Who Are the Marine Mammals?

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Contents

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Learning goals

- Get acquainted with marine mammals and how they have evolved.
- Understanding physiological and morphological adaptations to marine life.
- Learn about marine mammals found in the North Sea and Baltic Sea.

1 Introduction

Marine mammals are found in several lineages among the more than 6000 species of mammals (all belonging to the class Mammalia). Not all marine mammals are closely related. Together they form a habitat-based group of animals associated with water. Mammals evolved on land some 250 million years ago. At least seven separate clades of mammals have returned independently to water, where they have adapted to aquatic habitats. Despite huge differences between species, terrestrial and marine mammals share many common features (Table 1).

Today, some 130 living species of mammals depend on the ocean for most, or all, of their lives. Marine mammals are divided into three taxonomic orders (Cetacea, Sirenia and Carnivora) with different terrestrial ancestors (Table 2, Figs. 1 and 2).

Cetaceans (whales) evolved from terrestrial ancestors which were hoofed animals (ungulates, belonging to the order Artiodactyla which also contain hippopotamus, pigs and deer) more than 50 million years ago, during the geological epoch called the Eocene. The closest now-living terrestrial relative of cetaceans is the hippopotamus and the ruminants, including cattle. One of the earliest known cetaceans is *Pakicetus* (meaning 'the cetacean from Pakistan'). *Pakicetus* was mostly terrestrial but walked and most probably hunted in shallow waters. It looked like a small dog with a long snout, incisors and hooves.

Sirenians (sea cows) are herbivores that emerged during the same time period as cetaceans. Sirenians share a common ancestor with elephants and hyraxes. Early sirenians possessed an elongated body and had four legs, with dense and large ribs. They were

Table 1 What does terrestrial and marine mammals have in common?

Viviparity and lactation	In mammals, the embryo grows inside the mother. After birth, the newborn is nursed by mammary glands that provide milk
Homeothermy	Mammals are warm-blooded and usually covered by hair. Seals have fur, but whales have no or very few hairs
Heart	The mammalian heart has four compartments and a left aortic arch
Skeleton	Mammals have a lower jaw with one single bone called dentary. Most mammals have teeth
Ear	The mammalian middle ear has three bones: the malleus, incus and stapes. Most mammals have an external outer ear
Cervical vertebrae	Mammals have seven cervical vertebrae forming the neck
Brain	Mammal brains have a cerebral cortex. This outer layer of neural tissue plays a key role in for example, language, memory and attention
Blood	Mammals have red blood cells delivering oxygen to tissues. Red blood cells lack a nucleus
Respiration	Mammals have a *thoracic diaphragm*. When this muscle contracts, it increases the thoracic cavity, facilitating air entering the lungs

Table 2 Marine mammals have evolved from three taxonomic orders

Order	Examples of marine mammals	Number of species
Cetacea (whales)	Toothed and baleen whales	92 species
Carnivora (carnivores)	Seals and sea lions Polar bear Sea otter	37 species
Sirenia (sea cows)	Manatees and dugong	4 species

