Fish or Mammals?

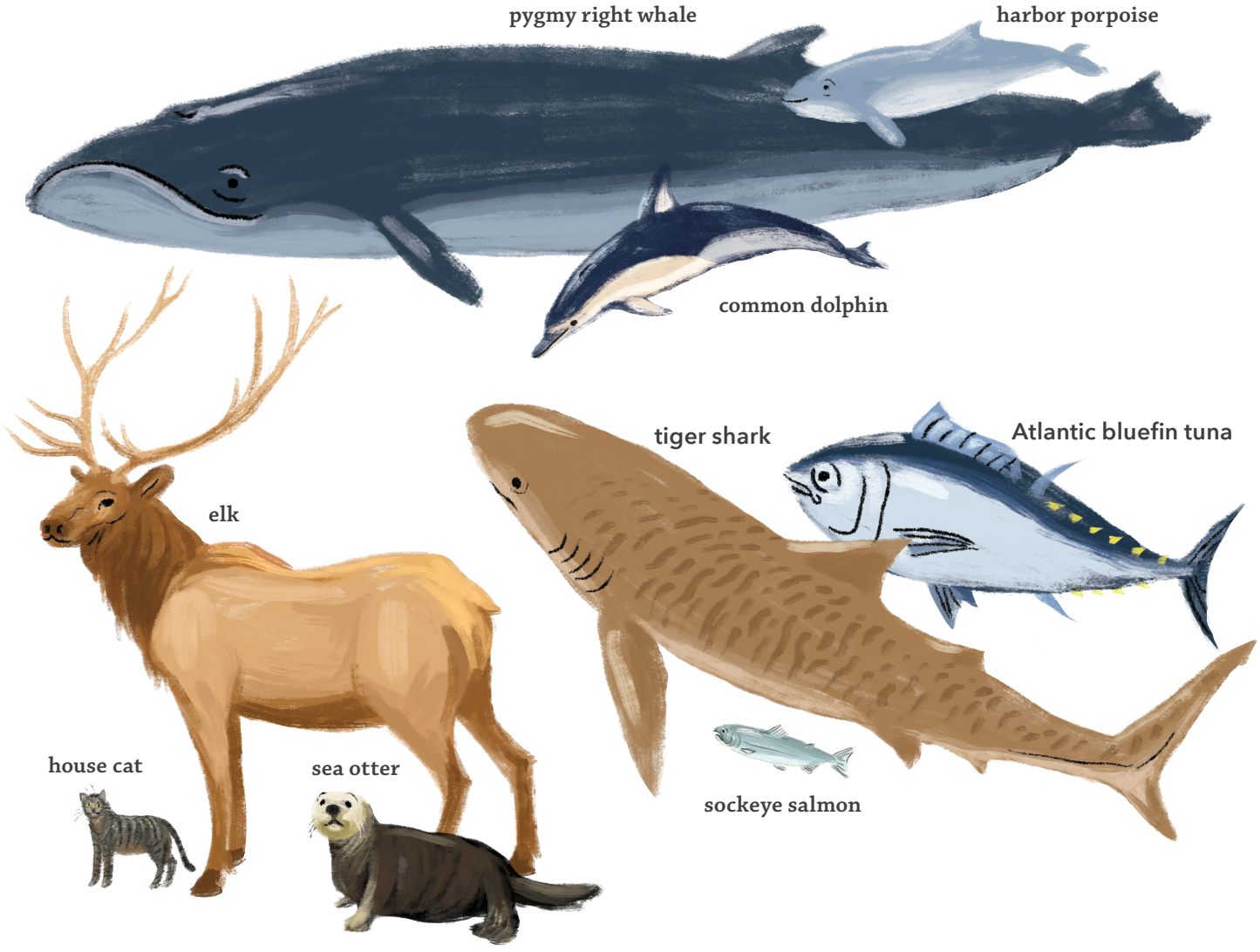
Case study

Background

Cetaceans (sih-TAY-shuns) are a group of animals made up of about 90 different species, including porpoises, dolphins, and whales. Like fish, Cetaceans spend their whole lives in the water. But, like mammals, they need to come to the surface to breathe air.

