JAWS
TOWARDS JAWED VERTEBRATES

Aims:

- Characteristic features of vertebrates
- Early vertebrates → Jawless fishes
- On the diversity of jawed fishes

What are Vertebrates (Subphylum Vertebrata)?

- Vertebrates have ***Vertebrae (***serially arranged structures to make up the spinal column or backbone***),*** formed from the notochord during embryonic development, encircling the spinal nerve chord.
- not *all* vertebrae are bony and some vertebrates (hagfishes) entirely lack vertebrae
- A uniquely derived feature of all vertebrates is to have a skull ***(Cranium,*** bony or cartilaginous structure surrounding the brain***)***. Thus, ***Craniata*** might be better than Vertrbrata to define the group
- All vertebrates possess a ***neural crest*** → tissure originating at the neural plate (an early embryonic form of the main nerve chord), before migration to various body regions (forming e.g. sensory organs and the peripheral nervous system).
- The forebrain ***(telencephalon,*** area of higher processing***)*** is absent in Amphioxus, whereas midbrain and hindbrain find their homologous structures
- All vertebrates show a duplication in the ***Hox gene complex (***a set of genes regulating the expression of other genes to determine the body plan***)***: amphioxus has one set, jawless fishes have two sets, jawed vertebrates have >four sets

Three Germ Layers and their Functions in Vertebrates

1. The ***Ectoderm*** forms the skin and large parts of the nervous system including sense organs
2. The ***Endoderm*** forms the digestive tract (also liver and pancreas), and lungs
3. The ***Mesoderm*** forms muscles, skeleton, circulatory and urogenital system. It splits to form the coelom (body cavity containing internal organs). Later, the ***Peritoneum*** forms (a thin layer of mesoderm lining the cavity and suspending the intestines)

- According to some scientists ***the dorsal crest can be seen as a fourth germ layer*** unique to vertebrates

Embryonic Development

- Early vertebrate embryos all look very similar
- In the embryo, all ancestral features of chordates are at some point present
- ***Biogenetic law*** → ontogeny is a recapitulation of phylogeny, Ernst Haeckel

Adult Tissue Types: the Integument

- The ***Epidermis (***ectoderm***)*** is the outermost layer ("skin"), followed by a ***dermis*** unique in vertebrates ***(***mesoderm and neural crest, containing sensory organs, blood vessels and pigment cells***).*** The innermost integument ***(Hypodermis)*** overlays muscles and bones ***(***fat storage and small striated muscles***)***
- ***Keratin*** is a ectoderm protein unique for vertebrates. It forms hair, scales, feathers, claws…
- Three types of tissues can become mineralised ***(enamel*** and ***dentine*** for teeth, as well as ***bone)***
- ***Otodonts (***tooth-like elements in the skin, e.g. part of the armour of extant shark***)*** are the oldest known mineralised structures, and homologous to mammal teeth
- Two types of bones: ***dermal bones*** formed in the skin, and ***endochondral bones*** based on cartilaginous tissue

Origin Of Birds

- Compared to their closest living relatives (crocodylians), birds show a large number of anatomical specialisations
- Fossil records show that many of these features evolved ***before*** the origin of birds
- There are now many "intermediate" taxa within Dinosauria that show various combinations of birs-like features
- The discovery of "feathered dinosaurs" has been particularly important
- ***"Protofeathers"*** now known from saurischians ***and*** ornithischians
  - Likely originally evolved for ***insulation –*** indication of endothermy?
  - Flight feathers evolved much later
- Lineage of theropod dinosaurs that gave rise to birds characterised by sustained evolution of ***small bosy size*** over 50 million years
- Several major theories for evolution of flight in birds
  - ***"ground up" –*** wings initially evolved for stabilisation when running after prey or to help catch insects?
  - ***"trees down" – wings evolved for gliding in tree tops***
  - ***Wing assisted incline running (WAIR) –*** wing beat allows running up steep slopes e.g. tree trunks
- "trees down" model perhaps more plausible given the existence of small gliding theropods e.g. *Microraptor*
- *Archaeopteryx* often reffered to as the oldest tru bird – 150 million years old, (Germany)
- However older birds are now known - ~160 million years old from China – e.g. *Achiornis*
- Study of structures called ***melanosomes*** preserved in fossils gives insight into the probable colour of these animals when alive
- Early birds e.g. *Anchiornis* and *Archaopeteryx* retain plesiomorphic features lost in moder birds:
  - Long tail (rather than pygostyle – the "parsons nose")
  - Teeth
  - No beak
  - Claws on forelimb