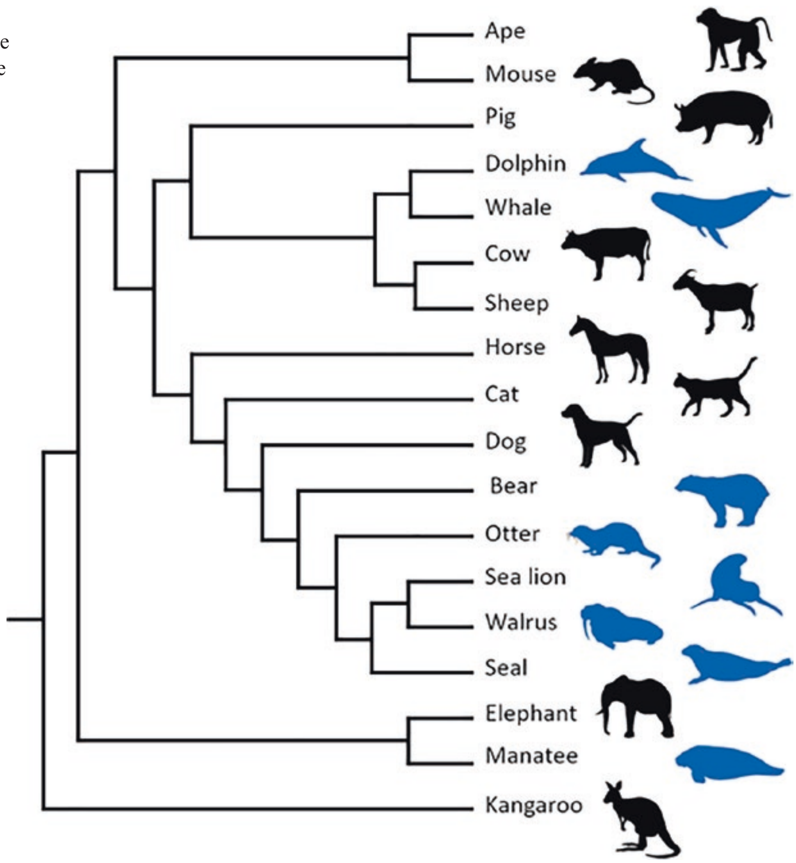

Fig. 1 Simplified phylogenetic tree showing the relationships between marine mammals (in blue) and their closely related terrestrial groups (in black)

probably found in rivers and estuaries, living from plants and seagrass.

Pinnipeds (seals, sea lions and walruses) evolved from another group of terrestrial mammals 25 million years ago during the late Oligocene epoch. Pinnipeds shares a common ancestry with so-called *arctoid carnivores*, to which both bears and otters belong.

The polar bear (from the bear family, Ursidae) and sea and marine otters (from the family Mustelidae) are more recently derived from terrestrial clades. Polar bears evolved from brown bears around 600 thousand years ago. They have adapted to a marine and Arctic lifestyle through a lack of fur pigmentation, shorter but more curved claws, specialized front paws for swimming, and a larger and more round body. Sea and marine otters have aquatic adaptations that distinguish them from other mustelids, such as their large size.

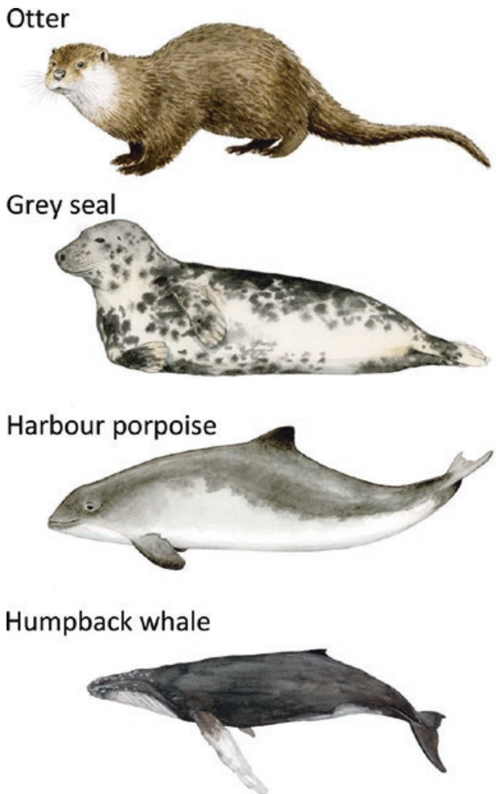

Fig. 2 Different marine mammals. Not to scale. Drawings by Annika Toth

2 Marine mammals from the North and Baltic Seas

The IUCN Red List of Threatened Species is a comprehensive inventory of the global conservation status of plant and animal species. It uses a set of quantitative criteria to evaluate the extinction risk of thousands of species. These criteria are relevant to most species and all regions of the world. The IUCN Red List is an authoritative guide to the status of biological diversity.

In descending order of threat, the IUCN Red List threat categories are as follows:

- Extinct
- Extinct in the wild
- Critically endangered
- Endangered
- Vulnerable
- Near threatened
- Least concern
- Data deficient

Name: Harbour porpoise (Fig. 3)

Scientific name: *Phocoena phocoena*

Behaviour: Usually a rather slow swimmer, generally wary of boats, and almost never seen to bow-ride (i.e. surf the wave created by boats, as often observed in dolphins). They can speed up and change direction quickly, sometimes making arc-shaped leaps when chasing prey. Most dives last less than 5 min. The blow is not easily seen but can be heard from quite some distance in calm weather and resembles a sharp, puffing sound. Harbour porpoises are often sighted by themselves or in small groups and prefer coastal and shallow waters, even though in some areas they are also found in deeper waters. Occasionally, they have been observed swimming up rivers.

Distribution: Coastal waters of the Northern Hemisphere, both in the Atlantic and Pacific Ocean. Also found in the Baltic and Black Seas. Probably rarer in deeper waters.

