Amphibian Characteristics, Taxonomy, and Evolution

Goal of the Lecture

To familiarize students with characteristics of the Class Amphibia, the diversity of extant amphibians, and the fossil record of amphibians.

Reading Assignments:
1) Handouts (Zardoya and Meyer 2001, Laurin 2002)
2) Duellman and Trueb: pp. 424-443

Lecture Outline

Class Amphibia Characteristics

Extant Amphibia Families

Amphibian Fossil Record
What are Amphibians?

Ectothermic tetrapods that have a biphasic life cycle consisting of anamniotic eggs (often aquatic) and a terrestrial adult stage.

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Amphibia (amphibios: “double life”)  
Subclass: Lissamphibia

Orders:
- Anura (frogs)
- Caudata (salamanders)
- Gymnophiona (caecilians)

Amphibia Characteristics

1) Cutaneous Respiration
   - Oxygen and CO₂ Transfer (moist)
   - Family Plethodontidae (lungless salamanders)
   - Gills (larvae, few adult salamanders), 2 Lungs (adults)
   - Mucous Glands (cutaneous respiration, antibiotic properties)
   - Glanular Glands (toxic secretions - neurotoxins, alkaloids)
   - Paratoid Glands

2) Skin Glands
   - Musian Glands (cutaneous respiration, antibiotic properties)
   - Glanular Glands (toxic secretions - neurotoxins, alkaloids)
   - Paratoid Glands
   - Other glands (not in all species)
     - Nuptial
     - Wax

Amphibia Characteristics

3) Modifications of middle and inner ear
   - Middle ear consists of 2 elements
     - Stapes (colunnella)
     - Opisthoticus
   - Inner ear consists of 2 sensory epithelial patches
     - Papilla basilaris (>1000 Hz)
     - Papilla amphibiorum (≤5000 Hz)
Amphibia Characteristics

4) Green Rods in Retina (excluding caecilians)
   - Involved in hue discrimination (433 nm = blue light)
   - Other Light Receptors: red rods, single and double cones

5) Focus eye by changing position of lens
   - Levator bulbi underlying the eye control elevation

6) Bicuspid Pedicellate Teeth
   - Crown (above gum), Pedicel (connected to jawbone)
   - New Crown Emerges from Pedicel

7) Reductions in skull bones
   - General trend associated with paedomorphosis
     (phenotypic change in which adults retain juvenile traits)

Modern Orders of Amphibia

- Gymnophiona (caecilians)
  - 6 Families
  - Limbless (pectoral & pelvic girdles absent)
  - Elongate and annulated bodies
  - Degenerate Eyes (recessed with skin or bone)
  - Internal Fertilization (phalloidous)
  - Tentacle between eye and nostril
  - Left lung reduced or absent
  - Some with dermal scales
  - Distinct skulls
  - Stegokrotaphic versus Zygokrotaphic

  167 species

- Caudata (salamanders)
  - 559 species

- Anura (frogs)
  - 2,420 species

  88% Anurans

  3% Caecilians

  9% Caudates

Gymnophiona

- Tropical Distribution

- 280 Species in U.S.
  (86 Species in TN)

- Ichthyophis kohtaoensis
- Dendrobates tinctorius
- Plethodon shermani
Gymnophiona

Families:

1) Caeciliidae (Common Caecilians)
- 95 species (57%)
- Primary Annuli
- Most fossorial
- Stegokrotaphic Skull

2) Ichthyophiidae (Fish Caecilians)
- 38 species (23%)
- Primary Annuli
- Secondary & Tertiary
- True tail
- Stegokrotaphic Skull
- Females attend eggs

3) Typhlonectidae (Aquatic Caecilians)
- 14 species (8%)
- Primary Annuli
- No true tail
- Zygokrotaphic Skull
- Strongly aquatic

4) Rhinatrematidae (Beaked Caecilians)
- 9 species (5%)
- Primary Annuli
- Secondary & Tertiary Grooves
- True tail
- Zygokrotaphic Skull

5) Scolecomorphidae (Tropical Caecilians)
- 6 species (4%)
- Primary Annuli
- Zygokrotaphic Skull
- Calcified spines on phalodes
- Some are viviparous

6) Uraeotyphlidae (Indian Caecilians)
- 5 species (3%)
- Primary Annuli
- Secondary Grooves
- True tail
- Stegokrotaphic Skull
- Some are viviparous