Modern Birds

- Modern birds (***Aves***) comprises >10,000 living species
- Two major groups**:**
  - ***Palaeognaths - ~****50 living species*
    - Included the flightless ratites (ostriches, cassowaries, rheas, kiwis, moas etc.) but also the flying tinamous of South and Central America
    - Used to be thoigh that all the ratites evolved from a flightless ancestor
    - More recent studies indicate that the different ratites became flightless independently
  - ***Neognaths - ~****10,000 living species*
    - ***Galloanserae*** ("fowls") – includes ducks, geese, chickens, phesants, peacocks etc
    - ***Neoaves –*** everything else
    - More than half of the total neognath diversity (5,000 species) is comprised of ***passeriforms*** (perching birds/songbirds such as wrens, tits, crows, larks, starlings)

Turtles

- There are >300 species of living turtles and tortoises
- All show a very specialised morphology characterised by the presence of a shell formed by their ribs

  - Most were ***relatively small bodies***
  - ***Relatively large brain***
  - ***Secondary palate***
  - ***Relatively complex teeth***

Lactation
- Milk of mammals is produced by ***mammary glands*** (probably modified by sweat glands)
- Mammary glands not preserved in any known fossil, so we don't know exactly when it evolved within synapsida
- Two main hypotheses:
  - Milk developed from glandular secretions that ***prevented eggs drying out*** (amniote eggs are less vulnerable to dehydration, but it can still occur if conditions are dry enough)
  - Milk developed from ***antimicrobial secretions***
  - Maybe secretions performed both roles?

Diphyodonty
- Most vertebrates replace their teeth constantly ***(polyphyodonty)***
- Living mammals instead show ***diphyodonty -*** only two generations of teeth for incisors, canines and premolars
  - ***Deciduous*** ("milk") teeth
  - ***Permanent/successor teeth***
  - ***Molars*** of mammals have only one generation (i.e. not replaced)
- Three reasons for the evolution of ***Dipyodonty:***
  - Initial dental eruption is ***delayed*** because offspring initially feed on milk
  - ***Determinate*** growth of skull – skull reaches a fixed size (in most other amniotes, including non-mammalian cynodonts, the skull can grow continuously throughout life)
  - Upper and lower teeth need ***to fit together*** (occlude) very precisely to function correctly – regular replacement of teeth would disrupt this

Evolution of the Mammalian Middle Ear
- Most tetrapods have ***a single bone*** in the middle ear for transmitting vibrations to the inner ear (Cochlea)
  - This bone is the ***stapes*** or ***stirrup*** (sometimes called the ***columella*** in lissamphibians)
- Also, the lower jaw is made up of multiple bones, and the jaw joint is between the ***articular*** bone (lower jaw) and the ***quadrate bone*** (upper jaw/skull)
- Living mammals have ***three bones (ossicles)*** in the middle ear for transmitting vibrations to the inner ear (cochlea)
  - ***Stapes or stirrup →*** between cochlea and incus
  - ***Incus or anvil →*** between stapes and malleus
  - ***Malleus or hammer →*** between incus and ear drum
- Also, the lower jaw is made up of a ***single bone each side*** (the ***dentary***) and the jaw joint is between the ***dentary bone*** (lower jaw) and ***squamosal bone*** (upper jaw/skull)

Where have the two extra bones (malleus and incus) in the middle ear of living mammals come from?

How did the dentary-squamosal jaw joint of mammals evolve? Where have the quadrate and articular gone?
- Evidence from palaeontology and developmental biology ***supports the same conclusion***
- Fossil record of synapsids shows progressive ***enlargement*** of the ***dentary bone*** and ***reduction in size*** of the ***other (postentary) bones*** in the lower jaw

DIVERSITY OF MODER MAMMALS

BRIEF RECAP:
Amniote phylogeny:
- Current evidence suggests a basal split between
  - ***Synapsida***
  - ***Sauropsida*** (which includes ***Parareptilia and Diapsida***)
- Mammals are they only living synapsids

Origin of mammalia:
- The oldest and most primitive true mammals are about ***200-220*** million years old

Diversity and Distribution of Modern Mammals
Three major clades:
- ***MONOTREMATA*** (Monotremes) → ***5 describes species =0.1%*** of total living diversity – Australia and New Guinea only
- ***MARSUPIALIA*** (Marsupials) → ***>350 extant described species = 6-7%*** of total living diversity – almost exclusively Australia, New Guinea and South America (1 species occurs in North America, north of Mexico)
- ***PLACENTALIA*** (Placentals) → ***>5000 extant species*** describes ***>93%*** of total living diversity – worldwide (including oceans)