Description: Compared to most dolphins, the rostrum of porpoises is shorter. The dorsal side is dark grey, while the ventral side is white, and there is often a dark stripe from the corner of the mouth to the pectoral fin. The dorsal fin is low and triangular. The body shape is rather short and round, limiting heat loss in cold waters.

Weight and size: 35–90 kg and 135–180 cm in length. Females are larger than males.

Lifespan: Approximately 3–10 years, rarely up to 20 years or more.

Fig. 3 Harbour porpoise, *Phocoena phocoena*. © Florian Graner, Fjord&Bælt

Fig. 4 Harbour seal, *Phoca vitulina*. © Prof. Krzysztof Skóra Hel Marine Station, University of Gdańsk

Diet: Fish (e.g., herring, gobids, sprat, cod, whiting, sole, sand eel), crustaceans and squid.

Potential predators: Grey seals, sharks and orcas; also killed by bottlenose dolphins.

IUCN red list status: North Sea and inner Danish water populations are of least concern, whereas the Baltic Sea population is critically endangered.

Special features: In the Baltic Sea there are two spatially separated and genetically distinct populations.

Name: Harbour seal (Fig. 4)

Scientific name: *Phoca vitulina*

Behaviour: Harbour seals usually swim and dive alone, whereas on land they can congregate in great numbers. They usually stay within 50 km from where they reside on land but can also cover longer distances on feeding trips, males generally swimming larger distances than females. Harbour seals haul out on land to rest, thermoregulate, and give birth. On land, they are shy and easily disturbed by nearby boats or humans.

They are less vocal in air than grey seals but sometimes produce grunting and yelping sounds. Under water, the most commonly heard sounds are from males making repetitive stereotypical calls during the mating period in the summer. Harbour seals are curious and often play by themselves with kelp or other objects.

Distribution: Coastal waters in the North Atlantic and North Pacific Oceans, and in the southwestern Baltic Sea.

Description: Round head, pelage in different colours and with different patches. Short, dog-shaped snout with V-shaped nostrils.

Weight and size: Adult males are 160–190 cm long and weigh 70–150 kg, adult females are 150–170 cm long and weigh 60–110 kg. Size may vary between populations.

Lifespan: Up to 20 years, with females living longer than males.

Diet: Generalist feeder with a varied diet consisting of fish, cephalopods, and crustaceans. Diet varies between populations and can be area- and season-specific.

Natural predators: Orcas, sharks, walruses, grey seals and eagles (pups).

IUCN red list status: Least concern.

Special features: One of the most widely distributed species of pinnipeds. In the southern Swedish part of the Baltic Sea, there is a small and genetically distinct population.

- **Name: Grey seal (Fig. 5)**

Scientific name: *Halichoerus grypus*

Behaviour: Grey seals may forage far offshore and spend the remainder of their time close to the coast. They are opportunistic feeders, consuming four to six percent of their body weight per day. Feeding methods vary between areas and populations. Small fish are usually consumed underwater and swallowed whole. Large fish are brought to the surface and held by prehensile front flippers. The fish head is bitten off and discarded, while the remainder of the fish is broken into small pieces and swallowed.

Distribution: East and western Atlantic, also in the Baltic Sea.

Description: Relatively large head with long snout, straight to convex profile and flat skull. W-shaped nostrils well separated at base. Females are silver-grey with dark patches on the dorsal side, males are dark grey with silver-grey patches; sometimes also completely brown or black.

Weight and size: Adult males are 200–210 cm long and weigh 230–270 kg, adult females are 180–190 cm long and weigh 155–186 kg. Size may vary between populations.

Lifespan: Up to 18 years or more (sometimes more than 40 years).

Diet: Generalist feeder consuming a wide range of species. Diet may be season- and area-specific and can consist of sand eels, herring, cod, flatfishes but sometimes also birds, harbour seals and even harbour porpoises.

Natural predators: Sharks and orcas (and pups have been observed being eaten by older grey seals as well as by eagles).

IUCN red list status: Least concern.

Special features: A grey seal pup may gain as much as 2.5 kg per day during the time it receives milk from its mother. This is because the milk contains 50% fat.

- **Name: Ringed seal (Fig. 6)**

Scientific name: *Pusa hispida*

Behaviour: Most ringed seals do not move over large distances, and they regularly return

Fig. 5 Grey seal, *Halichoerus grypus*. © Prof. Krzysztof Skóra Hel Marine Station, University of Gdańsk

Fig. 6 Ringed seal, *Pusa hispida*. © Pawel Bloch

to the same haul-out site during the night after their foraging trips.

