

# Tadpole Development, Ecology, and Metamorphosis



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## 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)

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## Lecture Structure

- I. Embryonic Development
- II. Hatchling Development
- III. Larval Development & Ecology
- IV. Metamorphosis

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## Embryonic Development

**Gosner (1960) Stages** Stages 1-19

**Herpetologica**  
16:183-190

**Nutrition**

- Egg Yolk
- Oviducts

**External Gills**

- Heart Beats

**Hatching**

- Frontal Glands
- Egg Tooth

*Elutherodactylus*

1 Fertilization  
2 Gray Crescent  
3 2-Cell  
4 4-Cell  
5 8-Cell  
6 16-Cell  
7 32-Cell  
8 Midcleavage  
9 Late Cleavage  
10 Dorsal Lip  
11 Yolk Plug  
12 Late Gastrula  
13 Neural Plate  
14 Neural Tube  
15 Elongated, Protuberant  
16 Neural Tube, Gill Plates  
17 Tail Bud  
18 Adhesive Organ  
19 Mouthparts, Olfactory Pits  
Head Back  
Gill Buds

EMBRYOS

↑ O<sub>2</sub>  
Development ↓

12 hrs – 27 days

**Vascularized Tissues**

- Tail
- Abdominal Walls

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## Embryonic Development

**Temperature Influences**

**Survival Maximized at Ideal Range of Temperatures**

**Adaptive Temps:**  
Across Species: 15-20 C  
•Cool Adapted: 10-15 C  
•Warm Adapted: 20-25 C

50-59F  
68-77F

**Adaptations**

- Breeding Behavior
- Tolerance Plasticity

**Tropical vs. Temperate**

**Development Faster at Warmer Temperatures**

**Tolerance Range:**  
Across Species: 5-35 C  
•Cool Adapted: 5-25 C  
•Warm Adapted: 15-35 C

41-77F  
59-95F

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## Hatchling Development

**Gosner (1960) Stages** Stages 20-25

**2 Pairs of Gills**

**3<sup>rd</sup> and 4<sup>th</sup> Branchial Arch**

**Direct Development & Viviparous**

**Absent**

20 Gill Outgrowth, Tail Elongation  
21 Cornua Transparent, Mouth Opening  
22 Tail Finns Transparent, Fin Discretion  
23 Operculum, Oral Disc, and Pigmentation  
24 External Gills Atrophy  
25 Operculum Closes on Right

HATCHLINGS

↑ O<sub>2</sub>  
Development ↓

**Operculum**

- Grows Posterior
- Distal "Transient" Gills Atrophy

**Ready to Swim & Eat!**  
Stage 25

**Oral Disc**

**Branchial Arches**

**Adhesive Organ**

**Stabilization**

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## Larval Development

### Gosner (1960) Stages

**Pre-Metamorphosis**  
Body Growth

Forelimbs develop about 1 stage behind hind limbs

Stages 26-41

**NH<sub>3</sub> Production**  
(ammonotel)

**Pro-Metamorphosis**  
Limb Growth  
Skin:  
Vascularized

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## Respiratory and Digestive Systems

### Respiration

*Rana catesbeiana*

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

### Digestion

- Intestines: 1.4 – 8X BL (1 – 7 in.; nutrients)
- Microphagus vs. Macrophagus

↑ BC Volume   ↓ Filtering Apparatuses

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## Larval Growth

### Sigmoidal Relation

American Naturalist  
141:717-728

**Fowler's Toad**

Gosner 25   Gosner 35   Gosner 41

*Scaphiopus multiplicatus*

Carnivore   Omnivore

Body Plan:

**30%**

**Tail Bilateral Muscles**

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## Tadpole Feeding Ecology



Richard Wassersug  
American Zoologist 15:405-417, Oecologia 120:621-631



Jim Petranka

**Microphagus Filter Feeders:**

- Herbivores (algae, detritus)
- Scrape and Filter
- Assimilation: 25-75%

Altig et al. (2007)

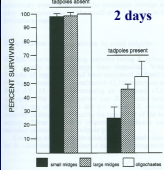


**Macrophagus Predators:**

**Lab Experiments:**

- 24-54% Invert Survival

**Pond Experiments:**

- 49% Less than Controls
- 1288 chironomids / m<sup>2</sup>
- Thrust forward and bite
- Keystone predators?
- Ephemeral Ponds