MONOTREMES
Modern Monotreme Diversity
- 5 living species
  - The platypus ***(ornithorhynchus anatinus)***
  - Four species of echidna (family ***Tchyglossidae)***
    - Short beaked echidna
    - Sir David's long beaked echidna
    - Eastern long-beaked echidna
    - Western long-beaked echidna

The Platypus (*Ornithorhynchus anatinus*)
- Range → Eastern Australia and Tasmania
- Body size → 0.7-2.4kg
- Diet → mainly aquatic invertebrates (worms, crustaceans, insect larvae)
- Reproduction → female lays 1-3 eggs in her burrow
- Soft electrosensitive bill (detects prey), webbed feet, beaver-like tail → adaptations for semi aquatic lifestyle
- Small eyes , no external ears (pinnae)
- No functional teeth → chews using horny pads in jaw
- Spur present on ankle of juveniles and adult males – in males, produced ***Venom*** during breeding season

Echidnas (Family *Tachyglossidae)*
- 4 living species
  - Short beaked echindna ***(Tachyglossus aculeatus)***
  - Three species of lon-beaked echidnas ***(Zaglossus spp.)***
- Range → throughout australia and parts of New Guinea (short-beaked echidna); New guinea (Zaglossus spp.)
- Body size → 2-7kg (Ta); 5-17kg (Z spp.)
- Diet → mainly ants and termites (Ta); mainly earthworms (Z spp.)
- Reproduction → female lays single egg that she carries in a pouch
- Long narrow snout (electrosensitive), dorsal spines, skeleton adapted for digging
- Small eyes, no external ears (pinnae)

- Shaped bone implements
- Fishing and fowling
- Burial with goods
- Expansion of networks
- Use of ‘harsh’ environments
- Art/symbolism

PRESERVING BIODIVERSITY

Number of Described species

How many species exist on the planet? A simple question without a simple answer

- We do not even know precisely how many species we have already described: estimates vary between ***1.6 and 2 million***
- The majority of all describes species (in the order of 1.2 million) are arthropods
- About 80% of arthropods (>1 million) are insects, and about 40% of insects (>400,000) are beetles
    - ***About one in three species on our planet is a beetle***

Number of Existing Species

- For an estimation of the total number of species (described ***and*** undescribes) on the planet, it might be best to focus on the most abundant group (i.e. beetles)
- Terry Erwin (1982): Canopy fogging of a single tropical tree (*Luechea seemanni)* in a central American rainforest revealed 12,000 beeteles with 163 species being tree-specific specialists
    - There are globally about 50,000 tropical tree species, which should therefore harbour 8150000 beetles
    - 40% of arthropods are beetles, resulting in a total of 20375000 insects. However, the proportion of canopy and soil insects on given areas is 2:1
    - ***This projection results in over 30 million of arthropods on the planet alone!***
- Terry Erwins study has subsequently been criticised as too simple and partially flawed
- Nevertheless the estimates produced since then have not converged and we made very little progress on the subject
- So we do not know how many species we have on the planet…
- …. And strikingly, we will probably never know
- Assuming 5 million species exist, and taxonomists describe new species at the same pace than since Linneaus (1758), we will need another approx. 730 years (=until about the year 2740) to describe the existing biodiversity
- ***Many (most?) species will likely have gone extinct before we can even describe them***

Current Biodiversity Research – “DNA taxonomy”

- Many species are very rare and/or difficult to identify, and there is an uneven global distribution of scientific resources negatively correlated with an uneven global distribution of species diversity
- ***“DNA – taxonomy” and “DNA – barcoding”: a potential solution to the problem?*** *Idea: focusing on a gene that has the same sequence across individuals within a species but differs between species, we can rapidly describe/identify/catalogue ne species without the requirement of specialist knowledge (time and identification skills). The current consensus is to focus on mitochondrial rather than nuclear genes (example: Cytochrome Oxydase I sequence)*