Distribution: Circumpolar distribution throughout the Arctic, and in northern and eastern part of the Baltic Sea.

Description: Ring-shaped marks on their fur as adults. Small head with a short cat-like snout with V-shaped nostrils and a plump body. Their fore-flippers have strong, thick claws.

Weight and size: Up to 100 kg and 150 cm in length.

Lifespan: Up to 19 years.

Diet: Prey often consists of schooling species that form dense aggregations. Commonly eaten prey in the Baltic are cod, herring and amphipods. There are regional variations in diet.

Natural predators: Polar bears, orcas, foxes, gulls and ravens.

IUCN red list status: Least concern.

Special features: Ringed seals breed on ice. They build caves or lairs on top of the ice and under the snow by using their strong claws. Here, they give birth and nurse their young. There is a very small land-locked population of ringed seals in lake Saimaa, Finland.

3 Adaptation to marine life

Living in water, marine mammals face challenges such as heat regulation, locomotion, and the need to hold their breath in search for food. As they evolved from terrestrial mammals, they have developed different adaptations to the challenges they meet with their aquatic lifestyle:

- Preventing water entering the respiratory tract and ears
- Avoiding breaking the rib cage during deep dives
- Seeing and hearing both underwater and in air
- Suspending breathing while diving
- Storing oxygen in blood and muscles
- Avoiding the formation of nitrogen bubbles in the blood when ascending from deep dives
- Maintaining their body temperature at 37 °C in a cold environment with a high thermal conductivity
- Being able to reproduce in conditions hostile to mammals (e.g. cold water, waves and large predators)
- Withstanding a high ambient pressure during dives
- Moving in water, which is far denser than air

Here, we discuss adaptations to these challenges in more detail.

3.1 Anatomy

Most marine mammals are large and roundish. While swimming, their drag is reduced by their torpedo-shaped bodies with short limbs and small or missing external ears. Whales, manatees and sea otters live their entire lives in water. Seals and polar bears live both on land and in water, and their bodies are therefore adapted to both environments.

Whales and dolphins have bodies adapted for moving through water. Any deviations from a torpedo shape are minimized to maintain laminar water flow around the body. Hairs, bristles, and outer ears have been lost, and sexual organs and mammary glands are placed in folds. The neck is shortened, hind limbs are suppressed and the forelimbs are flattened. Their body shape minimizes drag by allowing water to flow evenly around them.

Drag consists of several components. The most important ones are pressure and frictional drag. *Pressure drag* results from differences in water pressure between the front and rear part of the body. *Frictional drag* is the force exerted on the surface of the body due to the viscosity of the fluid. The amount of drag depends on the body shape. A sphere moving in the water develops high pressure drag (due to its large cross section area) but low frictional drag (because of the small surface-to-volume ratio). On the other hand, a long slender body has low pressure drag (due to its small cross section) and a high frictional drag (because of the high surface-to-volume ratio). Moving efficiently through water calls for minimizing both types of drag by compromising the body shape between these extremes. The shape with the smallest total drag is an elongated droplet with its largest diameter one-third body length from its front. This is the 'torpedo-like' body shape found in many dolphins and some of the fast baleen whales, such as the blue whale.

The roundish body shape, together with extraordinary thick fur or massive body fat also prevents the animal from becoming cold. Heat loss is an important issue for warm-blooded animals in cold water. Newborn marine mammals rapidly gain weight and fat to prevent heat loss. The sooner the newborns can start swimming and hunting on their own, the higher are their chances to survive.

Most marine mammals have a thick layer of fat, known as blubber, below the skin. Blubber has different functions. It acts as an insulator, improving thermoregulation. It affects buoyancy and streamlines the body during hydrodynamic locomotion. Blubber stores lipids, and thus energy, that play an important role during reproduction, parturition and lactation. Many species do not feed during these activities and entirely rely on stored energy to survive. Moreover, lipid is a source of metabolic water that can be used during lactation. Their thick blubber layer causes stranded whales to overheat and dehydrate, which can often lead to death.

The senses need to be modified when moving from air to underwater. Seeing both on land and in water can be difficult because air and water have different light propagation properties. The *refractive index* in air is 1, in water it is 1.3. Aquatic mammals display *emmetropia* (sharp vision) while submerged, meaning their eyes are adapted for optimal focusing under water. Both pinnipeds and cetaceans have developed an almost spherical or slightly elliptical lens to provide a sufficiently high refractive power under water. Fishes and cephalopods also have spherical eye lenses, so this adaptation for underwater vision has evolved independently many times, so-called *convergent evolution*. In cetaceans, emmetropia in water results in *myopia* (nearsightedness).