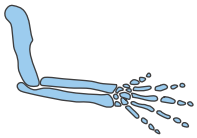
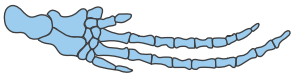
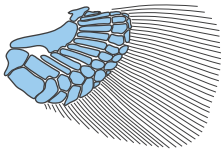
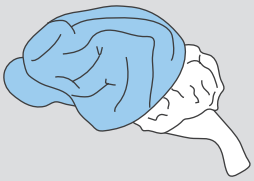
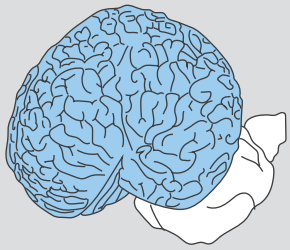
Through the centuries, scientists have used multiple lines of evidence to classify Cetaceans. As new lines of evidence have become available, we have been able to understand Cetaceans' relationship with other animals at finer levels of detail. Fairly recently, scientists were finally able to identify Cetaceans' closest living relative—the animal with which they share the most recent common ancestor.

Follow along to see what evidence scientists used. Analyze it to learn what it showed them.



Evidence from Anatomy

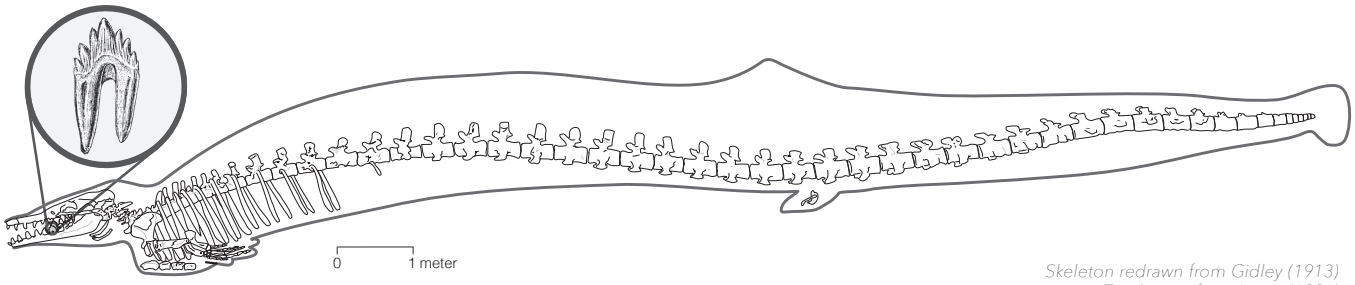
Before the early 1700s, people disagreed about whether cetaceans should be classified as mammals or as fish. The table below lists some of the observations about mammal, cetacean, and fish anatomy that were available 300 years ago.

Mammals	Cetaceans	Fish
Internal skeleton	Internal skeleton	Internal skeleton
Warm-blooded	Warm-blooded	Cold-blooded
Lungs	Lungs	Gills
Forelimb bones (mouse) 	Flipper bones (whale) 	Pectoral fins (shark) 
Live birth	Live birth	Lays eggs (with a few exceptions)
Mammary glands/milk	Mammary glands/milk	No mammary glands/milk
Skin is covered with fur	Adults have bare skin, but embryos have fur	Skin is usually covered with scales, sometimes bare
4-chambered heart	4-chambered heart	2-chambered heart
Brain anatomy (cat) 	Brain anatomy (whale) 	Brain anatomy (shark) 
Four limbs for moving on land	Flippers and a tail for moving in water	Fins and a tail for moving in water
Embryos have 4 limb buds. The front two become forelimbs, and the rear two become hindlimbs.	Embryos have 4 limb buds. The front two become flippers, and the rear two are absorbed back into the body.	Embryos have 4 fin buds. The front two become pectoral fins, and the rear two become pelvic fins.

Evidence from Fossils

In 1839, an anatomist determined that a fossil previously thought to be a dinosaur was actually an ancient whale that shared characteristics with mammals. The fossil, which he called Zeuglodon, revealed two key details:

- The Zeuglodon fossil looked different from any living whale, showing that whale species have changed over time.
- The Zeuglodon fossil had teeth with two roots. Reptiles (including dinosaurs) have teeth with one root. Most land mammals have teeth with two roots.



Skeleton redrawn from Gidley (1913)
Tooth inset from Lucas (1901)

Zeuglodon

You can see that Zeuglodon shares a lot of characteristics with modern orca:

Modern Orca The orca spends its life entirely in the water. It can be found in all of the world's oceans. It grows to be about 20 feet (6 meters) long, and it hunts fish, seals, and other animals for food.

