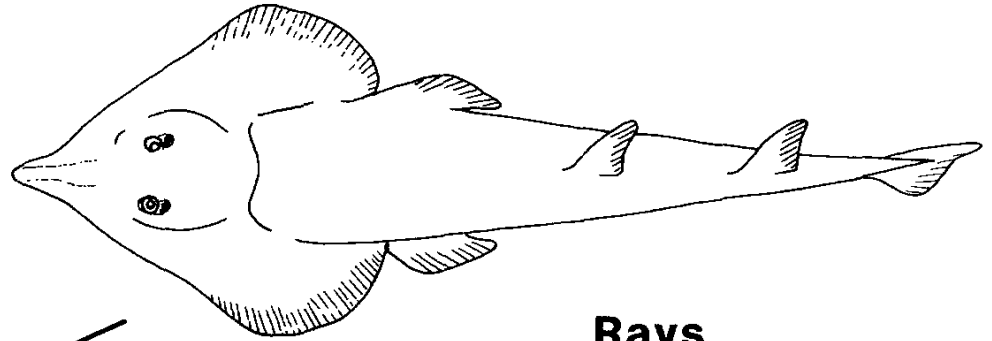


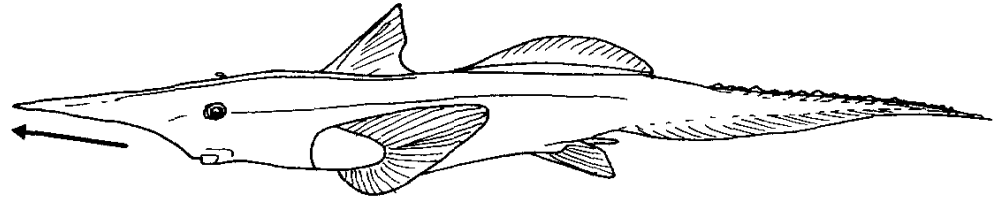
FIGURE 4 Calibrated phylogenetic tree derived using the fossil record. See text for detail.

Modern Chondrichthyans

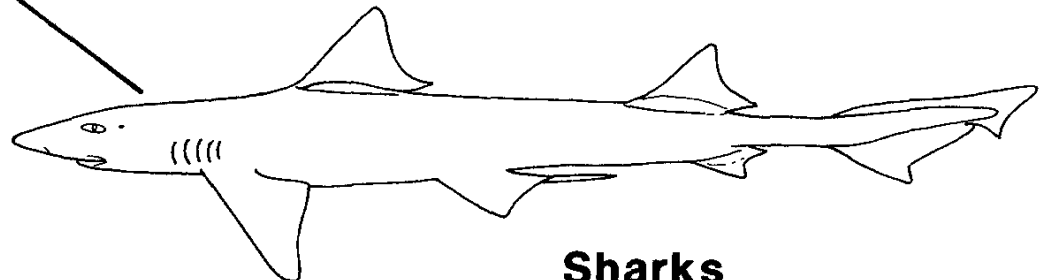
Neoselachians
Modern sharks and rays
(869+ species)



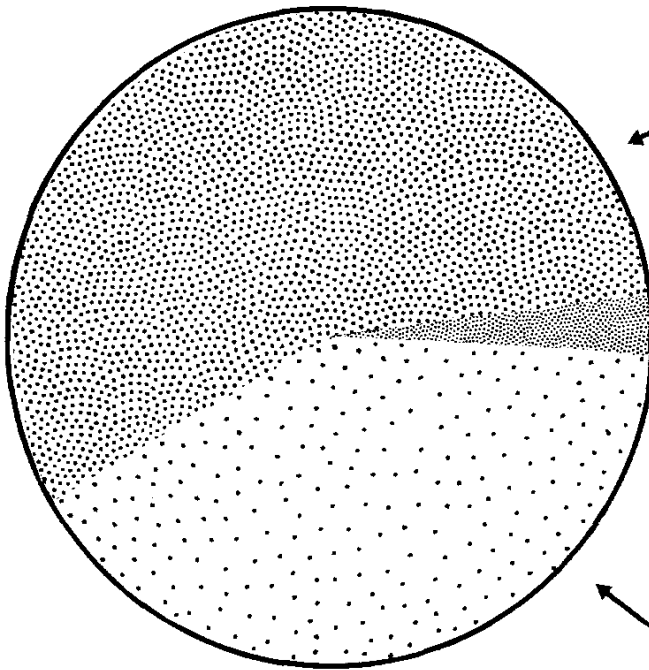
Rays
(494+ species, 55%)



Chimaeras
(31+ species, 3%)



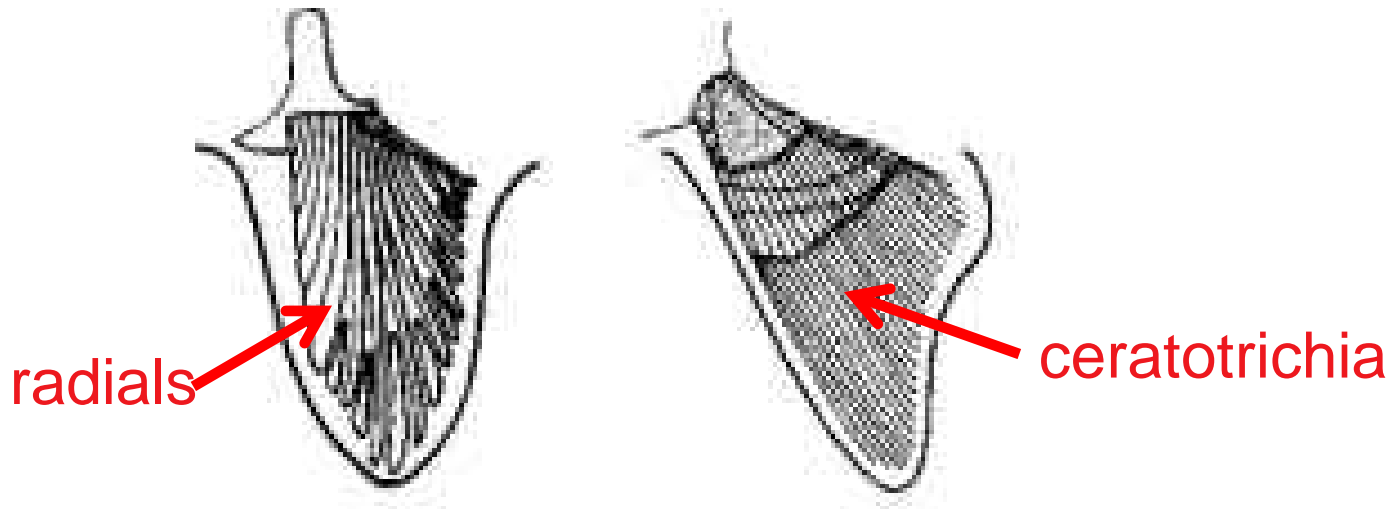
Sharks
(375+ species, 42%)



Chondrichthyans
(900+ species)

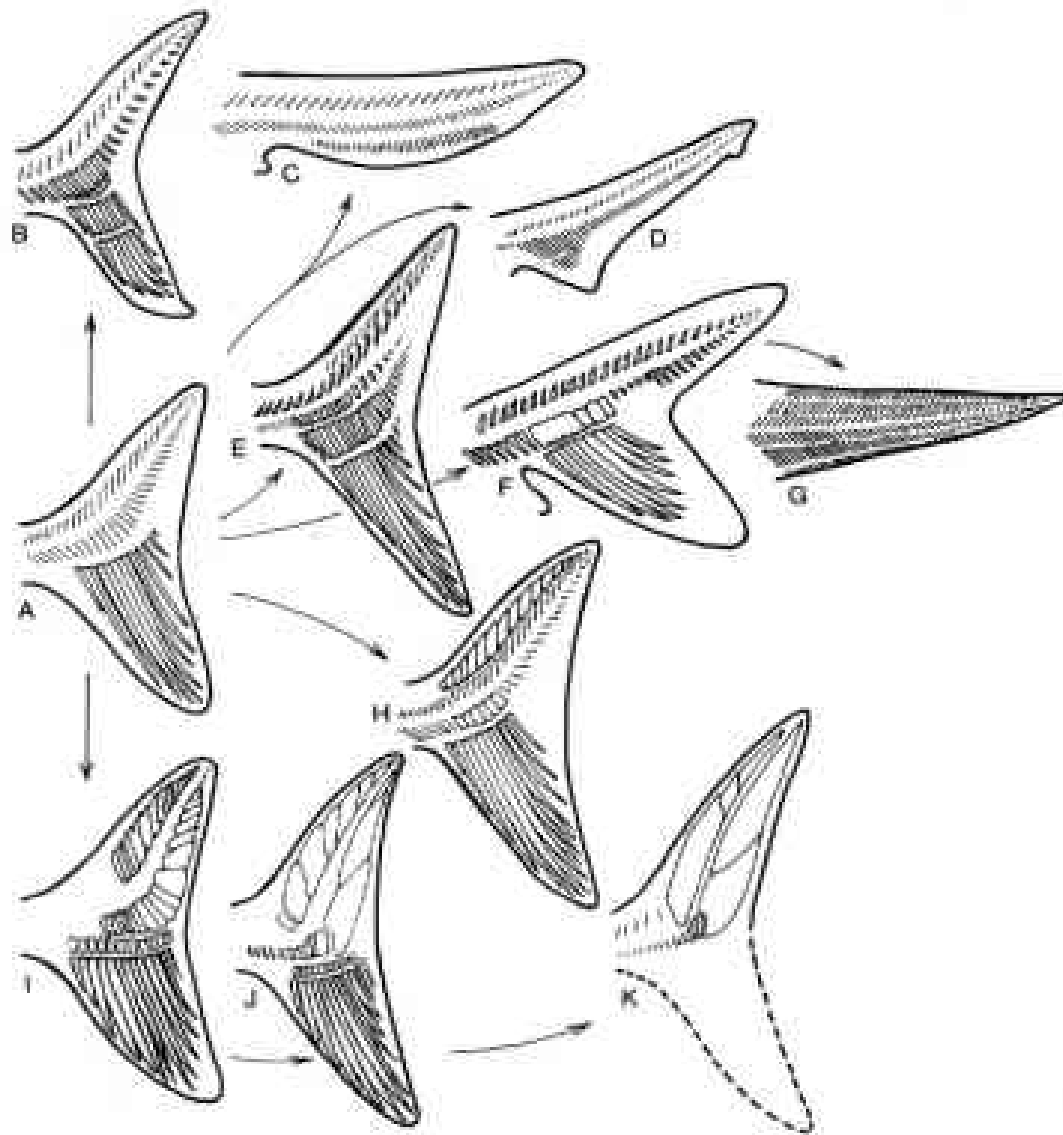
Hypothesized evolution of fins and caudal fins (loss of radials)