In seals, the lens is bifocal to accommodate well both in air and under water. Also, seals have a reflective retina that makes their eyes glow at night, similar to nocturnal mammals on land (such as cats and deer). Together with a larger pupil and many rods in the retina, this makes their eyes more light-sensitive than the human eye. Light-sensitive eyes are needed when hunting at great depths and at night. In addition, the highly sensitive vibrissae of seals and the ability for echolocation in dolphins and porpoises supplements and sometimes even substitutes vision, for example, in very murky waters and at night-time.

3.2 Whale skeleton

The curiously shaped skeletons of marine mammals result from evolution of the ones of ancestral mammals that lived on land.

Let us have a look at the skeleton of a harbour porpoise (◘ Fig. 7). The vertebral column is made up of the cervical, thoracic, lumbar, and caudal vertebrae. Cervical vertebrae are shortened and (in most species of cetaceans) fused. This helps forming the required torpedo shape but limits neck mobil-

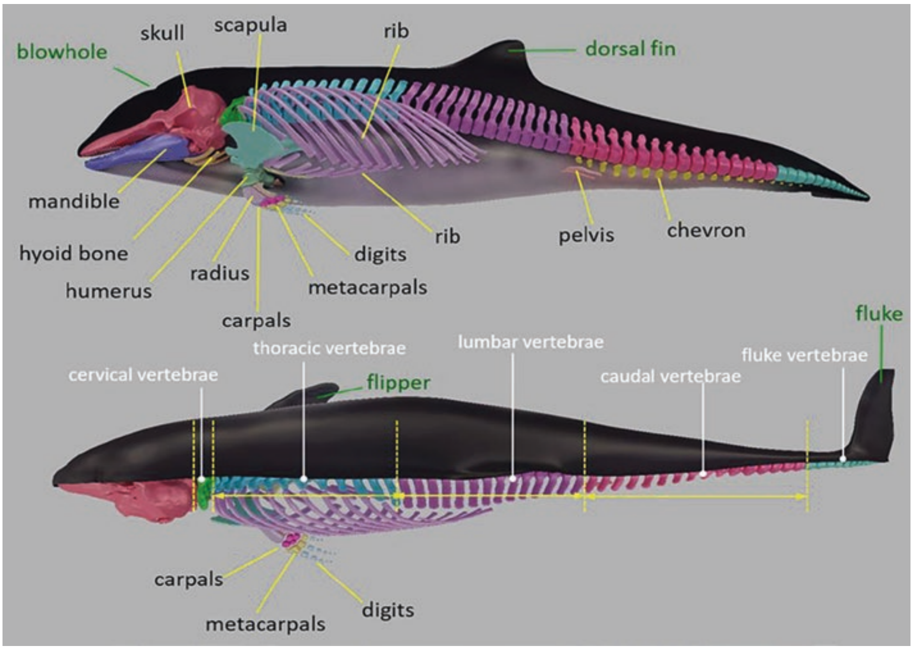

Fig. 7 Skeleton of a harbour porpoise, *Phocoena phocoena*

ity. Thoracic vertebrae are restricted to the extremely flexible rib cage, which is remarkable by its very small sternum, resulting in a higher number of 'free-floating' ribs. The thorax is extremely flexible, which allows for lungs being compressed during deep dives.

Lumbar vertebrae extend from the thorax to the anterior part of the caudal vertebrae. Hind limbs and sacrum have been lost during evolution. However, two 'free-floating' sacral bones can be found in some cetaceans. In males, they are used as attachments for muscles that can retract the penis into the genital fold.

Caudal vertebrae are easy to identify because they have *chevron bones* (bones of the ventral side of the vertebrae) that insert muscles to move the caudal fluke or hind limbs. At the caudal tip, the fluke is not supported by bones but by connective tissue. Whereas the caudal fin of most fish is in the vertical plane, the cetacean fluke is in the horizontal plane. This is because cetaceans evolved from terrestrial mammals where flexibility for walking and running occurs in the dorso-ventral plane. Contrary to fishes, the marine mammal dorsal fin is deprived of bones. The dorsal fin works as a keel to keep equilibrium when swimming fast.