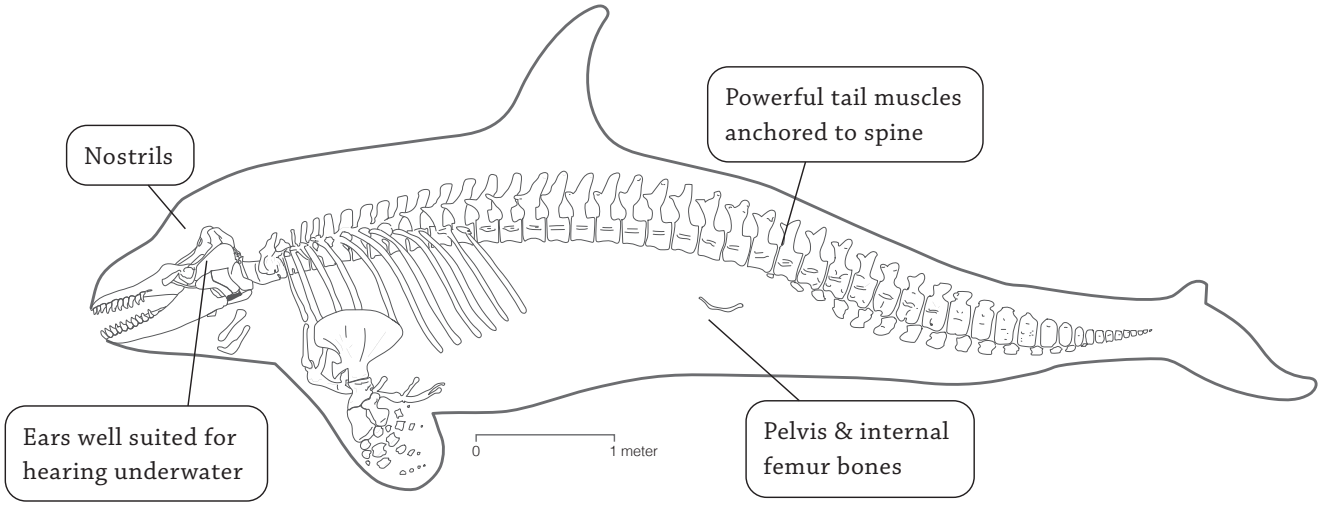


Image drawn from Clement & Schlader

Evidence from Fossils (cont.)

Paleontologists have uncovered a series of fossils with anatomical characteristics that are in between those of whales and land mammals. This evidence shows how the ancestors of Cetaceans changed over time.

Discovered: 1845

Dorudon With flippers and tiny hindlimbs, Durodon wouldn't have been able to move on land. Its fossils, which are an estimated **36–40 million years old**, have been found in coastal areas around the world. At 16 feet (5 meters) long, Dorudon lived during the same time period as Zeuglodon, but was much smaller in size.