plesodic fins, uncommon in modern sharks
(cartilaginous skeleton extends to the edge of the fin and in the fossil forms, the ceratotrichia are very delicate and fine)

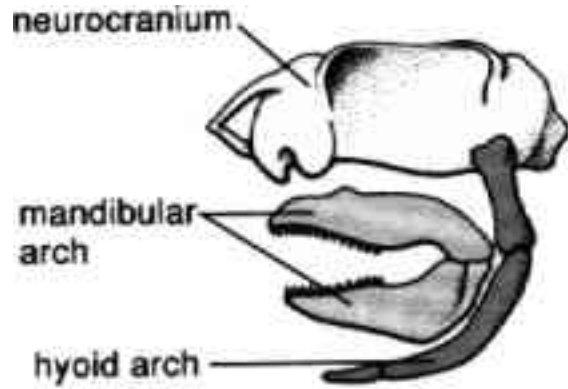


aplesodic fins, common in modern sharks
(with the cartilaginous fin skeleton reduced and the fin supported mainly by ceratotrichia)

Hypothesized evolution of fins and caudal fins (loss of radials)



Types of jaw suspension



hyostylic
(not attached to the
braincase)



amphystylic
(double support)

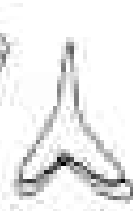


holostylic
(fused to the braincase)

Types of teeth

Paleozoic
(little diversity)

modern (highly specialized)



Cladoseleche

Hybodius

dogfish

white
shark

weasel
shark
(upper)

weasel
shark
(lower)

Mouth position



terminal
(paleozoic)

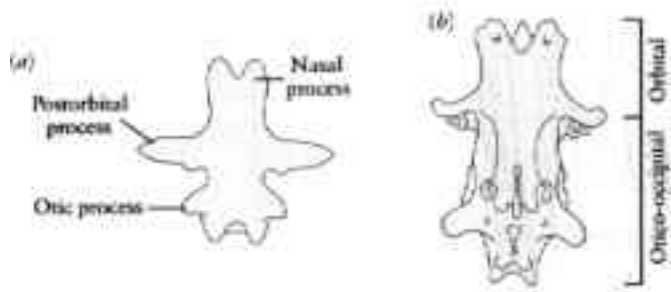
ventral
(modern)

Types of chondocrania

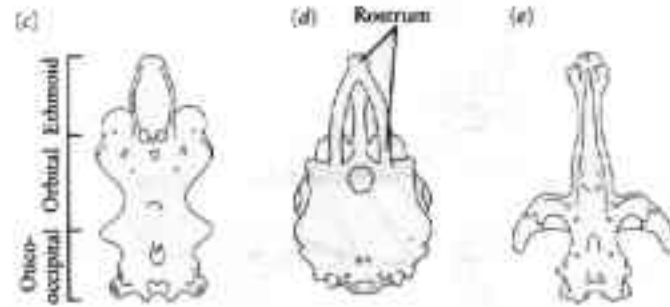
Paleozoic

Modern (highly specialized)

Cladoseleche



Xenacanthus



Squalus
(dogfish)

Isurus
(mako)

Rhinobatus
(guitarfish)

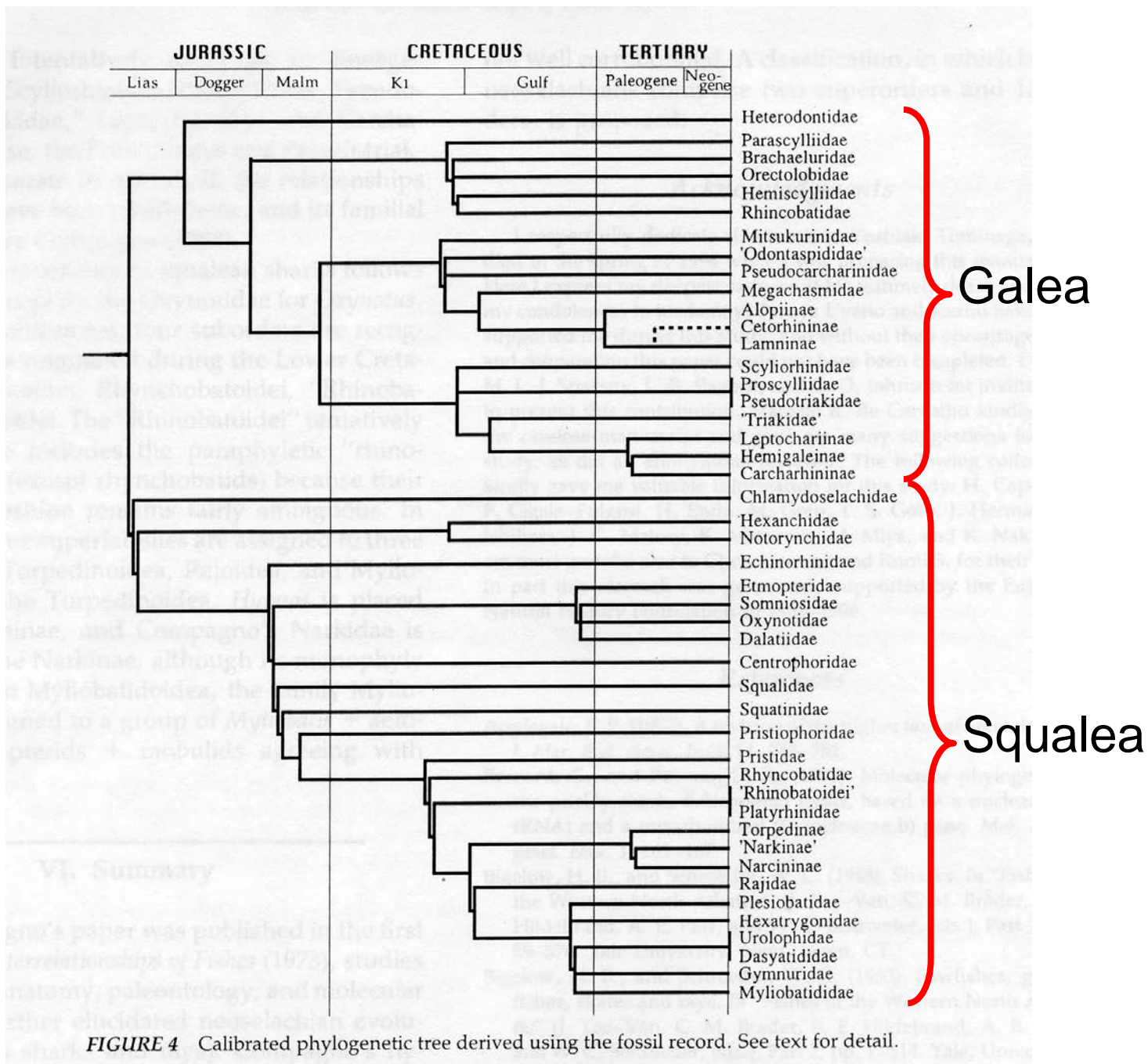
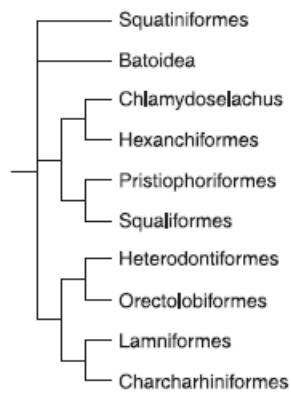
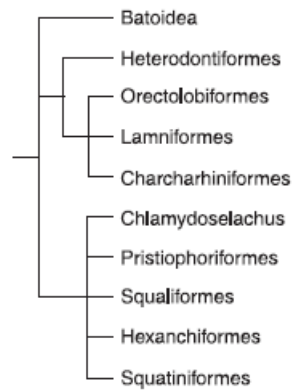


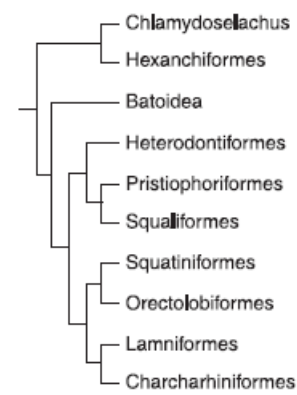
FIGURE 4 Calibrated phylogenetic tree derived using the fossil record. See text for detail.