Gymnophiona phylogeny

- Beaked
- Fish
- Indian
- Tropical
- Common
- Aquatic
Caudata

Characteristics:
- Tails and superficially segmented bodies
- Well-developed limbs (except aquatic)
- Internal Fertilization (most)
- Larval Development External (most)
- Pheromones (mucous glands)
- Lack Tympanum & Middle Ear

Mostly Temperate Distribution

10 Families

1) Plethodontidae (Lungless Salamanders)
   - 378 species (68%)
   - U.S. & Neo-tropics
   - Subterranean, crepuscular
   - Tadpoles (not free-swimming)
   - Eggs usually guarded

2) Salamandridae (True Salamanders)
   - 74 species (13%)
   - U.S., Europe, SE Asia
   - Aquatic larvae
   - Skin toxic and brightly colored

3) Hynobiidae (Asian Salamanders)
   - 51 species (9%)
   - China, NE Asia
   - Cutaneous respiration
   - Nasolabial groove

4) Ambystomatidae (Mole Salamanders)
   - 32 species (6%)
   - North America
   - Vomerine Teeth (M)
   - No operculum or op. muscle

5) Proteidae (Mudpuppies & Waterdogs)
   - 6 species (1%)
   - North America
   - Lidless eyes, no tongue pad

6) Sirenidae (Sirens)
   - 4 species (0.7%)
   - Europe, SW Asia
   - External Fertilization

7) Rhyacotritonidae
   - 4 species (0.7%)

8) Dicamptodontidae (Giant Salamanders)
   - 4 species (0.7%)
   - Coastal NW, WA
   - Vomerine Teeth (M)

9) Amphiumidae
   - 5 species (0.8%)
   - SE United States
   - No external gills, gill slits

10) Cryptobranchidae (Hellbenders)
    - 3 species (0.5%)
    - SE United States
    - No external gills, gill slits

Families:

1) Plethodon shermani
   - U.S., SE U.S.

2) Triturus cristatus
   - U.S., Europe, SE Asia

3) Hynobius chinensis
   - Asia

4) Ambystoma tigrinum
   - North America

5) Necturus maculosus
   - North America

6) Siren intermedia
   - Europe

7) Rhyacotriton kezeri
   - SW Asia

8) Dicamptodon ensatus
   - Coastal NW, WA

9) Amphiuma tridactylum
   - Coastal NW, Canada

10) Cryptobranchus alleganiensis
    - Europe

**Caudata phylogeny**

**Characteristics:**
- Shortened Presacral Vertebrate (usually 8)
- Ribs are reduced or absent (2nd or 4th)
- Presacral Vertebrae Firmly Articulated
- Large Hind Limbs, No tail (except 1 family)
- External Fertilization (usually)
- Flat heads and Large-Mouths (usually)
- Vocal Sacs in Males (usually)

**Global Distribution**

**Families:**
1) Leptodactylidae (Southern Frogs)
- 1263 species (24%)
- Male lays eggs
- Foam nest
- Tadpoles, direct dev., or vocalist

2) Hylidae (Tree Frogs)
- 835 species (15%)
- Vocal Sacs in Males
- Foam nest
- Free swimming tadpoles (most)

**Video**

**Anura**

**Characteristics:**
- Saltatorial 2-10X BL.

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3) Ranidae (True Frogs)
- 799 species (14.7%)
- Global (Africa, Asia most)
- Well-developed legs & webbed feet
- Free swimming tadpoles (most)

4) Bufonidae (True Toads)
- 493 species (9%)
- Global (Rubs most spp.)
- Cutaneous Glands
- Teeth nearly absent
- Bidder’s Organ
- Male lacks legs (most spp.)

5) Microhylidae (Narrow-mouthed Frogs)
- 449 species (8%)
- Mostly Tropical, Subtropical
- 2-3 Palatal Folds

6) Rhacophoridae (Asian Tree Frogs)
- 288 species (5%)
- Africa, India, SE Asia
- Hanging Foam Nest
- “Flying Frogs”
- Convergent with hylids

**Gastrophryne carolinensis**
- Africa, India, SE Asia
- Hanging Foam Nest
- “Flying Frogs”
- Convergent with hylids

**Rana catesbeiana**
- Africa, India, SE Asia
- Hanging Foam Nest
- “Flying Frogs”
- Convergent with hylids

**Bufo cognatus**
- Africa, India, SE Asia
- Hanging Foam Nest
- “Flying Frogs”
- Convergent with hylids

**Rhacophorus reinwardtii**
- Africa, India, SE Asia
- Hanging Foam Nest
- “Flying Frogs”
- Convergent with hylids
Anura

Families:

7) Hyperoliidae (African Tree Frogs)
   - 261 species (4.8%)
   - Africa, Madagascar, Seychelles
   - Eyes elliptical
   - Some fold leaves over eggs
   - Mantella madagascariensis

8) Dendrobatidae (Poison Arrow Frogs)
   - 252 species (4.7%)
   - Central & South America
   - Brightly colored, toxic skin
   - Most very small (<1 inch)
   - Makes noise for dominance
   - Eggs spread by amplexus
   - Dendrobates tinctorius

9) Mantellidae (Mantellas)
   - 165 species (3%)
   - Madagascar only
   - Brightly colored, toxic skin
   - Most very small (<1 inch)
   - Central & South America
   - Transparent skin (no ribs)
   - Most very small (<1 inch)
   - Brachytarsophrys carinensis

10) Centrolenidae (Glass Frogs)
    - 143 species (2.6%)
    - Central & South America
    - Brightly colored, toxic skin
    - Most very small (<1 inch)
    - Males wrestle for dominance
    - Tadpoles ride on males back
    - Centrolene prosoblepon

11) Megophryidae (Water Frogs)
    - 126 species (2.3%)
    - Sub-Saharan Africa
    - Leaf-like appearance
    - Tadpoles: Surface Foragers
    - Poor jumpers
    - Nocturnal
    - Cardioglossa aureoli

12) Myobatrachidae (Water Frogs)
    - 120 species (2.3%)
    - New Guinea, Australia, and Tasmania
    - Egg Nests in Water
    - Unique egg breeding
    - Limnodynastes dumerilii

13) Arthroleptidae (Squeakers)
    - 51 species (0.9%)
    - Sub-Saharan Africa
    - Previously a part of Rainfall
    - Direct development (some tadpoles)
    - Arthroleptis esculentus

14) Pipidae (Tongueless Frogs)
    - 31 species (0.6%)
    - Africa and South America
    - Fully Aquatic Frogs
    - No tongue
    - Xenopus laevis

15) Astylosternidae (Astylosternids)
    - 29 species (0.5%)
    - Sub-Saharan Africa
    - Differ from #13: horizontal pupils & toe discs
    - Brachycephalus ephippium

16) Discoglossidae (Disc-tongued frogs)
    - 11 species (0.2%)
    - United States, Mexico, Europe, and Eastern Asia
    - Explosive breeding
    - Fast developing larvae (cyanobacterial phenotype)
    - Brachycephalus ephippium

17) Pelobatidae (Spadefoots)
    - 11 species (0.2%)
    - United States, Mexico, Europe, and Eastern Asia
    - Explosive breeding
    - Fast developing larvae (cyanobacterial phenotype)
    - Alytes obstetricans

18) Brachycephalidae (Pumpkin Toads)
    - 10 species (0.2%)
    - SE Brazil
    - All direct development
    - Reduced digits
    - Brachycephalus ephippium

19) Limnodynastes dumerilii
Anura

**Families:**

19) *Bombinatoridae* (Ghost Frogs)
   - 10 species (0.2%)
   - Europe; East Asia
   - Toxic skin (venomous reflex)
   - Barbourulas: Rocky streams

20) *Hemisotidae* (Shovel-nosed Frogs)
   - 9 species (0.17%)
   - Southern Africa
   - Fast-flowing streams
   - Well-developed toe discs, spines, sucker-like oral disc (tadpoles)

21) *Heleophrynidae* (Ghost Frogs)
   - 6 species (0.1%)
   - Southern Africa
   - Fast-flowing streams
   - Well-developed toe discs, spines, sucker-like oral disc (tadpoles)
   - Skeleton Gorge: Cape Town

22) *Sooglossidae* (Seychelles Frogs)
   - 29 species (0.5%)
   - Madagascar
   - Inguinal amplexus (only Neobatrachid)
   - Secretive: litter and rocks
   - Direct development & tadpoles on back

23) *Leiopelmatidae* (Leiopelmatids)
   - 4 species (0.1%)
   - New Zealand
   - Do not call (no T, ME, VS)
   - Inscriptional ribs

24) *Pelodytidae* (Parsley Frogs)
   - 3 species (0.1%)
   - NW United States, British Columbia
   - Fast moving streams
   - Tadpoles develop in vocal sac (male)
   - “Rhinoceros nosed”