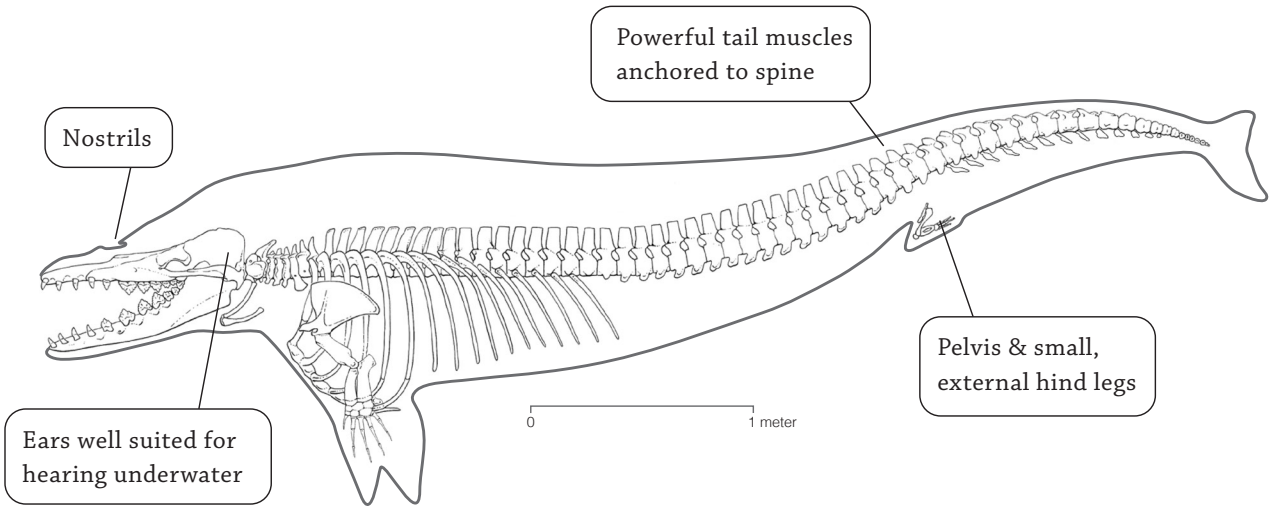


Image modified from Gingerich et al (2009)

Discovered: 1994

Rodhocetus probably spent time both in the water and on land. It probably moved speedily through water but quite awkwardly on land. Its fossils, which are about **46-47 million years old**, have been found in modern-day Pakistan.

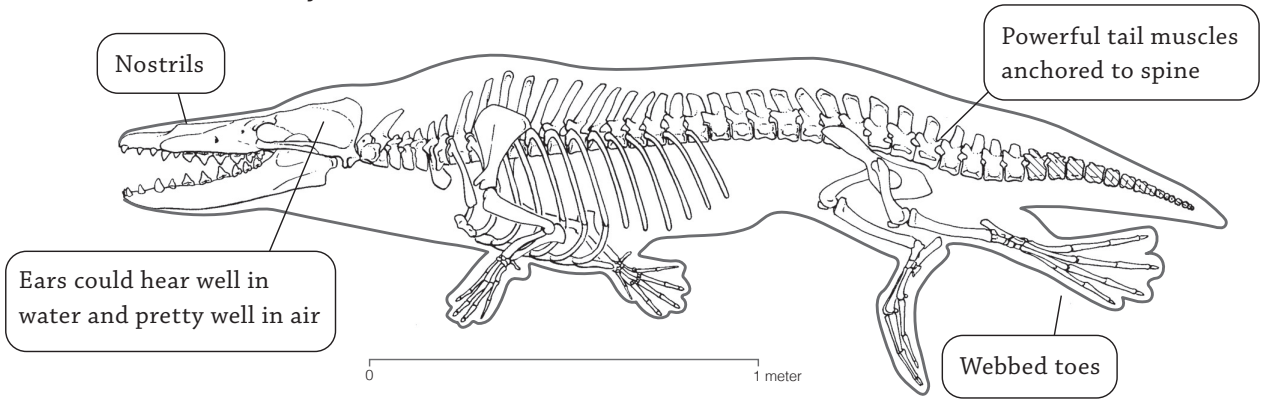


Image modified from Gingerich (2010)

Evidence from Fossils (cont.)

Ambulocetus means "walking whale." Ambulocetus probably moved comfortably both in the water and on land. Its fossils, which are about **49 million years old**, have been found in modern-day Pakistan.