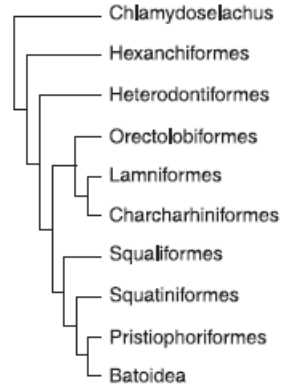
Compagno 1973



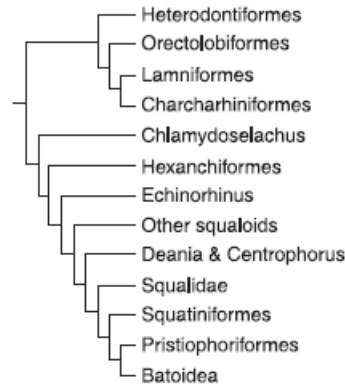
Maisey 1984b



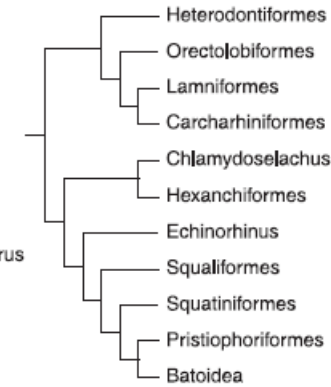
Theis & Reif 1985



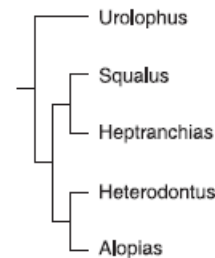
Dingerkus
(cited by Seret 1986)



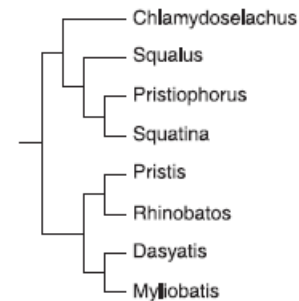
Shirai 1992



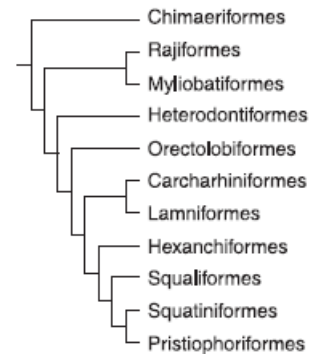
de Carvalho 1996



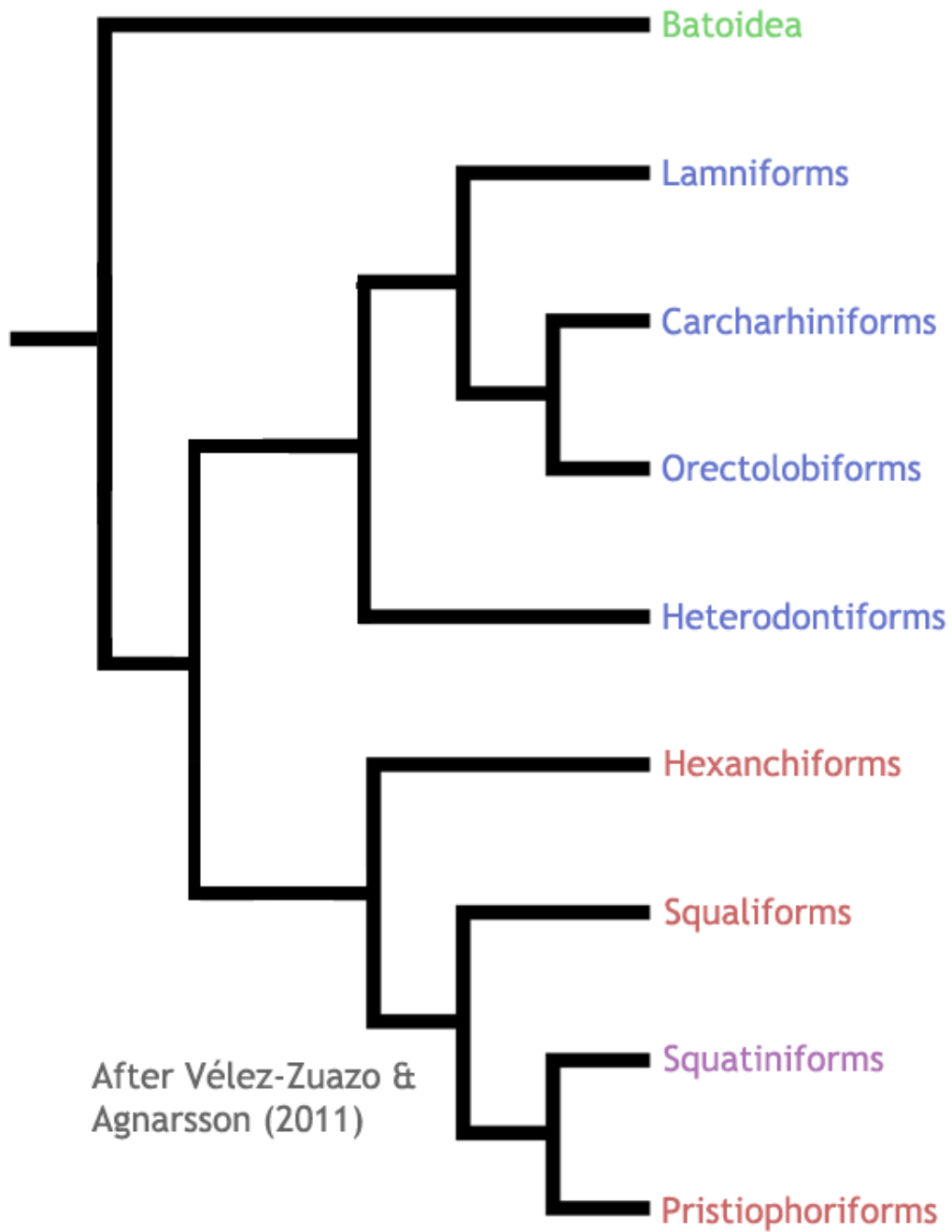
Dunn & Morrissey 1995



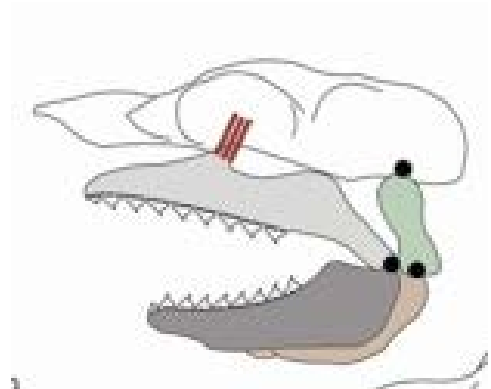
Kitamura *et al.* 1996



Douady *et al.* 2003

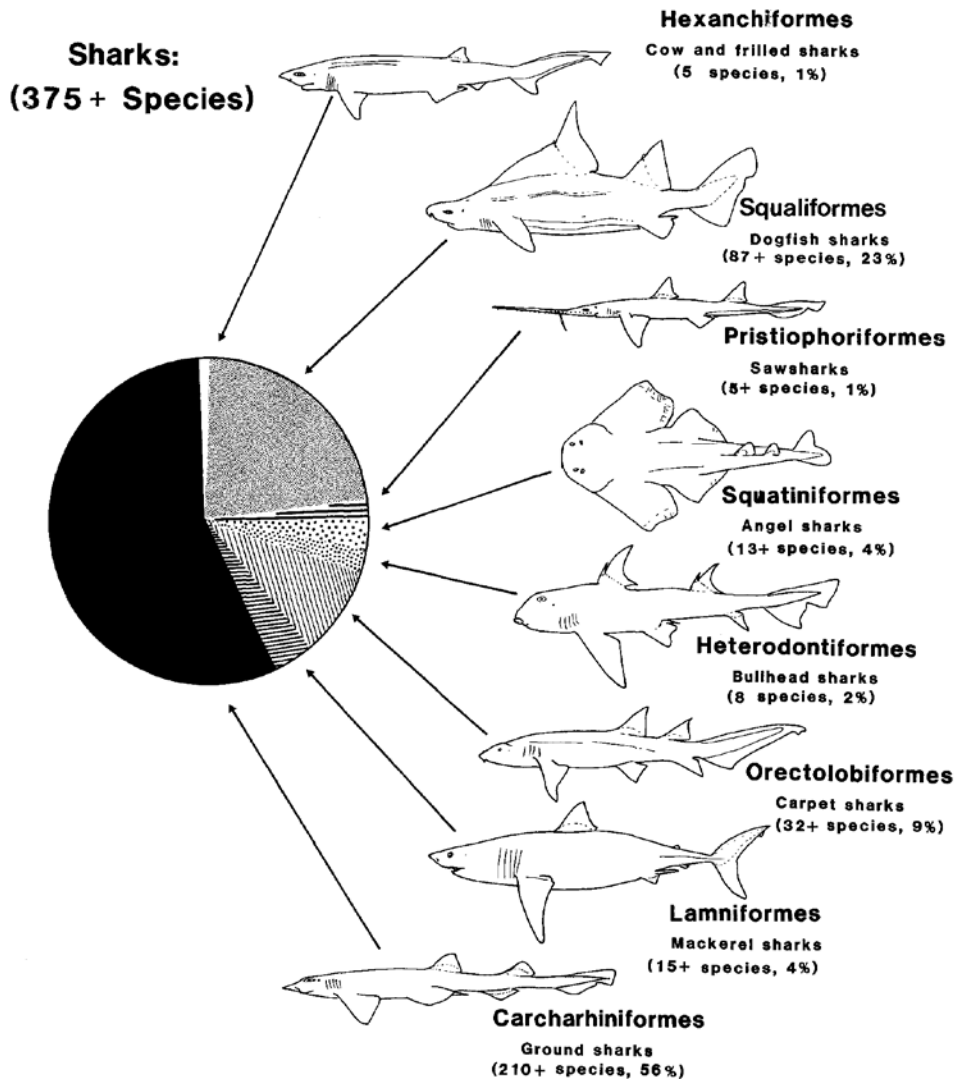


Galeopmorphii



New Squalomorphii
(orbitostylic
sharks)