The pectoral fins (also called flippers) have evolved from forelimbs originally used to move on land. The limbs of terrestrial mammals are used to support the animal's weight and typically end with claws, nails or hooves. In cetaceans, flippers are used for manoeuvres and locomotion, as paddles. Claws, nails and hooves have disappeared. The flippers are flattened to provide greater strength during locomotion. Moreover, the flipper is shaped as a wing of an airplane and can be used to 'lift' the body upwards towards the surface.

Besides being used for locomotion, flippers, dorsal fin and fluke have a thermoregulation function. Major arteries are located centrally, surrounded by veins. This structural organization is called a *counter-current heat exchanger*: heat from the warm arterial blood flow is transferred to the surrounding veins, heating the blood returning from body extremities. This system can regulate heat in two ways. If the animal needs to cool down, the blood flow to the fin is high. If the animal needs to warm up, it can keep blood closer to the core. Moreover, vascular links between dorsal fin and flukes of dolphins and their reproductive organs allows cool blood to enter the abdominal cavity to regulate the temperature around reproductive organs.

Different modifications can also be found in the head. An important one is the position of the nares (blowhole). In terrestrial mammals, nares are usually found rostrally (at the front) and directed horizontally or downwards. While swimming, a frontal position of nares is energetically expensive, as you need to lift your head to place your nose out of the water to take a breath. In marine mammals, nares are directed horizontally or even vertically, limiting the effort to breath. The most extreme cases are found in cetaceans, where the nose is directed straight up. Whales therefore do not need to emerge a large part of their head to breathe.

Marine mammal skulls are also characterized by elongated upper and lower jaws that result in a long mouth. Dolphins have numerous sharp conical teeth. Just as for crocodiles, their mouth 'design' is ideal for catching evasive prey, such as fast-moving fish or squid. In porpoises, the teeth are smaller and spatel-shaped. Dolphins and porpoises lack incisors, canines, premolars and molars, typically found in terrestrial mammals (and in seals), and they only have a single kind of tooth.

Baleen whales do not possess teeth, but they have rows of long baleen plates made of *keratin* (a protein also found in nails and hair), growing from their upper gums. Their upper jaw is dorsally curved whereas the lower jaw is laterally curved. Contrary to terrestrial mammals, the cartilaginous joints of the *rostral symphysis* (where the two lower jaws meet) are often missing, allowing the lateral spreading of the lower jaw. In this way they let large amounts of water enter the mouth. The water is sieved through the baleen plates on its way out. The baleen plates are broad and strong at the base but taper into fringes at the tip, forming a large brush that holds smaller prey when water is flushed through them.

3.3 Diving physiology

Most humans can hold their breath for a few minutes and free-dive no deeper than 5–10 m. Marine mammals dive much deeper and for longer durations. For example, Weddell seals can dive deeper than 700 m and stay below the surface for more than an hour. How is this possible?

Diving marine mammals undergo a *dive response*. The heart rate drops tremendously at the start of the dive. In grey seals, it can drop from 120 to 5 beats per minute. Also, blood supply is funnelled to the most vital organs of the animal, such as the brain and heart, whereas most other organs receive little blood and oxygen. The blood volume per kilogram body weight of marine mammals is almost twice as large compared to humans. Both blood and muscles of marine mammals contain larger amounts of oxygen-binding molecules, called haemoglobin (in blood) and myoglobin (in muscles). Whale and seal muscles are deeply red, almost black, because of their high content of myoglobin.

The dive response and other adaptations help marine mammals to store oxygen during their remarkably long and deep dives. Interestingly, humans also have a dive response with a reduced heartbeat, but it is not as dramatic as for marine mammals. While humans as well as cetaceans usually take a big breath before diving, seals breathe out and empty their lungs before they dive. An advantage with emptying the lungs is to prevent gases in the lungs becoming dissolved in blood and tissues at greater depths. If the animal surfaces too quickly, dissolved gases may result in bubbles that can cause blood clots. This problem is called *decompression sickness* and can be reduced if the lungs are emptied before diving. Empty lungs also allow the animal to sink passively without actively swimming upon decent. Many marine mammals can tolerate their lungs collapsing during deep dives through the adaptations of the rib cages explained above.

Current topics of marine mammal research

The dive reflex aids in the conservation of oxygen stores in mammals by initiating several specific physiologic changes during immersion. The dive response was first described in the 1940s. In these trials, the animal was forced under the surface and its physiological response was recorded. Nowadays, the diving response is investigated in trained as well as wild animals of many different species.