Discovered: 1993

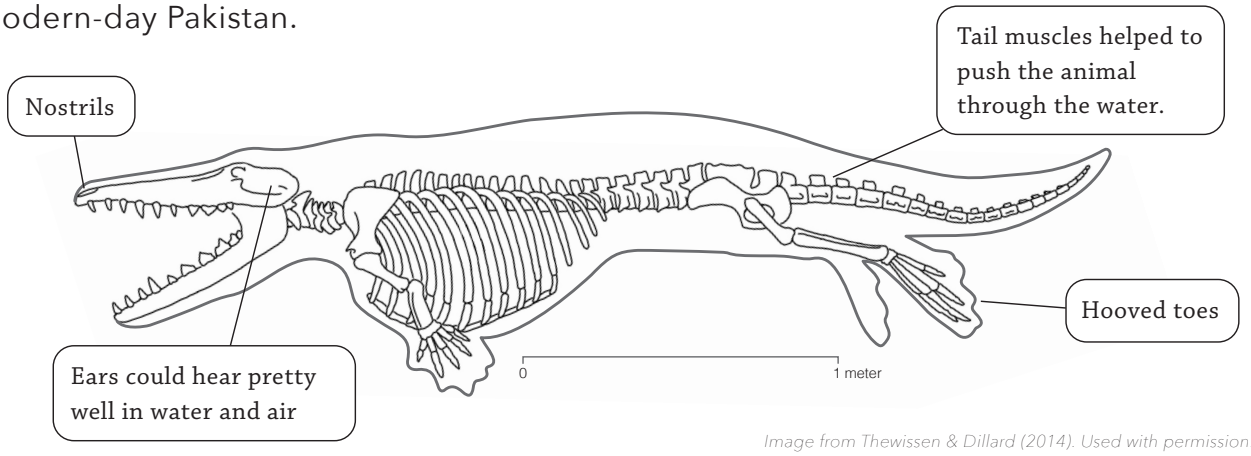


Image from Thewissen & Dillard (2014). Used with permission.

Pakicetus probably moved swiftly on land and spent most of its time there. However, molecular test results suggest that it ate mainly fish and other animals that lived in the water. Its fossils, which are about **50 million years old**, have been found in modern-day Pakistan.

Discovered: 1983

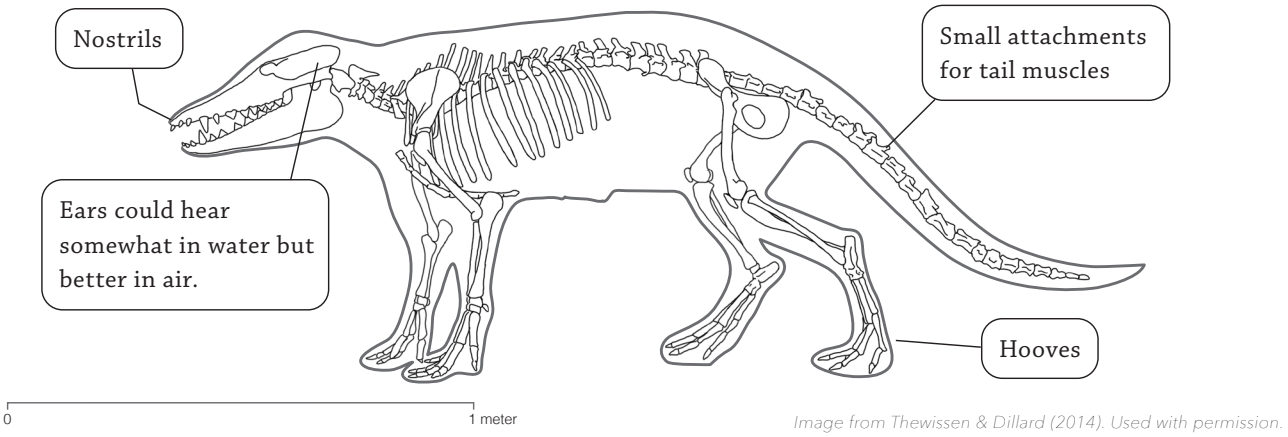
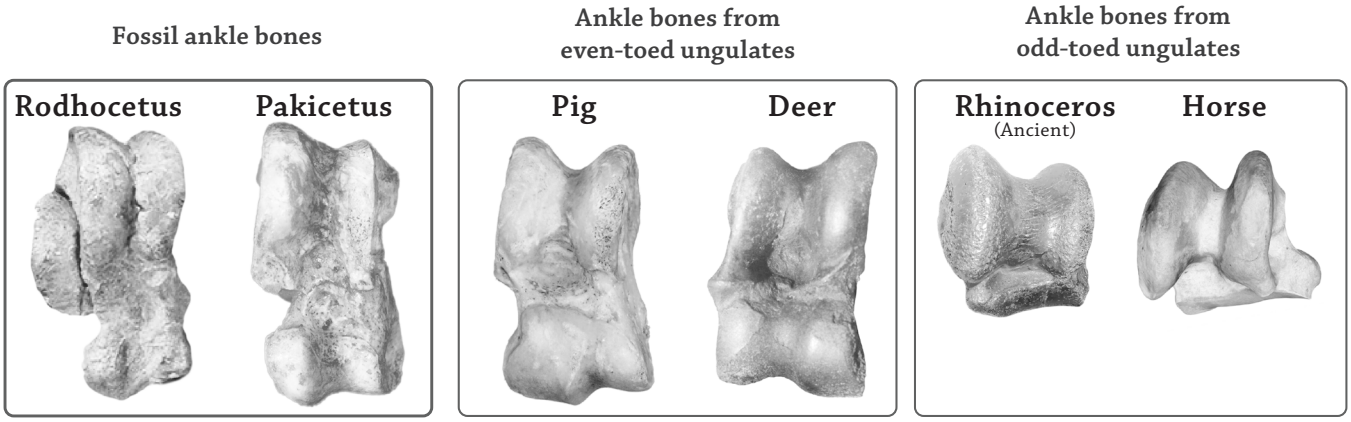


Image from Thewissen & Dillard (2014). Used with permission.

