6.1 Introduction: Diversity of Life History Strategies

• Variation in breeding strategies, fecundity, and probability of survival at different stages throughout life cycle lead to quite variable life history strategies

• Body size and reproductive potential

• Relationship between: \( r, R_0, G \)
Life History Variation

Groove billed – Ani
*Crotophaga sulcirostris*

*Jacana spinosa*

Brown pelican

Oropendolas
*Zarhynchus wagleri*

*Fregata magnificens*
6.1 Introduction: Diversity of Life History Strategies

- Relationship between Body Size and Reproductive Potential?

- Lotka 1925
- Cole 1954; Smith 1954 independently
- Relationship between: \( r, R_0, G \)

- \( \ln R_0 = rG \) \hspace{1cm} \text{eq 6.2} \\

- Thus if know 2 variables, third can be calculated for a popln with SAD.
6.1 Introduction: Diversity of Life History Strategies

• However there is not necessarily a relationship between $R_0$, $r$ & $G$

We now know from 1954 to 2011 that:

1) $r$ is inversely related to $G$
2) $G$ is directly related to body mass
3) $r$ is inversely related to body mass
4) life span and growth rate are negatively associated
5) high individual growth rates are positively correlated with $r$
6) growth rate is inversely related to body mass

See Fig. 6.1 and 6.2

- Small size associated with high $r$ values and shorter $G$
- Large size associated with low $r$ values and longer $G$
6.2 Power Laws or Scaling Laws

Relationship between body mass (size) and metabolic, physiologic and ecological functions

\[ Y = Y_0 M^b \quad \text{eq. 6.3a} \]

Where \( Y \) = physiological rate or some variable dependent on mass

\( Y_0 \) = normalization constant

\( M^b \) = mass in relation to allometric function

\( b \) = allometric function

\[ \log Y = \log Y_0 + b \log M \quad \text{eq 6.3b} \]

\( \checkmark \) expect linear relationship between mass and dependent variable with the slope equal to \( b \).
6.2 Power Laws or Scaling Laws

Relationship between body mass (size) and metabolic, physiologic and ecological function

Heart rate vs. body mass (\(-.25\)), life span vs. body mass (\.25\) and length of aortas and tree trunks vs. mass (.25) **ALL equal \(\sim 0.25\).**

Known as allometric relationships, because scaling factor, \(b\), does NOT = 1.0

Kleiber (1932) demonstrated that relationship between body mass and metabolic rate was \(b=3/4\) and applies to most organisms with confirming work in 2000s in plant systems!!

See Fig. 6.3 Allometric scaling
6.2 Power Laws or Scaling Laws

The scaling laws based on 3 fundamental principles for all plant and animals:

1) The system must fill the volume of the organisms to distribute essential nutrients to all of its cells

2) Terminal branches of networks should be ~ same size regardless of body size

3) Supply to networks should be efficient such that fluids move through system with minimum loss of energy

Self thinning law in plants now shown to also follow b=3/4, such that 

$-\frac{4}{3}$ represents independent variable = density and dependent variable = mass

Log plant mass

Log plant density
6.3 The metabolic theory of ecology

- Based on \( \frac{1}{4} \) power law (Brown et al. 2004) relationship between basic metabolic process to body mass and body temperature.
- Metabolism determines rate of acquisition of energy and nutrients by organism.
- Again using Kleiber (1932) where metabolic rate scales to \( b = \frac{3}{4} \).
- Consider WHOLE organism metabolic rate \( (I) \) and \( I_0 \) normalization constant with \( M = \text{mass} \):
  \[ I = I_0 M^{3/4} \]
  eq 6.5

Next Brown incorporated the effect of temperature on biological processes...
6.3 The metabolic theory of ecology - temperature

Whole organism metabolic rate ($I$) and $I_0$ normalization constant, $M = $ mass:

$$I = I_0 M^{3/4}$$

Eq 6.5

Where $E = $ activation energy

$k = $ Boltzmann constant – describes how temp affects rxn rate by changing proportion of molecules with sufficient kinetic energy

$T = $ absolute temp in degrees Kelvin

$$e^{-E/kT}$$

Eq 6.6

- $I = I_0 M^{3/4} e^{-E/kT}$

Eq 6.7a

- $\ln (IM^{-3/4}) = -E(1/kT) + \ln i_0$

Eq 6.7b

- Together two equations above predict mass-corrected whole organism metabolic rate is a linear function of inverse of absolute temp, $(1/kT)$

Note: You are not responsible for equations above but you need to know Fundamental Importance of metabolic theory
Recognized \( r = b - d \), thus species may increase by decreasing \textbf{mortality} \( (d) \).