After Vélez-Zuazo &
Agnarsson (2011)



Hexanchiformes (six, seven gill) 5 sp. 1%
Squaliformes (dogfish) 87+ sp. 23%
Pristiophoriformes (sawsharks) 5+ sp. 1%

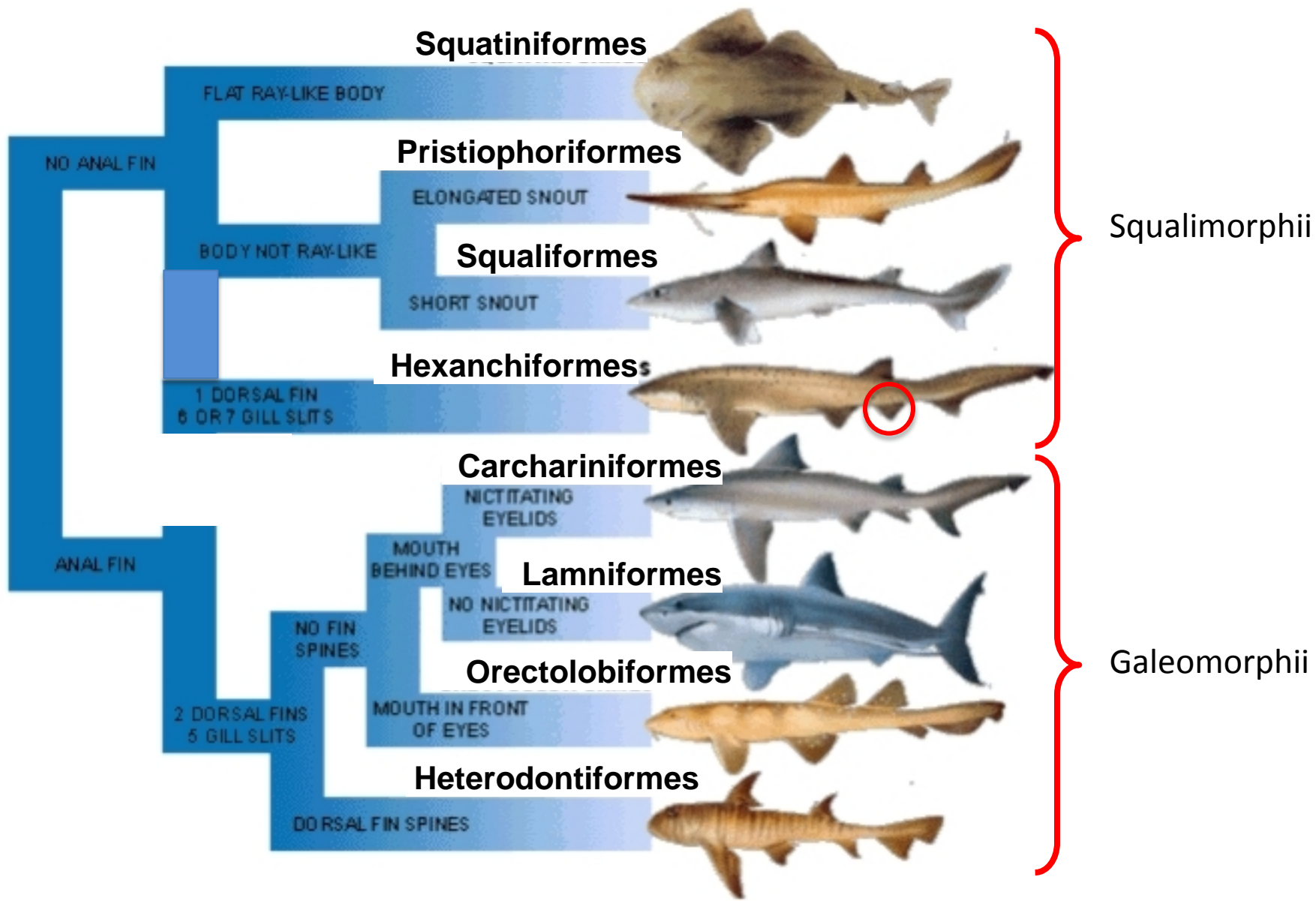
Squalimorphii

Squatinimorphii

Squatiniformes (angel sharks) 13+ sp. 4%

Galeomorphii

Heterodontiformes (bullhead sharks) 8+ sp. 2%
Orectolobiformes (carpet sharks) 32+ sp. 9%
Lamniformes (mackerel sharks) 15+ sp. 4%
Carcharhiniformes (ground sharks) 210+ sp. 56%



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squaleamorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

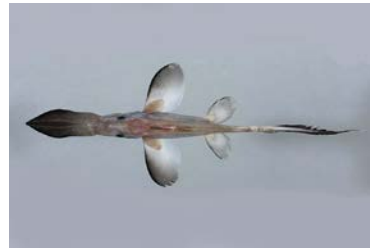
Order Rhinopristiformes

Order Myliobatiformes

- Marine
- Deep water
- No stomach (fused with intestine)
- 3 families
 - Callorhynchidae (3 species)



- Rhinochimaeridae (9 species)



- Chimaeridae (38 species)



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

- Deepwater
- One dorsal fin
- Anal fin
- 6-7 gill slits
- Ovoviviparous
- 2 families
 - Hexanchidae (5 species)
 - Chlamydoselachidae (2 species)

Sixgill sharks



Sevengill sharks

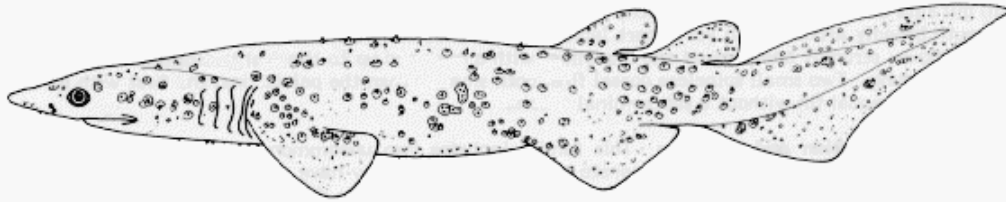


Frilled shark



- Deepwater
- Thorn-like denticles
- Large (up to ~4 m)
- 1 family
 - Echinorhinidae (2 species)

Bramble shark



Prickly shark



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

- Deepwater
- Diverse
- 6 families (121 species)
 - Somniosidae (23 species)
 - Squalidae (28 species)
 - Etmopteridae (46 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes



Cookie cutter shark

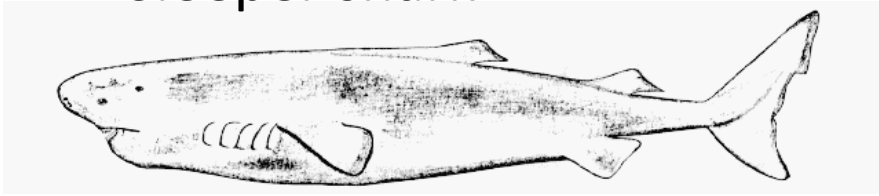


'Dogfish' sharks

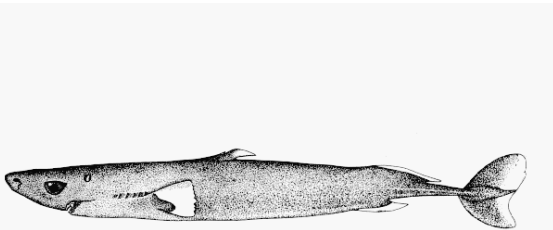
'Latern' sharks



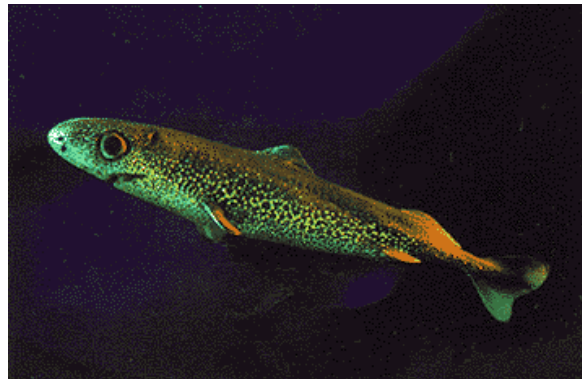
Sleeper shark



Greenland shark



FAO



Cigar shark, Pygmy shark, Dwarf shark

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

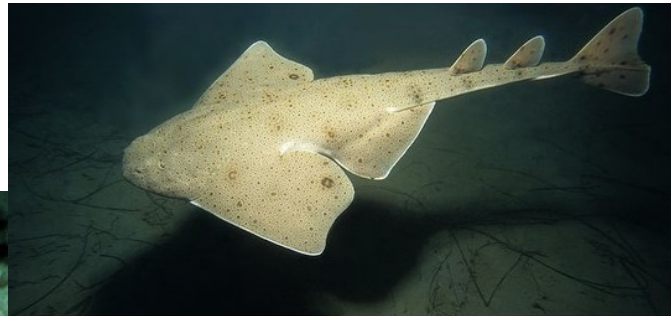
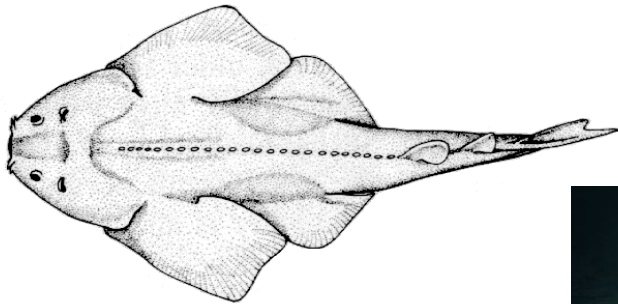
Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