Fossil ankle bones

Modern Cetaceans do not have ankles or ankle bones. But fossil whales do. The anatomy of fossil feet and ankles showed that ancestral whales had hooves. Animals with hooves are called ungulates (UHN-gyoo-litz).

Ungulates are further divided by whether they have an odd or even number of toes. Odd-toed ungulates have 1 or 3 toes—for example horses and rhinoceroses. Even-toed ungulates have 2 or 4 toes—for example pigs, deer, camels, and hippopotamuses.

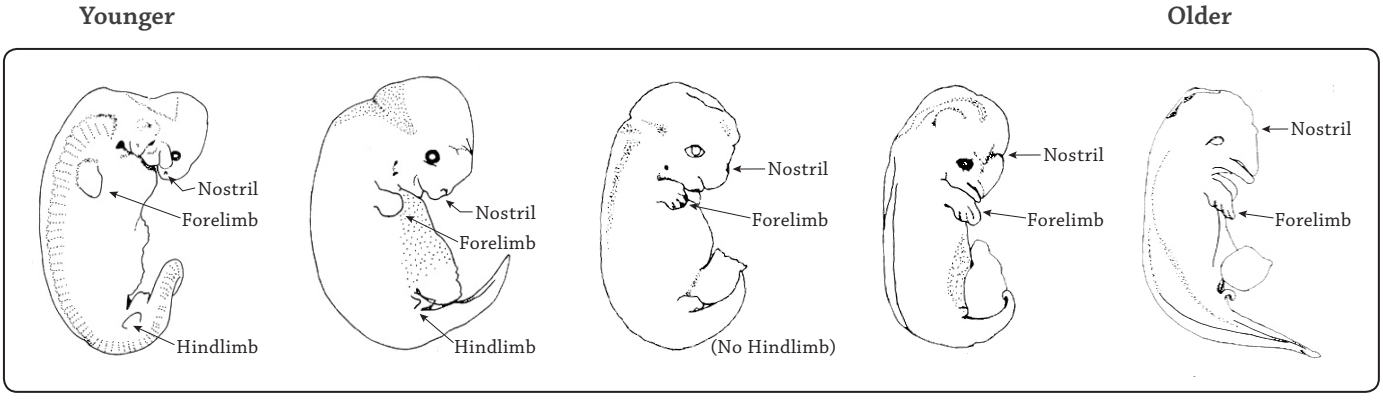


Pakicetus and pig bones © 2016 J. G. M. 'Hans' Thewissen

Evidence from Embryos

Notice how the position of the nostrils and the shape of the hindlimbs in the series of fossil whales changed over time.

Similar changes happen over time in the nostrils and hindlimbs of developing dolphin embryos:



Drawings from the Digital Library of Dolphin Development: http://web.neomed.edu/web/anatomy/DLDD/index.html

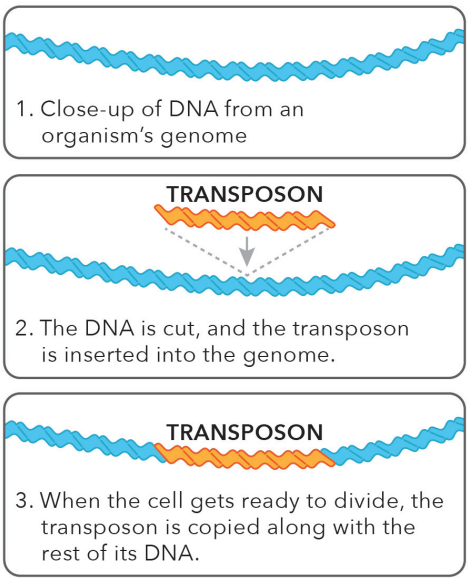
DNA Evidence: Comparing Amino Acid Sequences

