d. effects of some predators/parasites increase proportionately, but response lags (functional/numerical response)
- Peak predator/parasite impacts manifest after insect pop'ns initiate decline (due to *K*), and insect pop'n falls
- Insect scarcity causes predator/parasite pop'ns to decline, insect pop'ns rebuild

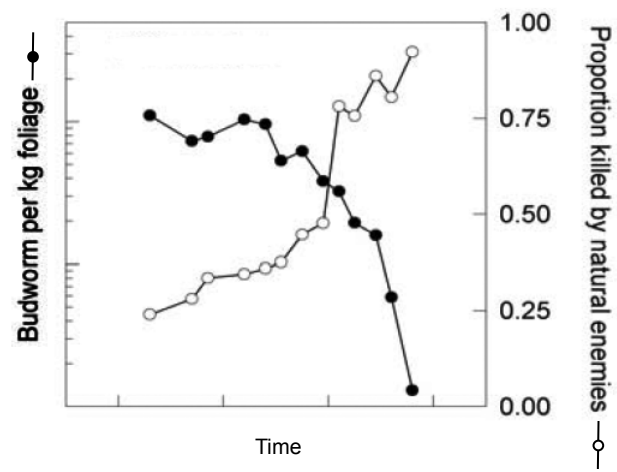
Population cycles: predator-prey interactions and lags 2

Predator/parasite – prey/host interactions and the eastern spruce budworm?



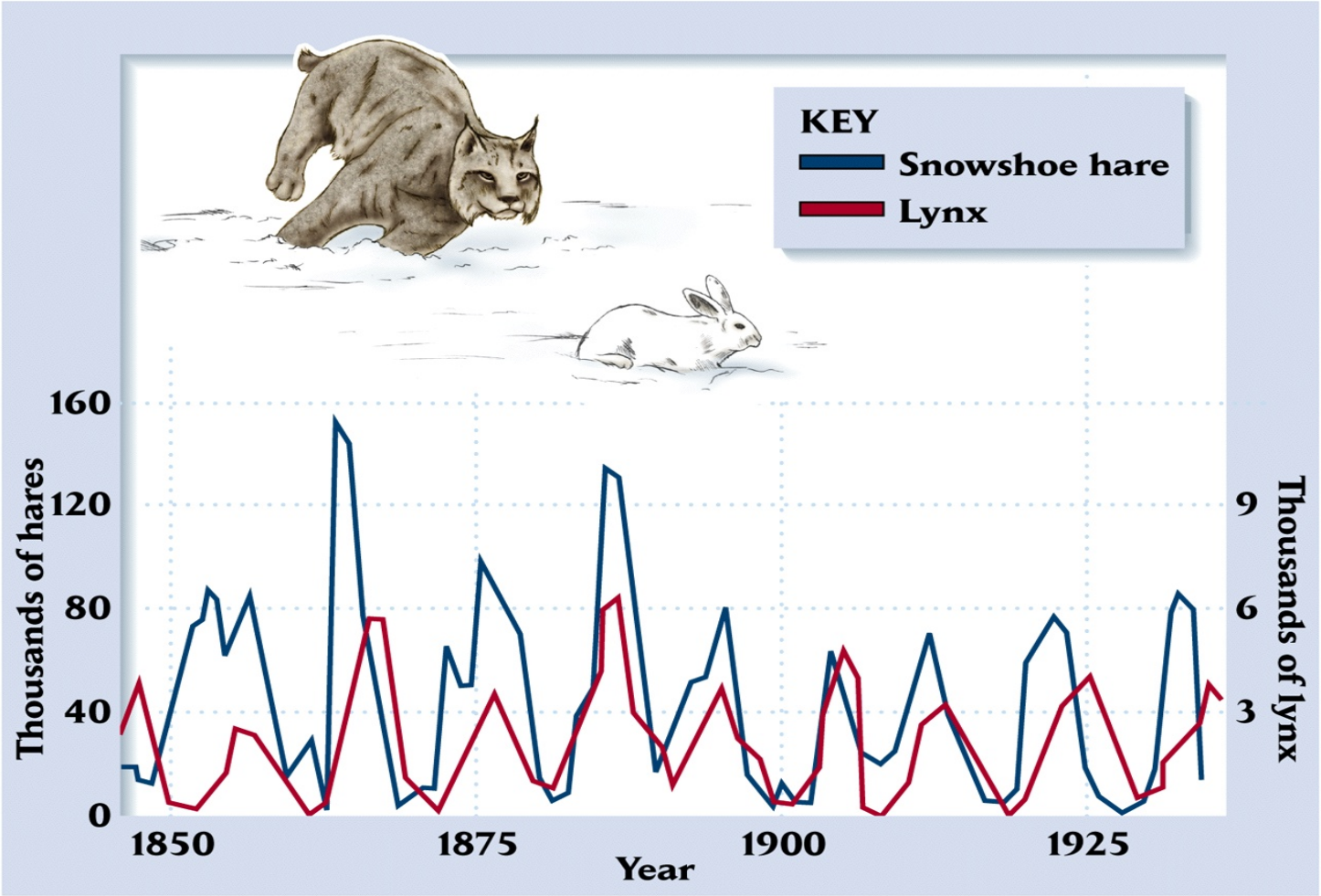
Adapted from Royama 1992

- 35-year cycle caused by lagged d.d. mortality occurring in the late-larval and pupal stages
- Generalist predators, parasitoids and possibly pathogens



