Goal of the Lecture

To familiarize students with tadpole development and ecology, including metamorphosis.

Reading Assignments:
1) See Website: Wells (2007)
2) Altig et al. (2007): Freshwater Biology 52:386-395 (Req: website)
3) Petranka and Kennedy: Oecologia 120:621-631 (Suppl: website)

Lecture Structure

I. Embryonic Development
II. Hatchling Development
III. Larval Development & Ecology
IV. Metamorphosis
Embryonic Development
Gosner (1960) Stages

Stages 1-19

Nutrition
- Egg Yolk
- Oviducts
- Epithelial cells

External Gills
- Heart Beats

Hatching
- Frontal Glands
- Egg Tooth

Vascularized Tissues
- Tail
- Abdominal Walls

12 hrs – 27 days

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12 hrs – 27 days

Temperature Influences
Adaptations
1. Breeding Behavior
2. Tolerance Plasticity

Survival Maximized at Ideal Range of Temperatures
Development Faster at Warmer Temperatures

Adaptive Temp:
Across Species: 15-20°C
10-15°C
20-25°C
68-77°F
50-59°F

Tolerance Range:
Across Species: 5-35°C
5-25°C
15-35°C
41-77°F
59-95°F

1. Breeding
2. Tolerance

Tropical vs. Temperate

Hatchling Development
Gosner (1960) Stages
Stages 20-25

2 Pairs of Gills
2 Pairs of Branchial Arch
Direct Development & Viviparous

Adhesive Organ

Oral Disc

Branchial Arches

Operculum

Gills Atrophy

Spiracle

Stabilization

Ready to Swim & Eat!
Stage 25
Larval Development
Gosner (1960) Stages

Pre-Metamorphosis
Body Growth

Foramen develop about 1 stage behind hind limbs

Stages 26-41

NH Production (ammonotely)

Pro-Metamorphosis
Limb Growth
Skin: Vasculatized

Respiratory and Digestive Systems

Respiration
- Skin: Vascularization Sparse
- Lungs: Few Capillaries
- Small Surface Area

Digestion
- Intestines: 1.5× BL, 6 – 7 in.; nutrients
- Microphagus vs. Macrophagus

Larval Growth
Sigmoidal Relation

Body Plan:
- 30% Bilateral Muscles
- Tail

American Naturalist
141:717-728

Funkhouser’s Tong
Gosner C. G. Gosner
25 35 41

Scaphiopus multiplicatus
Carnivore Omnivore
Tadpole Feeding Ecology

Microphagus Filter Feeders:
- Herbivores (algae, detritus)
- Scrap and Filter
- Cannot digest cellulose
- Assimilation: 25-75%

Macrophagus Predators:
- Lab Experiments:
  - 24-54% Invert Survival
- Pond Experiments:
  - 49% Less than Controls
  - 1288 chironomids/m^2
  - Thrust forward and bite
  - Keystone predators?

Eggs:
- 43 masses (4,258 embryos)
- 15 masses (1,506 embryos)
- No larvae captured

Wood Frog Survival
- 2 weeks

Larvae:

Carnivorous & Cannibalistic Morphs

Animal vs. Plant Matter
- Protein and Lipids
- Accelerate Growth
- Size at metamorphosis

Environmental Relations

Temperature:
- 24-42°C
- Positive: Ponds; Tadpoles
- Negative: Streams; Salamander Larvae

Salinity:
- 10-35 ppt
- 10-35 C
- Positive: Ponds; Tadpoles
- Negative: Streams; Salamander Larvae

Phototaxis:
- Positive: Ponds; Tadpoles
- Negative: Salamander Larvae

DO: <1 mg/L
pH: <4
Nitrogenous Waste
\( \text{NH}_4^+ > 0.5 \text{ mg/L} \)
\( \text{NO}_2^- > 2 \text{ mg/L} \)
\( \text{NO}_3^- > 30 \text{ mg/L} \)

\begin{tabular}{|c|c|c|c|c|}
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Species & Temp & pH & NH4 & NO3 \\
\hline
\text{Bufo viridis} & 68°F & 7.0 & 0.50 & 0.00 \\
\text{R. clamitans} & 82°F & 7.5 & 1.24 & 2.17 \\
\text{R. clamitans} & 86°F & 8.0 & 8.81 & 7.46 \\
\hline
\end{tabular}

 NOTE: pH & Temp & NH4 & NO3

\begin{tabular}{|c|c|c|c|}
\hline
DO (mg/L) & pH & NH4 & NO3 \\
\hline
<1 & 6.5 & 7.5 & 8.5 \\
2 & 6.5 & 7.5 & 8.5 \\
3 & 6.5 & 7.5 & 8.5 \\
4 & 6.5 & 7.5 & 8.5 \\
\hline
\end{tabular}
Tadpole Community Ecology

- Fecal Input: 5 mg/day
- Fish: 3.5 g/m² 35 kg/ha 3.1 lb/ac
- Schooling Activity
- Predation Defense
- Competeability
- Invertebrates (algae)
- Fish (invertebrates)
- Competeplexes: Congeners (both)
- Predators: Eggs: Inverts, Fish, Amphibians
- Larvae: Inverts, Fish

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Metamorph Development

Gosner (1960) Stages

- Foreslimbs: Emerge through Opercular Wall
- Stages 42-46

Duration of Larval Development:
- Temperate: 2-3 Months
- Tropical: 1-2 Months
- Scaphiopus: 10-14 days

- Metamorphosis Hormone Regulation

- T₃: Triiodothyronine
- T₄: Thyroxine

- Organism Effects:
  - Intestines: Shorten
  - Lungs: Functional (44)
  - Tail & Gill: Degeneration
  - Kidneys: Urea
  - Skin: Vascularization/Chromatophores/Thickens
  - Mandibles & Eyelids: Develop

- Metamorph Development: Permanent Puddling

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T₃ & T₄: Peak at Gosner 39

- Immune System: Dismantled
Factors Triggering Metamorphosis

Factors:
- Density of Conspecifics and Congeners
- Competition
- Cannibalism/Predation
- Density of Predators
- Growth rate increases
- Activity decreases in presence
- Water Characteristics
- Water quality
- Water volume vs. temperature vs. concentration
- Volume and Proximity to Water Surface
- Evolutionary capability to exhibit different phenotypes depending on environmental conditions.

Adaptive Plasticity:
- Developmental Plasticity
- Polyphenism (carnivorous vs omnivorous)

References:
- Werner (1986, 1988)
- Rowe and Ludwig (1990, 1991)
- Ecology 63:905-911,
  71:2313-2322,
  79:1859-1872