25) *Ascaphidae* (Tailed Frogs)
   - 2 species (0.1%)
   - NW United States, British Columbia
   - Fast moving streams
   - Tadpoles develop in vocal sac (male)
   - Tail: Cloacal Extension
   - Internal fertilization
   - Most primitive extant family (don’t call, 7 yrs to maturation)

26) *Rhinodermatidae* (Purse String Frogs)
   - 2 species (~0.1%)
   - Southern South America (Chile)
   - Tadpoles develop in vocal sac (male)
   - “Rhinoceros nosed”

27) *Allophrynidae* (Ruthven’s Frog)
   - 1 species (~0.1%)
   - NE South America
   - Centrolenidae (related?; foot muscle morphology)
   - Little known about its biology
   - Termite and ant specialists
   - No teeth

28) *Nasikabatrachidae* (Purple Frog)
   - 1 species (~0.1%)
   - India (discovered 2003)
   - Fossorial
   - Explosive breeders
   - Little known

29) *Rhinophrynidae* (Mexican Burrowing Toads)
   - 1 species (~0.1%)
   - Costa Rica to Rio Grande
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Anura Phylogeny

Evolutionary history of Amphibians

Events in Geologic History

Fish to Tetrapods

Tetrapods to Amphibians

Fossil Record of Amphibians

Modern Amphibians
(late Permian)
550 MYA

Carboniferous

First Amphibians
Mississippian
350 MYA
Evolutionary transitions
First tetrapods appeared in the Devonian (400 MYA)
Tropical/subtropical latitudes
Primitive plants and arthropods

Why did fish emerge on land?
1. Find food or evade predators
2. Low oxygen levels
3. Periodic droughts

Fish to Tetrapods
Sarcopterygian (lobe-finned fishes)
Eusthenopteron
- Pelagic
- Internal nostrils
- Distinct humerus, ulna, and radius and femur, tibia, and fibula

Panderichthys
- Long snout
- Dorsal eyes
- Reduced median fins

Tiktaalik
- More developed limbs with wrist and finger bones (body postures)
- Robust rib cage
- Lungs and gills
- Neck separated from body

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Fish to Tetrapods
Ichthyostega
- Piscivorous
- Limbs likely used for navigating
- Tail for balance
- Skeletal structure
  - ¾ forelimbs

Acanthostega
- Piscivorous
- Fish-like
- Limbs likely used for paddling
- Skeletal structure
  - Elbow could not bend
  - Gills and Lungs
  - 8 digits

Greenland

Ichthyostega
- Piscivorous
- Limbs likely used for navigating
- Tail for balance
- Skeletal structure
  - ¾ forelimbs

Acanthostega
- Piscivorous
- Fish-like
- Limbs likely used for paddling
- Skeletal structure
  - Elbow could not bend
  - Gills and Lungs
  - 8 digits
Fish to Tetrapods

30 million year gap in the fossil record for tetrapods
Relationships between Devonian and Carboniferous tetrapods obscured

Temnospondylous Amphibians
Carboniferous and Permian Periods

- 1.5-2 m long
- Bicuspid pedicellate teeth
- Lungs & Cutaneous Respiration
- Likely piscivorous
- Engulfed prey
- Not a strong swimmer or fast tetrapod
  (likely hunted by stealth or opportunity)
- Shoulder disconnected from skull
**Lepospondylous Amphibians**

**Carboniferous and Permian Periods**

**Nectridia**
- Mostly Aquatic
- Resembled Newts (flat tails)
- Some with triangular heads
- Small fish and aquatic invertebrates

**Microsauria**
- "Small Lizards"
- Terrestrial and fossorial

**Lysorophia**
- Elongate body
- Diminutive limbs
- Fenestrated skulls

No larval forms known

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**Phylogenetic Hypotheses**

(Zardoya and Meyer 2001, Laurin 2002)

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**Fossil Record of Lissamphibia**

**Triassic, Jurassic and Cretaceous Periods**

1) **Anurans**
   - *Paleobatrachus*
   - Probable Triassic for all orders
   - Origin: Madagascar
   - Early Triassic (250 mya)

2) **Salamanders**
   - *Kazanophis sharovi*
   - Late Cretaceous (100 mya)
   - Origin: Kazakhstan

3) **Caecilians**
   - *Apoda pricei*
   - Early Triassic (170 mya)
   - Origin: Gondwanaland (SA)
Historical Biogeography

Continental drift and Caecilians

Lecture summary

- General characteristics of amphibians
- Characteristics of extant amphibian orders
- Diversity of extant amphibian orders
- Evolutionary history of amphibians