Questions addressed focusing on \( b \):

1) what are the advantages to repeatedly reproducing prior to death (=iteroparity) vs. reproducing once and then dying (= semelparity)

2) the effect of the length of the pre-reproductive period on \( r \)

3) effect of litter or clutch size \( (B) \) on \( r \):

\textbf{Assumed}:

1) No mortality
2) Litter size does not change with age
3) Iteroparous species continues to breed indefinitely
6.4 Cole

• Cole’s Result:

The absolute gain in intrinsic population growth (r) that could be changed from switching from a semelparous (annual or obligate biennial) to an iteroparous (perennial) life cycle = adding 1 to the average litter size of a semelparous species.

Semelparous: \( r = \ln B \)

Iteroparous: \( r = \ln (1+B) \) **IF** complete survival of all age classes

**WHY?** Tremendous variation between juvenile & adult survivorship

Also noted importance of:

Age of first reproduction = \( \alpha \)

Age of last reproduction = \( w \)

Litter size = \( B \)
6.4 Cole

If juvenile survivorship > adult survivorship then semelparity favored:

Cole (1954) analyzed relative gains of r on:

1) Age of first reproduction ($\alpha$)
2) Litter size (B)
3) Iteroparity

Table 6.1 Scenarios

<table>
<thead>
<tr>
<th>Age</th>
<th>lx</th>
<th>1: mx</th>
<th>2: mx</th>
<th>3: mx</th>
<th>4: mx</th>
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<tr>
<td>0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>0.1</td>
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<td>0</td>
<td>0</td>
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<td>10</td>
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<td>0</td>
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<tr>
<td>3</td>
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<td>50</td>
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<tr>
<td>4</td>
<td>0.010</td>
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<td>0</td>
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<td>0</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>1: mx</th>
<th>2: mx</th>
<th>3: mx</th>
<th>4: mx</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRR</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>$R_0$</td>
<td>1.25</td>
<td>1.25</td>
<td>1.00</td>
<td>1.25</td>
</tr>
<tr>
<td>$G$</td>
<td>2.2</td>
<td>2.6</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td>$r$</td>
<td>0.102</td>
<td>0.086</td>
<td>0.000</td>
<td>0.074</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>1.11</td>
<td>1.09</td>
<td>1.0</td>
<td>1.08</td>
</tr>
</tbody>
</table>
Lewontin noted Cole’s work and its application to colonizing ability

“Selection for colonizing ability”

How does a species establish in a novel habitat?

Lewontin

- Examined slight changes in fecundity, longevity, and length of pre-reproductive period on $r$
- Relaxed ~ removed some of Cole’s simplifying assumptions

$$V_x = l_x m_x$$

Omitted assumption of infinite life span and constant fecundity
6.4 Lewontin (1965)

Fig. 6.4 Summary of Lewontin’s analysis

Identified 4 important parameter’s similar to Cole
\( \alpha = \) age of 1\(^{st}\) repro.
\( w = \) age reproduction ends
\( \delta = \) age of maximal reproduction
\( S = \) total reproductive output ~ area under triangle

NOTE: you are not responsible for the Rigid Analysis discussed in text
6.5 Theory of $r$- and $k$- selection

- Another application of MacArthur and Wilson’s work on Island Biogeography (1967)

- $r$- and $K$- selection as applied to life history strategies
- $r$- Selected species -> grow rapidly and disperse ~ adv. for colonizing spp.
- Hypothesized that new unpopulated environments would be colonized by $r$- selected spp.
- Once an environment completely colonized then reach $K$ (carrying capacity) AND now these populations will experience $K$- selection (ability to survive under these crowded conditions vs. ability to grow)

- Review Table 6.3 (pg 146) from Pianka (1970)
<table>
<thead>
<tr>
<th>TABLE 6.3</th>
<th>Trait</th>
<th>r – selection</th>
<th>K - selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
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<td></td>
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<tr>
<td>Survivorship</td>
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<td></td>
<td></td>
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<tr>
<td>Population size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recolonization frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competitive ability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment in defense</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parental care</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of life</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successional stage</td>
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<td>Developmental rate</td>
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<td></td>
<td></td>
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<tr>
<td>$r_{\text{max}}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-reproductive period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of offspring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of offspring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dispersal ability</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.6 Cost of reproduction and energy allocation

- Theory of r- and K- selection illustrate -> life history strategies evolve

- Tradeoffs often take place among growth, maintenance, & reprod.