- Dorso-ventrally flattened
- Benthic
- 1 family
 - Squatinidae (20 species)

Angel shark



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

- ‘Saw sharks’
- Marine
- Gills on side of body
- Pectoral fins not fused to side of body
- Pair of barbels on saw
- Saw teeth alternate (large/small)
- Deepwater
- Small (up to ~1.5 m)
- 1 family
 - Pristiphoridae (7 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes



- Benthic
- Shallow water
- Small (<1.5 m)
- Dorsal spines
- Oviparous
- 1 family
 - Heterodontidae (9 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

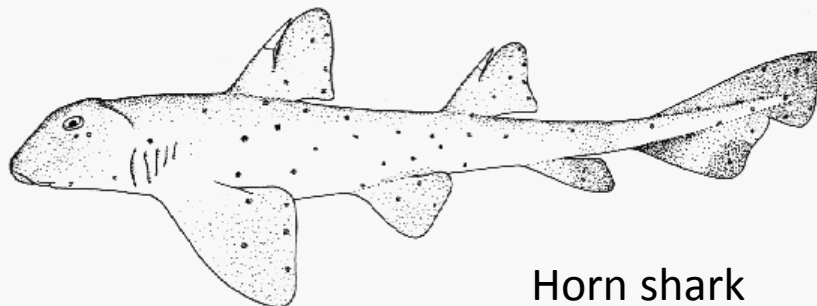
Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes



Port Jackson shark



Horn shark



- Tropical
- Diverse
 - Benthic to pelagic
 - Small to LARGE
- No fin spines
- Anal fin
- Ovoviviparous
- 6 families
 - Orectolobidae (12 species)
 - Hemiscyllidae (15 species)
 - Rhincotyidae (1 species)



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

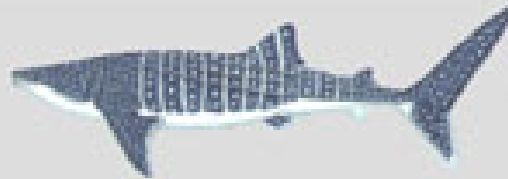
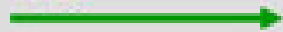
Order Rhinopristiformes

Order Myliobatiformes

Guide to Orectolobiformes

Mouth huge, nearly terminal; Caudal fin with strong ventral lobe

Yes



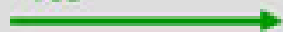
Whale Sharks
RHINCODONTIDAE

No



Caudal fin about as long as body; Strong dermal ridges along back

Yes



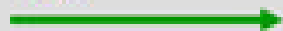
Zebra Shark
STEGOSTOMATIDAE

No



Head and body greatly flattened; Head margin with prominent skin flaps

Yes



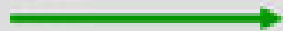
Wobbegongs
ORECTOLOBIDAE

No



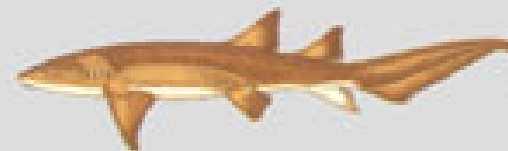
Spiracles large; Prominent lobe and groove around outer edges of nostrils

Yes



Bamboo Sharks
HEMISCYLLIIDAE

No



Nurse Sharks
GINGLYMOSTOMATIDAE

- Marine
- Pelagic
- Viviparous
- Diverse
- Anal fin
- 9 families (15 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

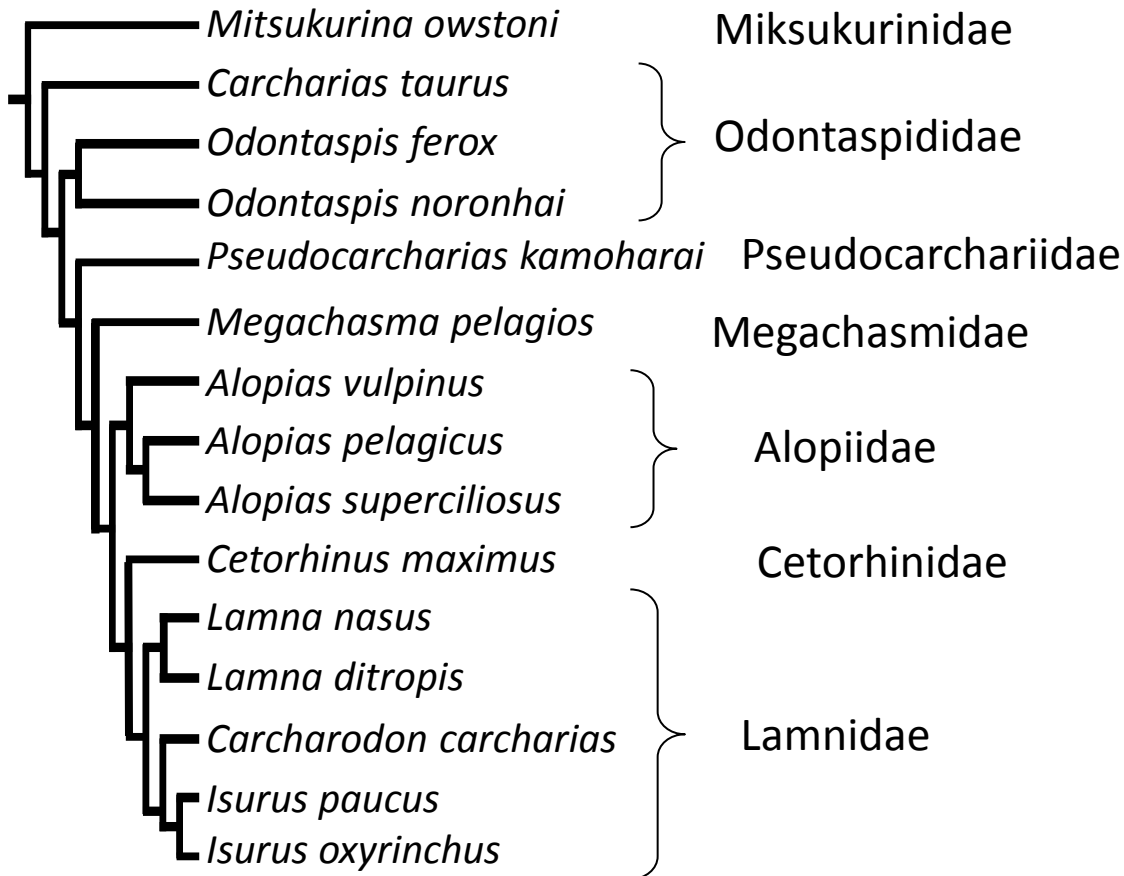
SuperOrder Batoidea

Order Rajiformes

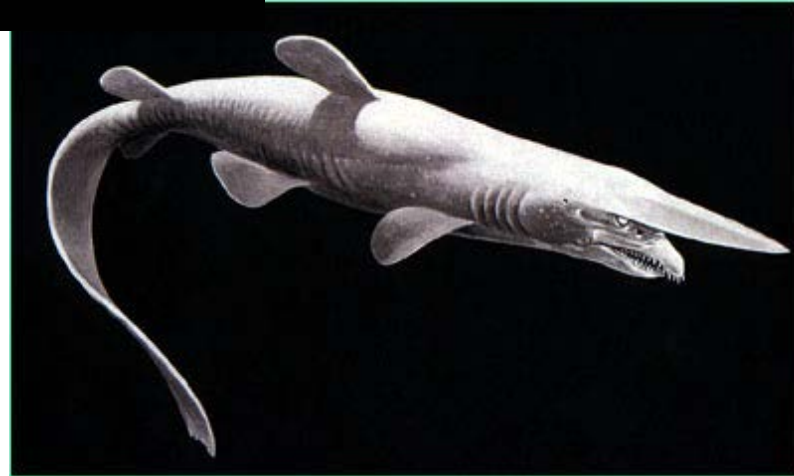
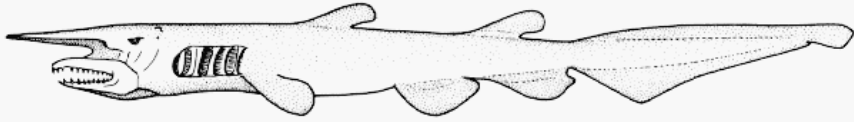
Order Torpediniformes