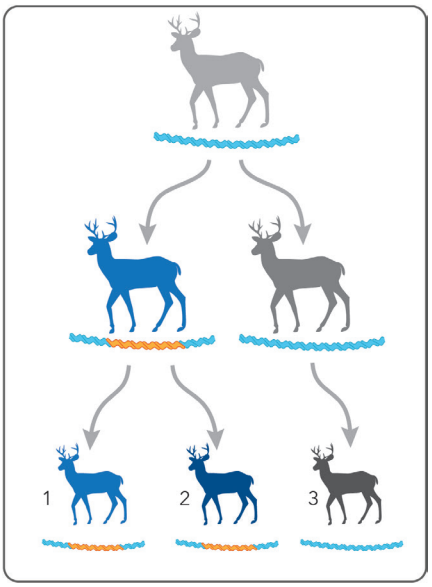
Whales make milk to feed their babies. Caseins are nutritional proteins that are found in milk. Since all mammals make milk, they all have genes that code for casein. In the mid-1990s, one group of researchers decided to investigate which mammals are most closely related to whales by looking at the amino acid sequences of casein proteins:

ANIMAL	Number of amino acids that differ from whale casein	Percent identical to whale casein
Pig	48 out of 152	**68.4%**
Cow	56 out of 153	**63.4%**
Hippopotamus	24 out of 145	**83.4%**
Camel	36 out of 156	**76.9%**
Goat	52 out of 155	**66.5%**
Water buffalo	51 out of 153	**66.7%**
Mouse	90 out of 146	**38.4%**

DNA Evidence: Transposons

Transposons are chunks of DNA from viruses that get inserted randomly into a cell's genome. They are commonly found in the DNA of most living things.





The neat thing about transposons is that once they pop into an animal's germline (the cells that give rise to eggs and sperm), they are passed to all of its offspring.

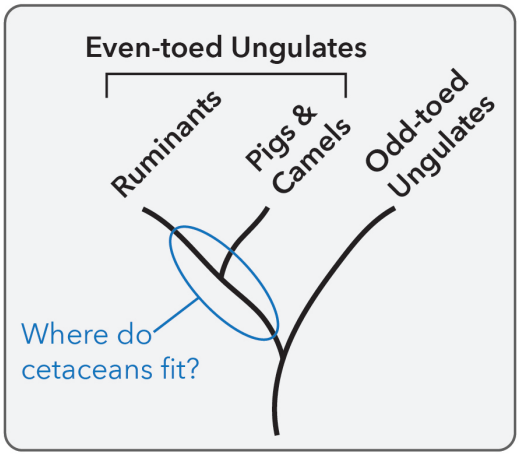
At this point, the transposons have usually been inactivated. They do not code for proteins, and they cause no harm. But organisms that carry a transposon continue to pass it to their offspring, for thousands or even millions of generations.

Only the descendants of the original ancestral animal will have the transposon in that particular place in their genome.

DNA Evidence: Transposons (cont.)

The tree shows the relationships among groups of animals with hooves (ungulates).

Even-toed ungulates can be further divided into ruminants (ROOM-in-entz), which share a certain kind of stomach anatomy, and another group that contains pigs and camels.



To find out where cetaceans fit on this tree, researchers looked for 5 different transposons in specific locations in the genomes of several ungulates. The table shows what they found.

○ = no transposon ● = transposon

ANIMAL	Transposons				
	A	B	C	D	E
Camel	○	○	○	○	○
Pig	●	○	○	○	○
Ruminants (deer, giraffe, sheep & cow)	●	●	○	●	○
Hippopotamus	●	●	●	○	○
Whales	●	●	●	○	●

References

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Accession numbers for casein amino sequences (GenPept/UniProtKB/Swiss-Prot):

Q27952.1 (fin whale; *Balaenoptera physalus*)
F5CIN1 (pygmy right whale; *Caperea marginata*)
P02668.1 (cow; *Bos taurus*)
P02670.2 (goat; *Capra hircus*)
P11841.2 (pig; *Sus scrofa*)
Q28441.1 (hippopotamus; *Hippopotamus amphibius*)
P79139.1 (camel; *Camelus dromedarius*)
P11840.2 (water buffalo; *Bubalus bubalis*)
P06796.2 (mouse; *Mus musculus*)