Adapted from Régnière and Nealis 2007

Population cycles: predator-prey interactions and lags 3



- Historic data from Hudson Bay Co. trapping records
- Note regular periodicity, and lag by lynx pop'ns

http://theglyptodon.wordpress.com/2011/05/02/the-fur-trades-records/

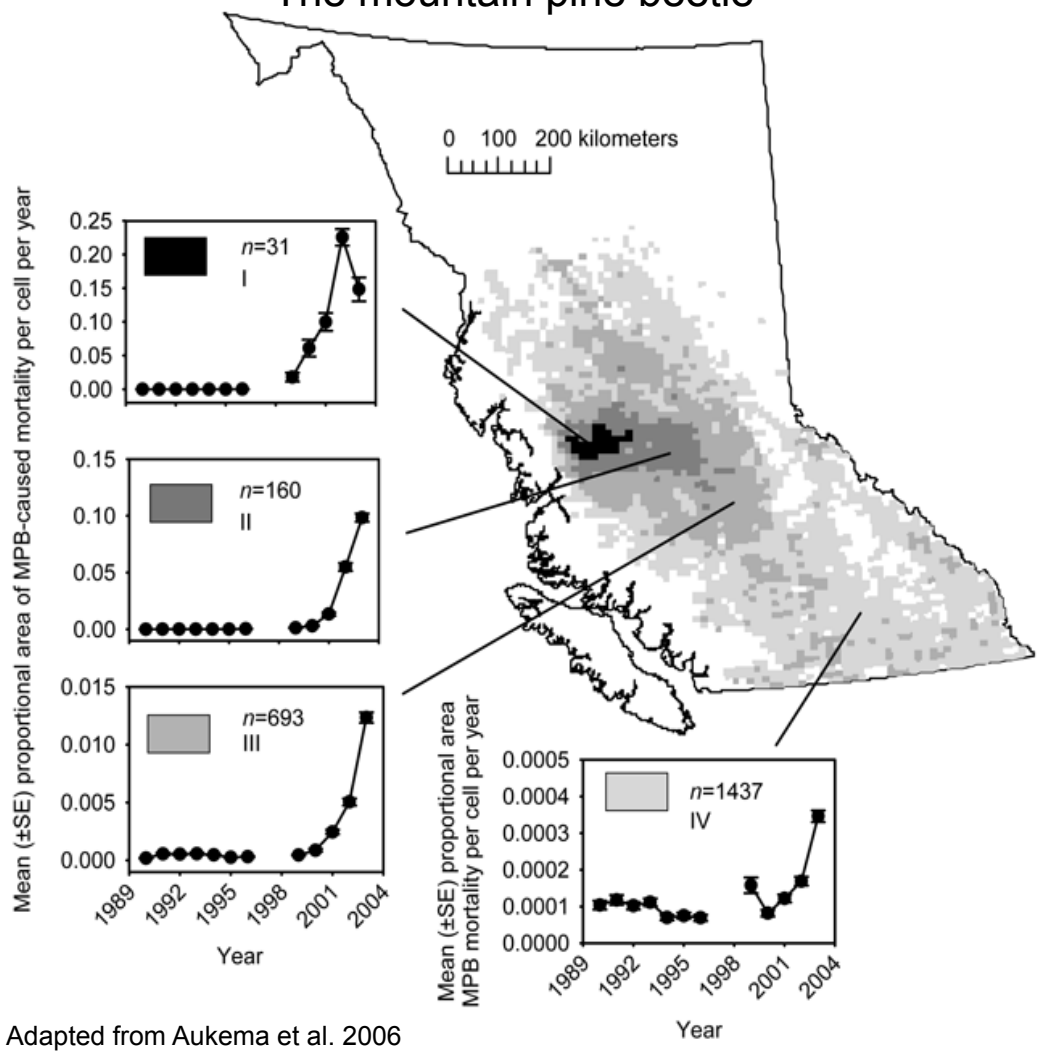
Integrating density-dependent and density-independent factors

Population synchrony via density-independent factors: the Moran effect

Geographically disparate populations with similar population processes will become temporally synchronized when exposed to a density-independent perturbation that is correlated over large areas (e.g. drought, El Niño, etc.)

- MPB populations synchronized at distances >900 km
- Weather (temp., precip.) correlated over similar area
- Tweedsmuir Park **not** the source of the MPB outbreak

The mountain pine beetle



Adapted from Aukema et al. 2006