Order Rhinopristiformes

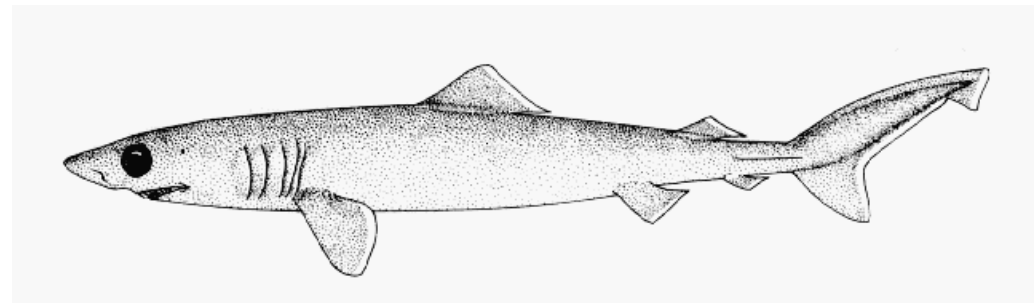
Order Myliobatiformes



Family: Mitsukurinidae (1 species)
Goblin shark (*Mitsukurina owstoni*)



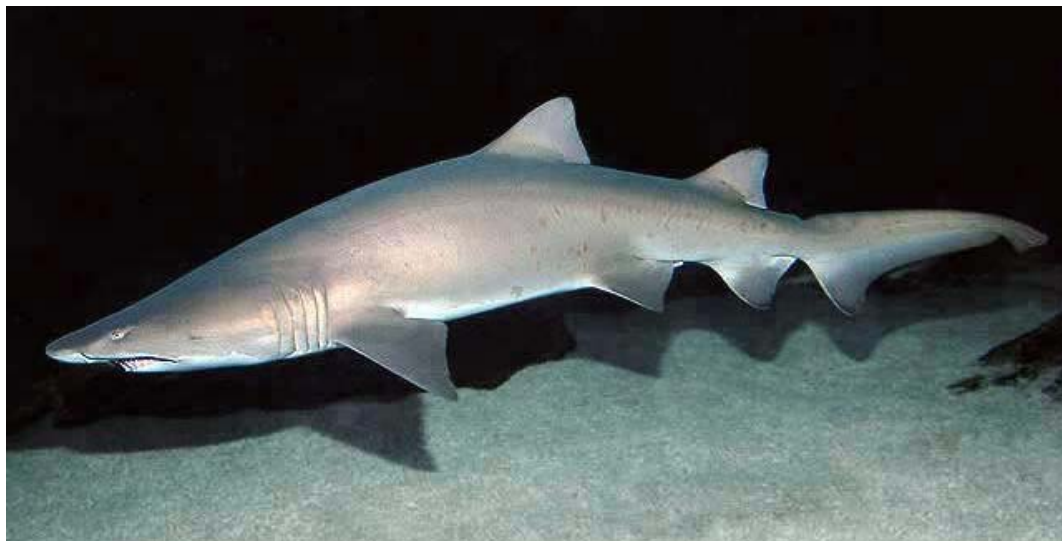
Family: Pseudocarchariidae (1 species)
Crocodile shark (*Pseudocarcharias kamoharai*)



Family: Odontaspidae (3* species)

Sand tiger sharks

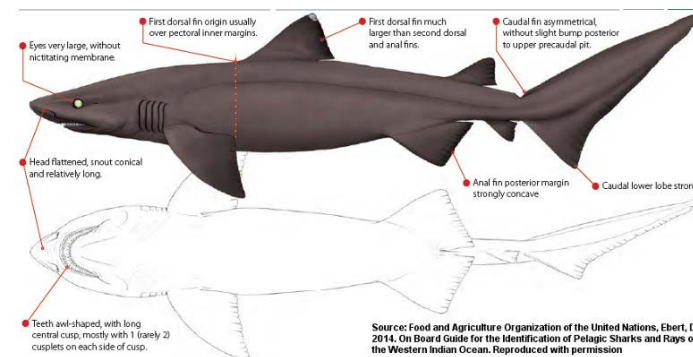
Sand tiger (*Carcharias taurus*)



Bigeye sand tiger (*Odontaspis noronhai*)

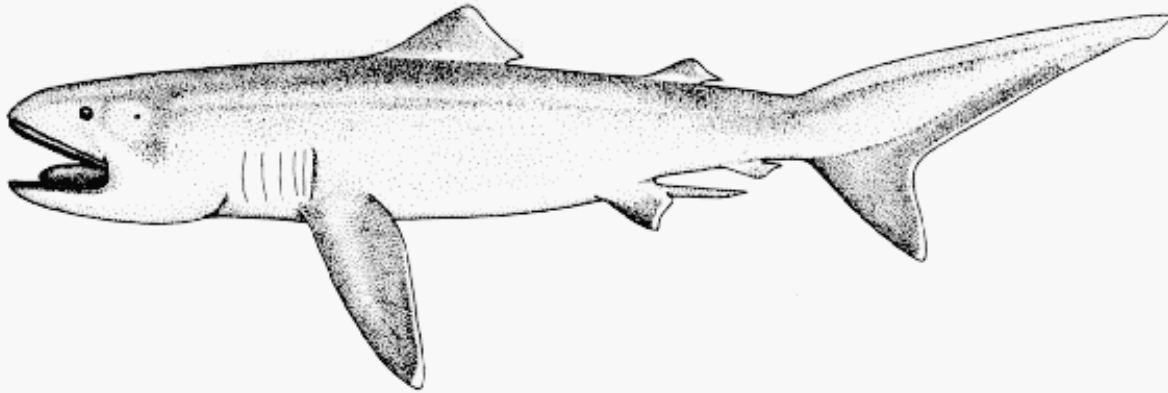


Smalltooth sand tiger (*Odontaspis ferox*)



Source: Food and Agriculture Organization of the United Nations, Ebert, D.A. 2014. On Board Guide for the Identification of Pelagic Sharks and Rays of the Western Indian Ocean. Reproduced with permission

Family: Megachasmidae (1 species)
Megamouth shark (*Megachasma pelagios*)



Family: Cetorhinidae (1 species)
Basking shark (*Cetorhinus maximus*)



Family: Alopiidae (3* species)
Thresher sharks

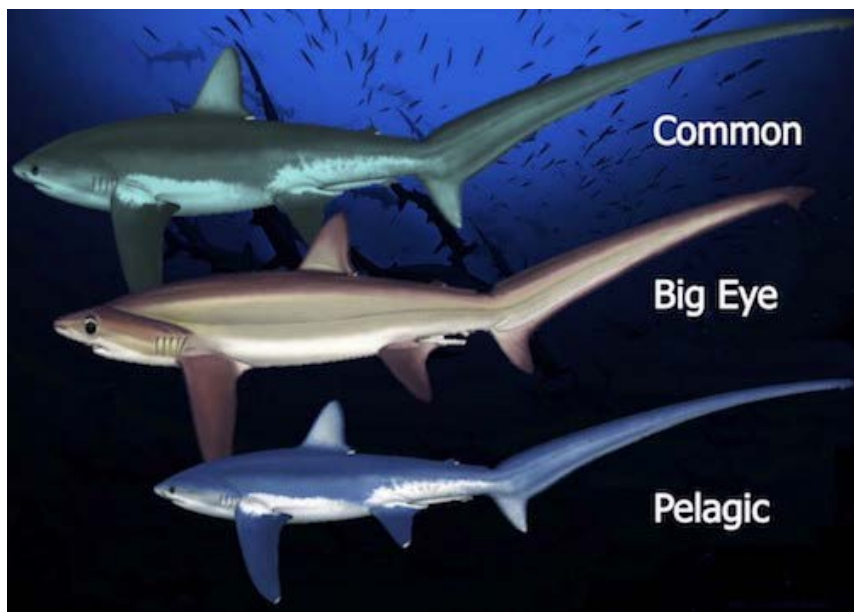
Bigeye thresher (*Alopias supercilliosus*)



Common thresher (*Alopias vulpinus*)

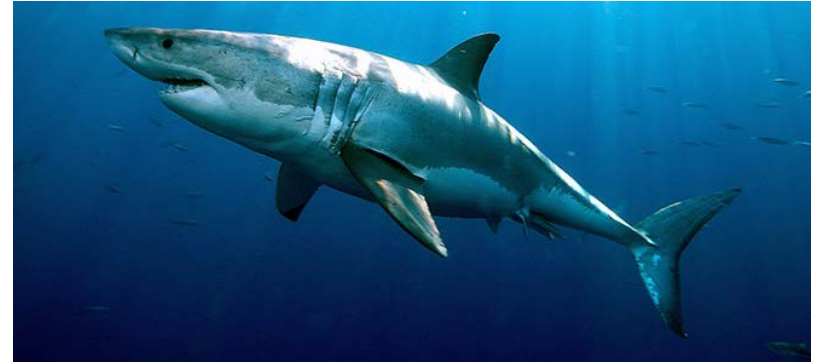


Pelagic thresher (*Alopias pelagicus*)



Family: Lamnidae (5 species)
Mackerel sharks

White shark (*Carcharodon carcharias*)



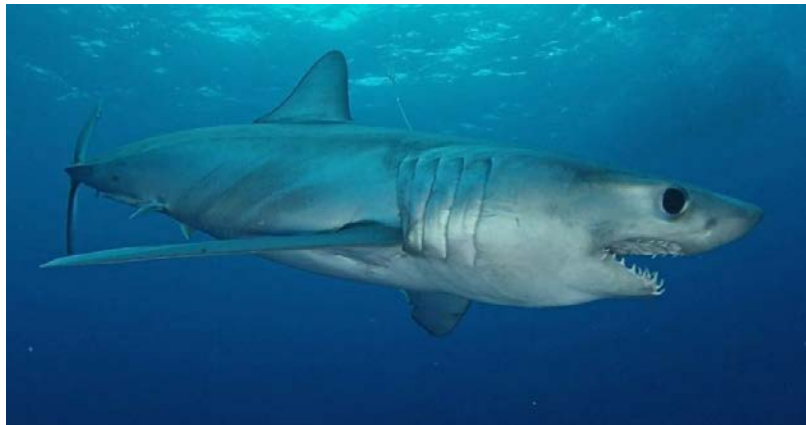
Porbeagle (*Lamna nasus*)



