D. POPULATION & COMMUNITY DYNAMICS

Week 10. Population models 1:

- Lecture summary:
  - Distribution and abundance
  - The logistic equation
  - Intraspecific competition
  - Interspecific competition
  - Lotka-Volterra model
2. Distribution and Abundance:

- Primary goal of modern ecology:
- Key processes within natural communities:
  - Competition.
  - Predation (including herbivory and parasitism).
  - Mutualisms.

<table>
<thead>
<tr>
<th>Table 10-1</th>
<th>Fitness effects of ecological relationships between species¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/0</td>
<td>Neutralism: Species interact without affecting each other’s fitness.</td>
</tr>
<tr>
<td>0/+</td>
<td>Commensalism: One species gains with no affect on the other.</td>
</tr>
<tr>
<td>0/--</td>
<td>Amensalism: One species suffers, the other does not.</td>
</tr>
<tr>
<td>--/--</td>
<td>Competition: Two species use the same limiting resource(s).</td>
</tr>
<tr>
<td>--/+</td>
<td>Herbivory, parasitism, predation: One species eats another.</td>
</tr>
<tr>
<td>++/+</td>
<td>Mutualism: Two species benefit.</td>
</tr>
</tbody>
</table>

¹For each of two interacting species, signs show that a relationship increases fitness (+), decreases fitness (−), or has no effect (0).
3. The Logistic Equation:

- Formulated primarily by Alfred Lotka and Vito Volterra:
  - After Thomas Malthus 1798 & Pierre-François Verhulst 1838

- Classical means of describing the dynamics of interactions:
  - Either within a species:
    - via intraspecific competition, or,
  - Between species:
    - via either interspecific competition or a consumer-consumed or exploitative interaction
4. Exponential population growth:

- Described by:
- \( \frac{dN}{dt} = rN \)
  - where:
    - \( N \) = population size
    - \( t \) = time
    - \( r \) = intrinsic rate of natural increase
  - Fig. 6.29 Begon et al. (1996)

Begon, Harper & Townsend (1996)
5. Intraspecific competition and the logistic curve:

- \( \frac{dN}{dt} = rN(K-N)/K \)
  - Sigmoidal population growth after intraspecific competition for limited resources to the carrying capacity \( K \).
  - This can be modified to describe interspecific competition with the addition of a competition coefficient that describes the effect on species \( i \) of species \( j \) and vice versa.
  - As shown in Table 10-1, \( \alpha_{ij} \) and \( \alpha_{ji} \) can vary in magnitude from strongly negative to strongly positive.
6. Interspecific Competition:

- Like intraspecific competition, competition between species can be defined as:

  “an interaction between individuals, brought about by a shared requirement for a resource in limited supply, and leading to a reduction in the survivorship, growth and/or reproduction of at least some of the competing individuals concerned”

Begon, Harper & Townsend (1996)
7. Competition between diatoms:

- For example, Tilman's diatoms (exploitation/scramble) of Fig. 7.3.
- Also bear in mind Connell's "the ghost of competition past"
  - The current product of past evolutionary responses to competition!

Begon, Harper & Townsend (1996)
8. Two basic outcomes of competition:

- **(1) Coexistence:**
  - If two competing species coexist in a stable environment, then they do so as a result of niche differentiation (of their realized niches).
  - Character displacement *(Figs 7.18, 7.19 & 7.20).*

- **(2) Competitive exclusion:**
  - "Competitive exclusion principle" or "Gause's principle"
  - If there is no niche differentiation, then one competing species will eliminate or exclude the other.
  - Thus exclusion occurs when the realized niche of the superior competitor completely fills those parts of the inferior competitor's fundamental niche which the habitat provides.
  - See Fig. 7.4 of exclusion in reed species.
9. The Lotka-Volterra model of interspecific competition:

- \( \frac{dN}{dt} = rN((K-N)/K) \)

  - Logistic equation describes sigmoidal population growth as a result of intraspecific competition:
    - After Volterra (1926) & Lotka (1932)
    - With the inclusion of the competition coefficients \( \alpha \) and \( \beta \) we can represent population size changes for the two competing species as:
      - \( \frac{dN_1}{dt} = r_1N_1((K_1-N_1-\alpha N_2)/K_1) \)
      - \( \frac{dN_2}{dt} = r_2N_2((K_2-N_2-\beta N_1)/K_2) \)
10. Model parameters:

- **Competition coefficients**
  - \( \alpha \) is the effect on species 1 of species 2 (\( \alpha_{12} \)):
    - if \( \alpha < 1 \) interspecific competition has less impact than intraspecific competition.
    - If \( \alpha > 1 \) interspecific competition has more impact.
  - \( \beta \) is the effect on species 2 of species 1 (\( \alpha_{21} \)).
- \( N_1 \) & \( N_2 \) population sizes of spp 1 and 2.
- \( r_1 \) & \( r_2 \) intrinsic rates of natural increase for 1 & 2.
- \( K_1 \) & \( K_2 \) carrying capacities for spp 1 & 2.
11. Lotka-Volterra competition model - zero isoclines:

- Zero population growth isoclines in graphs of $N_2$ plotted against $N_1$ in Figs. 7.6 and 7.8 where $dN/dt = 0$

- When this is true for species 1, then:

\[- r_1N_1(K_1-N_1-\alpha N_2) = 0, \& K_1-N_1-\alpha N_2 = 0\]

  - Therefore $N_1 = K_1-\alpha N_2$
  - When $N_1 = 0$, $N_2 = K_1/\alpha$
    - Result of pure interspecific competition at A in Fig. 7.6a
  - When $N_2 = 0$, $N_1 = K$
    - Result of pure intraspecific competition at B in Fig. 7.6a
12. Four outcomes of the Lotka-Volterra competition model (Fig. 7.8):

• **(1) Species 1 wins** (competitive exclusion):
  – Species 1 is a stronger interspecific competitor:
    • $K_1 > K_2/\beta$ therefore $K_1\beta > K_2$
  – Even though intraspecific competition within species 1 is stronger than the interspecific effect of species 2:
    • $K_1/\alpha > K_2$ therefore $K_1 > K_2\alpha$

• **(2) Species 2 wins** (competitive exclusion):
  – Converse of 1.
13. Four outcomes of the Lotka-Volterra competition model (continued...)

• (3) **Either species 1 or species 2 wins:**
  – Interspecific competition greater in both species than intraspecific competition.
  – Outcome depends on starting densities.

• (4) **Coexistence:**
  – Both species have less competitive effect on the other species than they do on themselves.
  • $K_1 > K_2 \alpha$, and $K_2 > K_1 \beta$ - gives a stable equilibrium.
Figure 7.18: Character displacement in seed-eating ants
Figure 7.19: Character displacement in three-spined sticklebacks

One species

Two species

Ln mean gill raker length (mm)
Figure 7.20: Character displacement in two snail species
Figure 7.4: Asymmetric competition between cattail species
Figure 7.6: $N_1$ and $N_2$ zero isoclines of the Lotka-Volterra competition equations
Figure 7.8: Outcomes of competition generated by Lotka-Volterra equations