In 2015, Dr Siri Elmegaard and her research team from Aarhus University studied trained harbour porpoises at Fjord&Bælt in Kerteminde, Denmark. Siri tested if a porpoise could voluntarily adjust its diving response depending on the duration of the dive. They designed an experiment where the animal was trained to go for a short or a long dive. The length of the dive was indicated to the animal before the trial using an acoustic signal. During the trials, the animal's heart rate was measured using a device attached by suction cups to the animal (◘ Fig. 8).

The experiment indicated that harbour porpoises may be able to adjust their heartbeat voluntarily depending on the length of the dive. In this way, the animal can optimize the oxygen demands while diving. If this phenomenon is widely spread in different species, it may have important implications for conservation biology of cetaceans. If the animal is disturbed and forced to dive, for example being scared by a boat, the ability to save energy during the dive may be negatively affected if there is no time for the animal to 'plan' its dive. Therefore, its ability to hunt for prey may be reduced.

4 Teaching materials

Exercise 1.1: Marine mammals vs. terrestrial ancestors

Marine mammals are divided into three taxonomic group (orders Cetacea, Sirenia and Carnivora), each with its own terrestrial ancestor. Through evolution, these groups gradually adapted to the marine environment.

Select a marine mammal and compare it with related animals that live on land (◘ Fig. 1). What is the body shape like? How long are tail and limbs? What do the ears look like? (◘ Fig. 2)? Where are the nares?

Exercise 1.2: IUCN red list of threatened species

Many species of marine mammals are found on the *IUCN Red List of Threatened Species* (▶ https://www.iucnredlist.org/). The IUCN Red List is an authoritative guide to the status of biological diversity. The list uses a set of quantitative criteria to evaluate the extinction risk of animals from all regions of the world. There are different threat categories: 'Extinct', 'Critically Endangered', 'Endangered' and 'Vulnerable' consider species threatened by global extinction. 'Near Threatened' concerns species close to being threatened, or species that would be threatened without ongoing conservation measures. Species of 'Least Concern' have a low risk of extinction, and 'Data Deficient' means there is no assessment because of insufficient data.

Which marine mammals have you encountered, or would you like to encoun-

◘ **Fig. 8** Measuring the dive response in a harbour porpoise using a device attached to the back of the animal. © Siri Elmegaard, Aarhus University and Fjord&Bælt

ter? Find out what their status is on the IUCN Red List.

Exercise 1.3: Mammalian diving reflex: How is our heart rate affected by diving?

Marine mammals must come up to the surface to breathe. When they dive, they need to stay underwater for a long time to enable foraging. Marine mammals rely on anatomical features and physiological responses that have evolved to increase oxygen storage in the body as well as to reduce the use of oxygen for non-essential activities during dives. Marine mammals are also able to funnel their blood flow to essential organs, such as the brain, by constricting some of their blood vessels (*peripheral vasoconstriction*). They also conserve energy and reduce oxygen consumption by lowering their heart rate.

In this exercise, we will see what happens to *your* heart rate when *you* submerge your face in cold water.

Before you do the experiment, think about what you expect will happen. Do you think your heart rate will increase, stay the same or decrease while you are submerged?

Required materials

- Plastic bucket with cold water (approx. 10 °C)
- Thermometer
- Heart rate sensor
- Stopwatch
- Towels

Tasks

1. Measure the water temperature.
2. Making a reference measurement by placing the pulse oximeter on your finger and measure your heart rate.
3. Start the diving measurement. Place the pulse oximeter on your finger and measure your heart rate for 30 s while you dip your face into the basin filled with cold water. Record your results.

You can extend this exercise: Measure heart rates from all students in the class and calculate average change in heart rate. Is there a difference in diving response between males and females, or swimmers and non-swimmers? Induce the diving response by using a bag of ice on different body parts (back of neck, wrists, nose and eyes). What is the effect of such actions on the diving response? Repeat measurements with water of different temperatures. What temperature induce the strongest dive response?

Results

When mammals dive, their heart rate decreases—this is called the mammalian diving response. Decreased heart rate conserve energy expenditure and oxygen consumption. As a result, mammals can stay underwater longer and therefore also dive deeper. The diving reflex is stronger in marine than terrestrial mammals to allow for long dives. Elephant seals have a very strong dive response, and they can stay underwater for more than an hour. They are also helped by a high myoglobin content and a large blood volume (■ Table 3).

Exercise 1.4: Thermoregulation and insulation. How does cold water affect your muscles?