Salmon shark (*Lamna ditropis*)



Longfin mako (*Isurus paucus*)



Shortfin mako (*Isurus oxyrinchus*)



- Largest order
- Diverse (size, habitats, reproduction)
- Anal fin
- Nictitating membrane
- 8-11** families (258 species)

Leptochariidae (1 species; Barbeled hound shark)



Pseudotriakidae (8 species; False cat sharks)



Proscylliidae (3 species; Finback cat sharks)



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

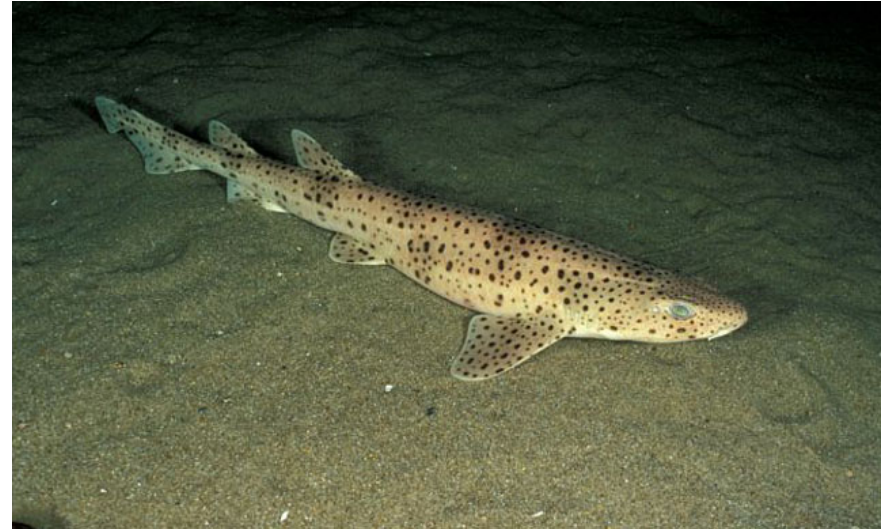
Family: Scyliorhinidae (~150 species)

'Cat sharks'

Swell sharks



Nursehound shark



Chain catshark



Family: Triakidae (44 species)
'Hound sharks'

Genus *Mustelus*: Smooth dogfish



Genus *Galeorhinus*: Tope sharks



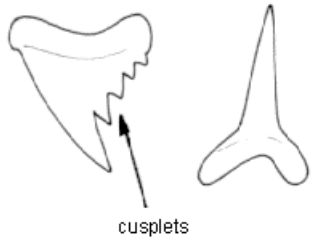
Genus *Triakis*: Leopard sharks



Family: Hemigaleidae (8 species)

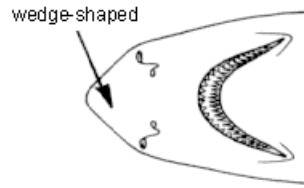
'Weasel sharks'

Snaggletooth shark



cusplets

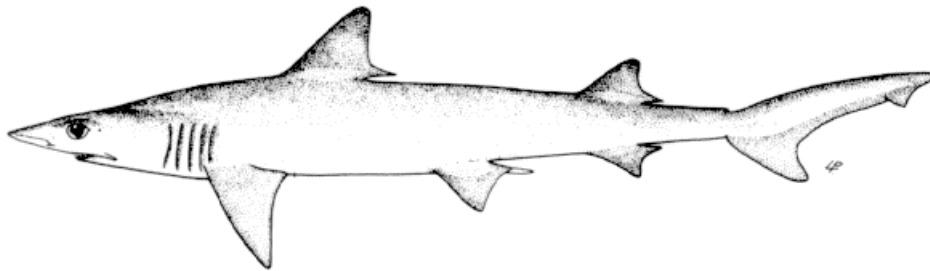
upper and lower teeth



wedge-shaped

underside of head

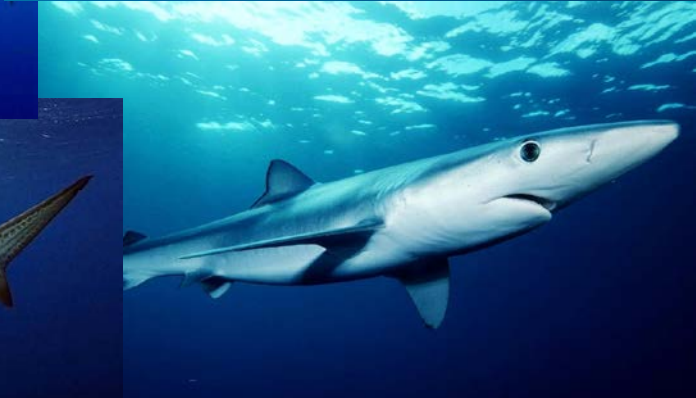
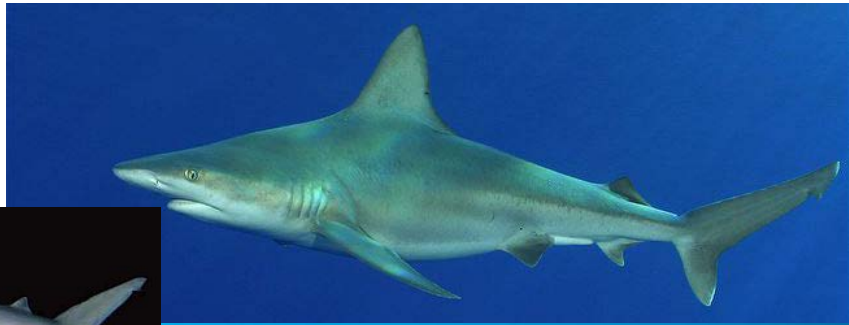
Hooktooth shark



FAO



Family: Carcharhinidae (~60 species)
'Requiem sharks' or 'Ground sharks'



Family: Sphyrnidae (8 species)
'Hammerhead sharks'

Winghead shark



Scalloped hammerhead



Great hammerhead



Bonnethead



Sphyrna tiburo



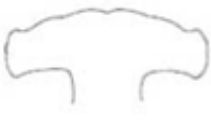
Sphyrna media



Sphyrna tudes



Sphyrna corona



Sphyrna lewini



Sphyrna zygaena

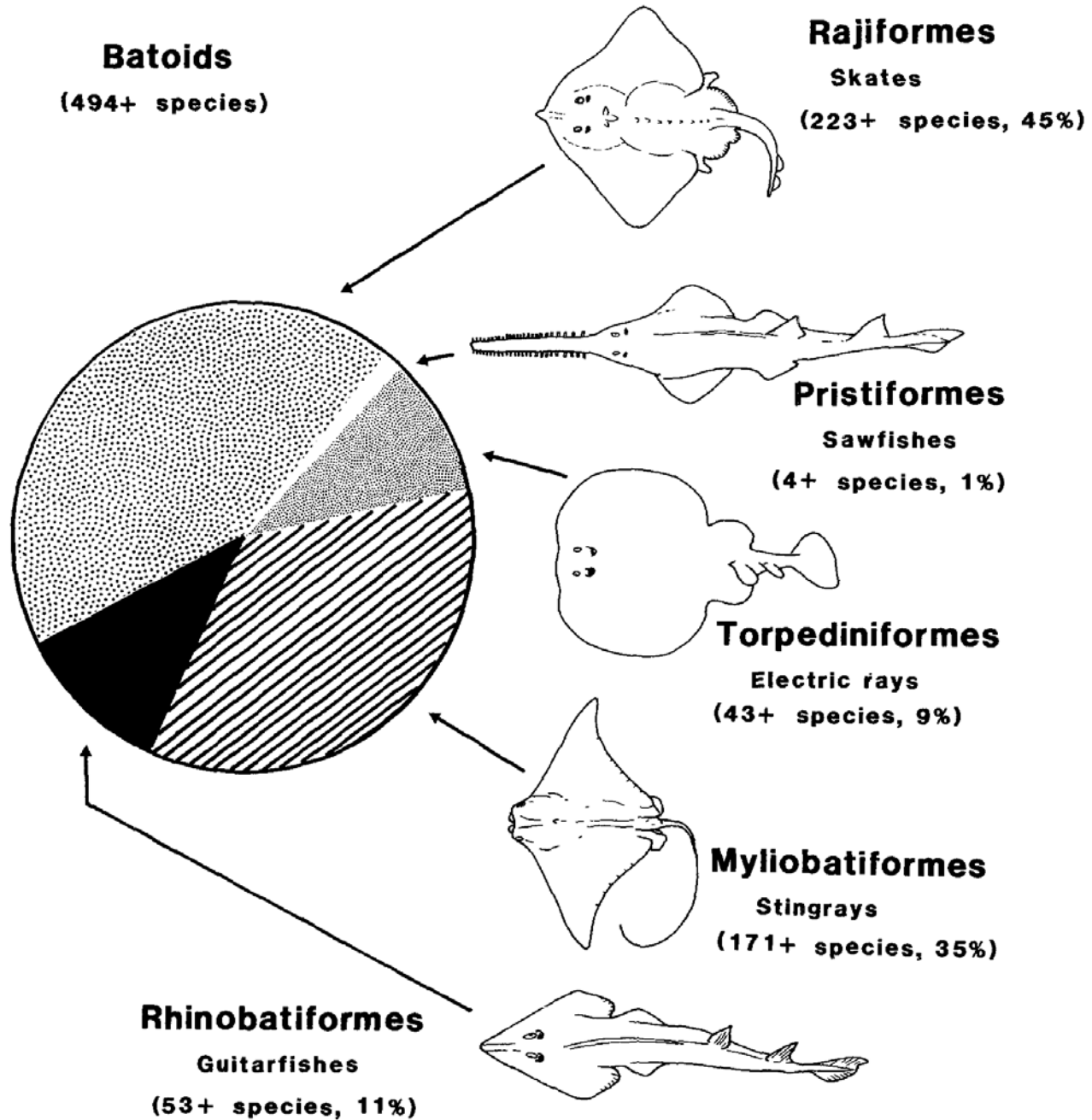


Sphyrna mokarran



Eusphyrna blochii

SuperOrder Batoidea



- 'Skates'
- Marine
- Oviparous
- 4 families (293 species)
 - Anacanthobatidae (~15 species)
 - Arhynchobatidae (~100 species)
 - Gurgesiellidae (~20 species)
 - Rajidae (~160 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