The Cause of Threat and Extinction

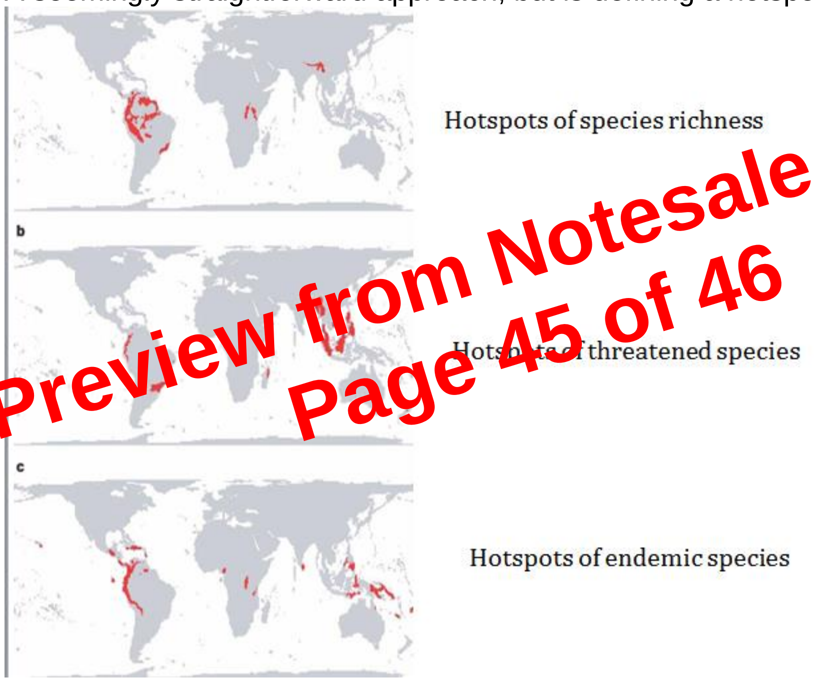
- ***Habitat destruction*** → The size of the global surviving rainforest is about equivalent to the size of the United States, and an area about the size of Florida is cleared every year.
- ***Introduced species*** → Brown tree snake introduced to Guam have brought 12 bird species and 6 lizard species to local extinction
- ***Overexploitation*** → Blue fin tuna has become reduced to only 20% in one decade (80s)
- ***Disruption of Key species*** → the local loss of sea otters resulted in a rise in sea urchins causeing a loss of kelp forests and this major changes in other species
- ***Pollution, agrochemicals and pharmaceuticals, introduced wildlife diseases…***

Habitat Loss and Degradation: The Biggest Threat in all Groups

- Habitat loss and degradation usually has the largest impact, whereas the importance of other factors varies depending on the taxonomic groups

Biodiversity Hotspots: An Efficient Concept for Conservation?

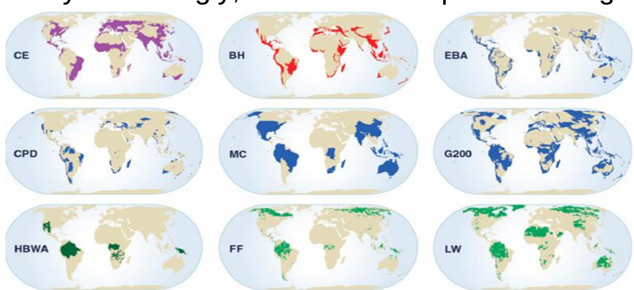
- ***Biodiversity hotspots*** → areas on the global map with particularly high biodiversity
- In 2005, the organisation Conservation International (conservation.org) defined 34 hotspots worldwide, to be used for prioritising global biodiversity conservation
- A seemingly straightforward approach, but is defining a hotspot really so easy?



-

The Nine Global Conservation Priority Templates

- Fairly confusingly, different concepts exist for global biodiversity priority areas



- CE: crisis ecoregions; BH: biodiversity hot spots; EBA: endemic bird areas; CPD: centers of plant diversity; MC: megadiversity countries; G200: global 200 ecoregions; HBWA: high-biodiversity wilderness areas; FF: frontier forests; LW: last of the wild.

The Value of Biodiversity: Why Care?

- ***118 out of the main 150 prescription drugs are from natural sources*** (74% from plants, 18% from fungi, 5% from bacteria and 3% from vertebrates)
- ***Pollination:*** over 100,000 animal species freely pollinate crop plants (bats, bees, flies, moths, beetles, birds and butterflies), with an estimated value of 5 billion $
- ***Ecosystems services:*** the minimum total value of ecosystem services (gas and water regulation, nutrient cycling, prevention of erosion etc) was estimated as ***over 38 trillion $ in*** a seminal study for 2001 (so higher now!)
- Preserving biodiversity is costly: ***23 billion$*** to protect 15% of land masses, ***10 billion$*** to protect 30% of marine areas (again these are 2001 data)
- ***Considering such data, nature conservation would be economically viable at a cost-benefit ratio of about 1:100!!*** A main problem is only that ecosystem services do not have a price tag…