Heat is lost 20 times faster in water than in air. When marine mammals dive, they need to stay warm and avoid losing too much heat. One of the ways they do this is having a thick layer of insulation called blubber, or a fur covering their body. Cetaceans only have blubber and sea otters only have fur, whereas seals have both. Blubber and fur decrease heat loss. Bowhead whales, for example, have a blubber thickness of up to 50 cm, serving them well in Arctic waters. Sea otters have the densest fur of any mammal. A mere 1 cm^2 of their fur amounts to the entire number of hairs that humans have on their head.

In this exercise, we will investigate how cold water affects our muscles.

What do you think will happen to your muscle strength when you put your hand in cold water?

Do you think your strength will be affected? Will you get stronger or weaker?

Table 3 (▶ Exercise 1.3) Results: Dive response. *bpm* beats per minute. Complete the table and the graph below

Name of student	Heart rate before facial submersion (bpm)	Heart rate after facial submersion in cold water (bpm)	Difference in heart rate (bpm)
Elephant seal	120 bpm	40	↓ 80
Harbour porpoise	150 bpm	50	↓ 100

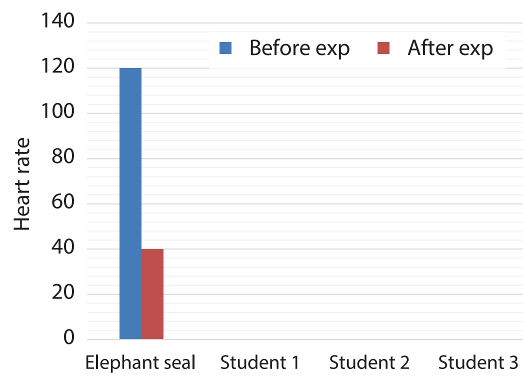

Table 4 (▶ Exercise 1.4) Results: Thermoregulation. Complete the table

Student name	Water temp. (°C)	Hand strength prior to submersion (N)	Hand strength after hand in water with cotton + plastic gloves (N)	Hand strength after hand in water with no gloves (N)

Required materials

- Bucket with cold water (approx. 10 °C)
- Thermometer
- Hand dynamometer
- Stopwatch
- Thick cotton glove
- Plastic glove (large enough to cover the cotton glove)
- Towel

Tasks

1. Measure water temperature of the water.
2. Do a reference measurement. Squeeze the hand dynamometer using one hand as hard as you can. Record your strength in Table 4.
3. Put on a thick cotton glove over your hand, and on top of it a plastic glove. Dip your hand in the bucket of cold water for 60 s. Remove your hand from the cold water and squeeze the hand dynamometer as hard as you can. Record your strength in Table 4.
4. Remove the gloves and dip your hand in the cold water for 60 s. Squeeze the hand

dynamometer as hard as you can. Record your strength in ◘ Table 4.

If you want to, you can extend this exercise. Collect results from all students and make a graph to see if there is a difference between males and females in the effect of low temperatures. The experiment can also be repeated using different temperatures of water. Is there a difference in muscle strength between submersion in 10 °C compared to 4 °C? Make a graph to explore the relationship between muscle strength and temperature. Instead of a thick cotton glove, use a large plastic glove and fill it with butter to simulate blubber. Use different amounts of butter to compare insulation efficiency. To make this exercise less messy and to use less butter, students can put on skin-tight plastic gloves on their hand before putting their hand in the large glove filled with butter. You can then use the same buttered glove for all students.

▪ Results

Thermoregulation is when an organism can keep its body warm even if its surroundings are colder. Insulation prevents the loss of body heat. When marine mammals dive into cold water, they need to keep their bodies warm. One way they do this is by having blubber and/or fur. This helps insulate the body and allows the animal to stay in the water without getting hypothermia (◘ Table 4).

▪ Home Pages

Committee on Taxonomy, Society for Marine Mammalogy; List of marine mammal species and subspecies: ►www.marinemammalscience.org

IUCN Red List: ► https://www.iucnredlist.org

Suggested reading

1. Berta A 2012. Return to the Sea. The life and evolutionary times of marine mammals. University of California Press.
2. Elmegaard SL, Johnson M, Madsen PT, McDonald BI 2016. Cognitive control of heart rate in diving harbour porpoises. Curr Biol. 26(2):R1175–6. https://doi.org/10.1016/j.cub.2016.10.020.
3. Hiebert SM, Burch E 2003. Simulated human diving and heart rate: making the most of the diving response as a laboratory exercie. Adv Physiol Educ. 27(3):130–45. https://doi.org/10.1152/advan.00045.2002.