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

Natality (births)  \[ \rightarrow \]
\[ + \]
Immigration  \[ \rightarrow \]
Population size  \[ \rightarrow \]
Emigration  \[ \rightarrow \]
Mortality (deaths)  \[ \rightarrow \]

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?

Mountain pine beetle in BC

\[ \frac{dN}{dt} = rN \]

\( r \approx 2 \)

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

Mortality factors
- 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 *proportionate* effect on population processes \((b, d, i, e)\) is **not** 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Pop’n before frost</th>
<th>Pop’n after frost</th>
<th>Mortality</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1000</td>
<td>500</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>2003</td>
<td>800</td>
<td>800</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>50,000</td>
<td>50,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>75,000</td>
<td>37,500</td>
<td>37,500</td>
<td>50</td>
</tr>
<tr>
<td>2006</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2007</td>
<td>200</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

- However, proportionate (%) mortality **not** related to population density
Density-independent effects: example 2

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Precip. (mm)</th>
<th>May 1</th>
<th>June 1</th>
<th>Mortality</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>70</td>
<td>500</td>
<td>100</td>
<td>400</td>
<td>80</td>
</tr>
<tr>
<td>2004</td>
<td>40</td>
<td>2,000</td>
<td>1,000</td>
<td>1,000</td>
<td>50</td>
</tr>
<tr>
<td>2005</td>
<td>50</td>
<td>1,500</td>
<td>600</td>
<td>900</td>
<td>60</td>
</tr>
<tr>
<td>2006</td>
<td>30</td>
<td>1,000</td>
<td>600</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>2007</td>
<td>60</td>
<td>2,500</td>
<td>800</td>
<td>1750</td>
<td>70</td>
</tr>
</tbody>
</table>

- 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?

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Mortality</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1,000</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>2003</td>
<td>5,000</td>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>2004</td>
<td>100,000</td>
<td>90,000</td>
<td>90</td>
</tr>
<tr>
<td>2005</td>
<td>800</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>2006</td>
<td>10,000</td>
<td>2,000</td>
<td>20</td>
</tr>
<tr>
<td>2007</td>
<td>50,000</td>
<td>25,000</td>
<td>50</td>
</tr>
</tbody>
</table>

- 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.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):

The Allee effect

- Implications to endangered species, invasives
  - A threshold population density is required for a species to persist
Complex density dependence 2: population eruptions

Eruptive species 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.

![Diagram showing logarithmic recruitment and attack density over years with a graph illustrating endemic and epidemic phases.](image)

From: Cooke and Carroll 2017
The relative roles of density-dependent and density-independent factors

e.g. The eastern spruce budworm

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

Adapted from Royama 1992
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?

- 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
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

Adapted from Aukema et al. 2006