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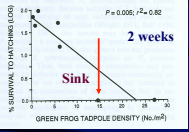
## Tadpole Feeding Ecology

### Carnivorous & Cannibalistic Morphs


SCAVENGE  
dead  
Conspecifics

**Eggs:**

**Wood Frog Survival**




**Larvae:** Animal Behaviour 46:87-94; Behavioral Ecology 10:436-443



D. flammiger

**Animal vs. Plant Matter**

- Protein and Lipids
- Accelerate Growth
- Size at metamorphosis ↑



Carnivore

**Overwintering *R. clamitans***

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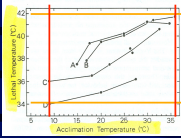
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## Environmental Relations

**Temperature:**

34-42 C  
93-104 F

**Highest:**  
Shallow Ponds and Tropics



**Phototaxis:**

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

**Salinity:**

- Intolerant of >0.5 ppt
- Bufo viridis*: 6 ppt (15%)

**DO:** <1 mg/L    **pH:** <4

**Nitrogenous Waste:**

- NH<sub>3</sub>: >0.5 mg/L
- NO<sub>2</sub>: >2 mg/L
- NO<sub>3</sub>: >30 mg/L

**NOTE:** ↑ pH    ↑ Temp    ↑ NH<sub>3</sub>    NH<sub>4</sub><sup>+</sup>

Temp (F)	Percent NH <sub>3</sub> of total ammonia				
	pH 6.5	pH 7.0	pH 7.5	pH 8.0	pH 8.5
68	.13	.40	1.24	8.82	11.2
77	.18	.57	1.77	5.38	15.3
82	.22	.70	2.17	6.56	18.2
86	.26	.80	2.48	7.46	20.3

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## Tadpole Community Ecology

**Tadpole Densities**

**Fishless**  
•700/m<sup>2</sup>

**Fish**  
•5/m<sup>2</sup>

**Competitors:**

- Invertebrates (algae)
- Fish (inverts)
- Conspecifics/Congeners (both)

**Predators:**

- Eggs: Inverts, Fish, Amphibians
- Larvae: Inverts, Fish, Amphibians

**Gape-limited: Fast Growth**

**Fecal Input**

5 mg/day  
•3.5g/m<sup>2</sup>  
35 kg/ha  
31 lb/ac

**Role of Tadpoles?**

**Predatory Defense**

- Palatability
- Activity
- Schooling

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## Metamorph Development

Gosner (1960) Stages Stages 42-46

**Forelimbs Emerge through Opercular Wall**

**ureotely**

**Duration of Larval Development**

Temperate: 2-3 Months  
Tropical: 1-2 Months  
*Scaphiopus*: 10-14 days

(Overwintering: Permanent Ponds)

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## Metamorphosis

### Hormone Regulation

T<sub>3</sub>: Triiodothyronine

T<sub>4</sub>: Thyroxine

**T<sub>3</sub> & T<sub>4</sub> : Peak at Gosner 39**

**Organism Effects:**

- Intestines: Shorten
- Tail & Gills: Degeneration
- Skin: Vascularization/Chromatophores/Thickens

- Lungs: Functional (44)
- Kidneys: Urea
- Mandibles & Eyelids: Develop

**Immune System: Dismantled**

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# Factors Triggering Metamorphosis

## Factors: •Density of Conspecifics and Congeners

- Competition
- Cannibalism/Predation

Ecology 63:905-911,  
Ecology 71:2313-2322,  
Ecology 79:1859-1872

## •Density of Predators

- Growth rate increases
- Activity decreases in presence



## •Water Characteristics

### Mortality vs. Growth

Werner (1986, 1988)  
Rowe and Ludwig  
(1990, 1991)

- Water quality
- Water volume vs. temperature vs. concentration
- ➡ Volume and Proximity to Water Surface

### Adaptive Plasticity:

BioScience 42(9):671-678

Evolutionary capability to exhibit different phenotypes depending on environmental conditions.

- Developmental Plasticity
- Polyphenism (carnivorous vs omnivorous )

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