Rajidae



Arhynchobatidae



Anacanthobatidae



Gurgesiellidae



- ‘Torpedo’ or ‘Electric’ rays
- Marine
- Electrogenic organs
- Eyes small (even absent!)
- Ovoviparous
- 4 families (74 species)
 - Hypnidae (1 species)
 - Narkidae (13 species)
 - Torpedinidae (24 species)
 - Narcinidae (32 species)

Hypnidae: Coffin Ray



Narkidae: Sleeper Rays



Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

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Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

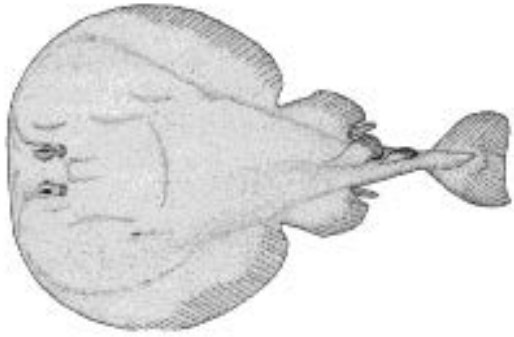
Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

Family: Torpedinidae (24 species)
'Torpedo rays' (200 VOLTS!)



Family: Narcinidae (32 species)
'Numbfish' (10-40 volts)



- Marine and freshwater
- Viviparous
- Shallow water (tropical)
- 5 families (59 species)
 - Rhinobatidae (43 species)
 - Rhinidae (10 species)
 - Pristidae (4 species)
 - Glaucostegidae (1 species)
 - Trygonorrhinidae (8 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

SuperOrder Batoidea

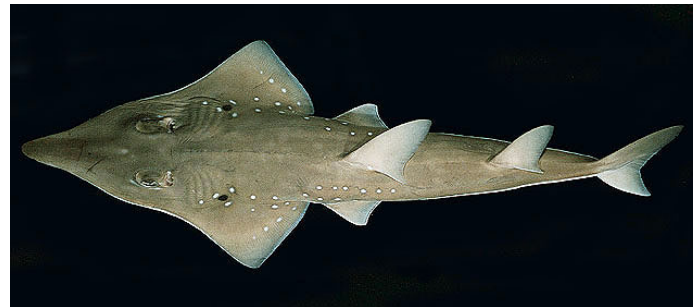
Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes

Guitarfish



Wedgefish

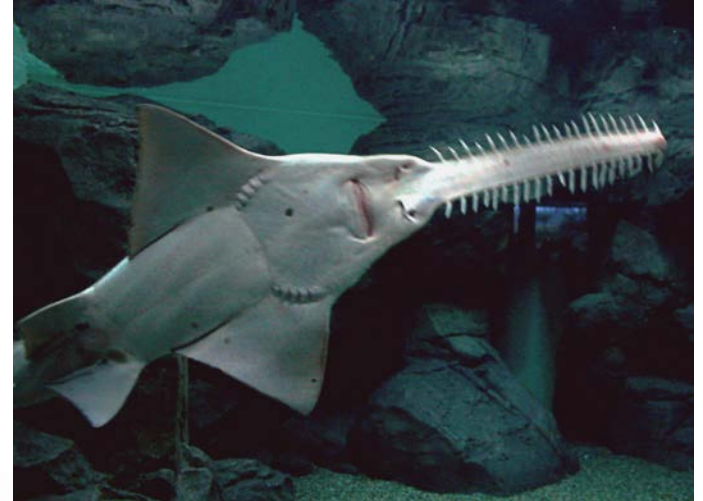


Banjo rays



Family Pristidae: 'Sawfish'

- Marine and freshwater
- Shallow water (tropical)
- Gills ventral (under head)
- Pectoral fins joined to body
- No barbels on saw
- Saw teeth symmetrical
- Large (to ~6 m)



- 'Rays'
- Marine and freshwater
- Viviparous
- Diverse
- 13 families (219 species)

Class Chondrichthyes

Subclass Holocephalii

Order Chimaeriformes

Subclass Elasmobranchii

SuperOrder Squalomorphii

Order Hexanchiformes

Order Echinorhiniformes

Order Squaliformes

Order Squatiniformes

Order Pristiophoriformes

SuperOrder Galeomorphii

Order Heterodontiformes

Order Orectolobiformes

Order Lamniformes

Order Carcharhiniformes

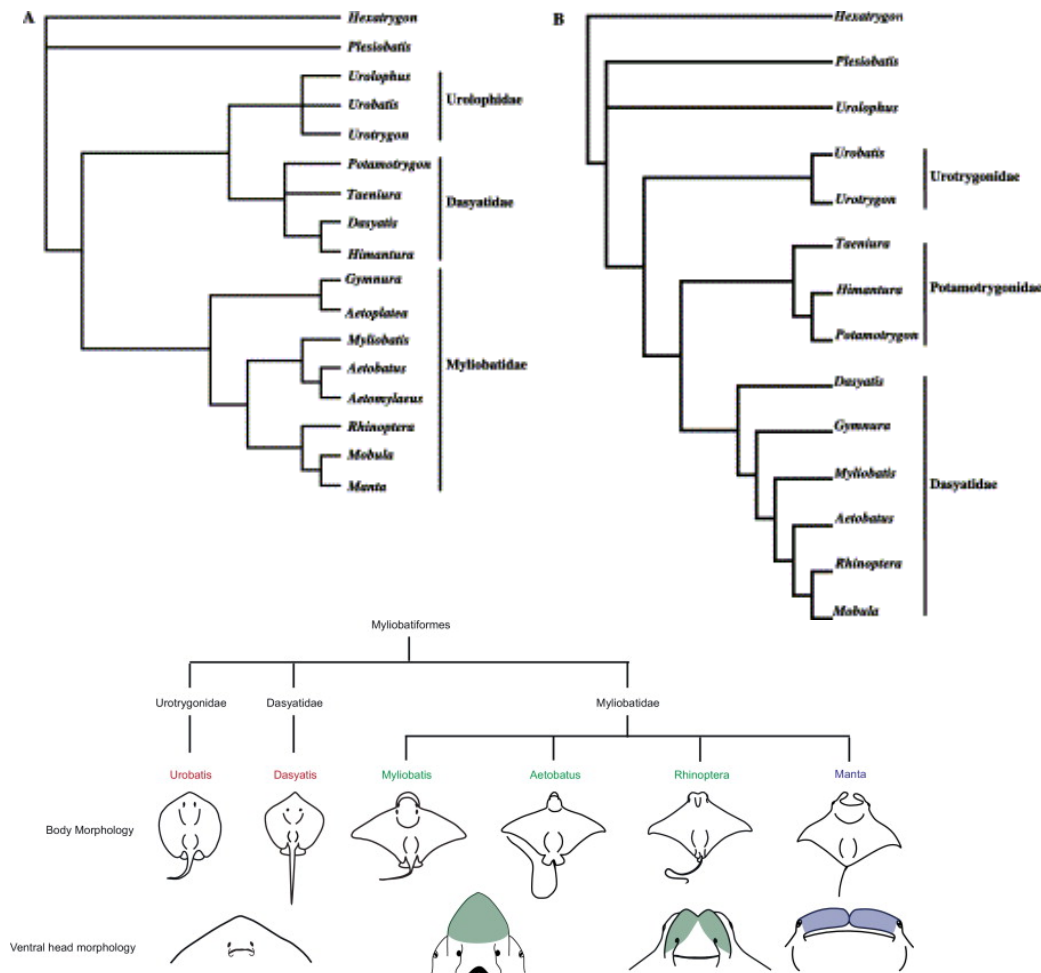
SuperOrder Batoidea

Order Rajiformes

Order Torpediniformes

Order Rhinopristiformes

Order Myliobatiformes



Family: Dasyatidae (~80 species)
'Stingrays' or 'Whiptail rays'



Southern stingray



Family: Gymnuridae (~15 species)
'Butterfly rays'



Family: Myliobatidae (~80 species)
'Eagle rays'

Spotted eagle rays



Cownose rays



(c) Doug Perrine

Bullnose rays



Family: Mobulidae (12 species)
'Manta rays' or 'Devil rays'