- Another way to think about this idea is allocation of energy devoted to reproduction throughout an individual’s life span.

- **Reproductive Effort** = Amount of energy devoted to reproduction throughout an individual’s life span

Returning to Cole (1954) lots of variation in iteroparity:

1) short vs. long pre-reproductive periods
2) annual vs. periodical reproduction
3) small vs. large amount of reproductive effort
4) many small vs. few large offspring

Pg 148 – KNOW Examples
6.7 Clutch size

Lack (1954 and 1966) Proposed that clutch size in birds evolved through natural selection and corresponded to the number of young that could be taken care of (~fed) within a nest.

Data do not totally agree with this idea because an increase in brood size resulted in an increase in # young fledged without influencing parental survival.

- Although often juvenile survival and fertility were lower in larger broods than in normal brood sizes
- Many cases where brood size modified after egg laying

Insurance Hypothesis = is where hatching asynchronously created marginal offspring that can serve as replacements if initial brood suffers mortality within the season.
6.8 Latitudinal gradients in clutch size

Lack (1966), Cody (1966) and Assmole (1963) and Southwood et al. (1974) have demonstrated:

An increase in clutch size occurs as move from tropics to higher latitudes

Table 6.4

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Number of species</th>
<th>Average clutch size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Forest</td>
<td>82</td>
<td>2.3</td>
</tr>
<tr>
<td>Tropical grass and shrub lands</td>
<td>260</td>
<td>2.7</td>
</tr>
<tr>
<td>Tropical deserts</td>
<td>21</td>
<td>3.9</td>
</tr>
<tr>
<td>Middle Europe</td>
<td>88</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Also: Smaller clutch and litter sizes on islands than mainlands

Overall support that Repro. Effort is based on age specific mortality rates
6.9 Predation and its effects on Life History traits

- Dave Reznick and John Endler (1982) and others have demonstrated the role of predation on life history strategies.

- Guppies (*Poecilia reticulata*)

1) When predator prefers mature fish, guppies devote high % of body mass to reproduction. Results in short generation time and small size at maturity.

2) When predator prefers immature fish or no predators are present, then guppies devote small % of body mass to reproduction. Results in long generation time and they mature at a larger size.
6.10 Bet Hedging – when environment unpredictable

• Recall Cole’s Law – The absolute gain in intrinsic population growth (r) that could be changed from switching from a semelparous (annual or obligate biennial) to an iteroparous (perennial) life cycle = adding 1 to the average litter size of a semelparous species!

Semelparous: \( r = \ln B \)

Iteroparous: \( r = \ln (1+B) \)

• Timing of reproduction

• Safety in numbers

• Alternative strategies
Grime (1977) model based on plant life history strategies. What limits plant biomass or productivity?

1) Stress – any condition that restricts plant repro.
2) Disturbance – reduction in biomass from biotic or abiotic forces (Disturbance: low, medium, or high)

Table 6.5

<table>
<thead>
<tr>
<th>Intensity of disturbance</th>
<th>Intensity of Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>high</td>
</tr>
<tr>
<td>Low</td>
<td>Competitive strategy</td>
</tr>
<tr>
<td></td>
<td>Stress-tolerant strategy</td>
</tr>
<tr>
<td>High</td>
<td>Ruderal strategy</td>
</tr>
<tr>
<td></td>
<td><em>No viable strategy</em></td>
</tr>
</tbody>
</table>
6.11 Grime: Three life history strategies for plants

Grime (1977) model based on plant life history strategies. What limits plant biomass or productivity. See Fig. 6.5

A) Competitive Strategy – compete for immediate resources among neighbors

B) Stress-tolerant Strategy – common of individuals in unproductive habitats

C) Ruderal Strategy – common in disturbed habitats

During succession:

1st a ruderal strategy
2nd a competitive strategy
3rd a stress tolerant strategy
Highlights of Chap 6

• Diversity of life history strategies
• Power laws
• The metabolic theory of ecology
• Pioneering research by Cole (1954) and Lewontin (1965)
• MacArthur and Wilson “r” and “K” selection theory
• Cost of reproduction, energy allocation, and clutch size
• Trade off between seed size and seed number
• Predation and life histories
• Grime model of plant life histories

Questions?