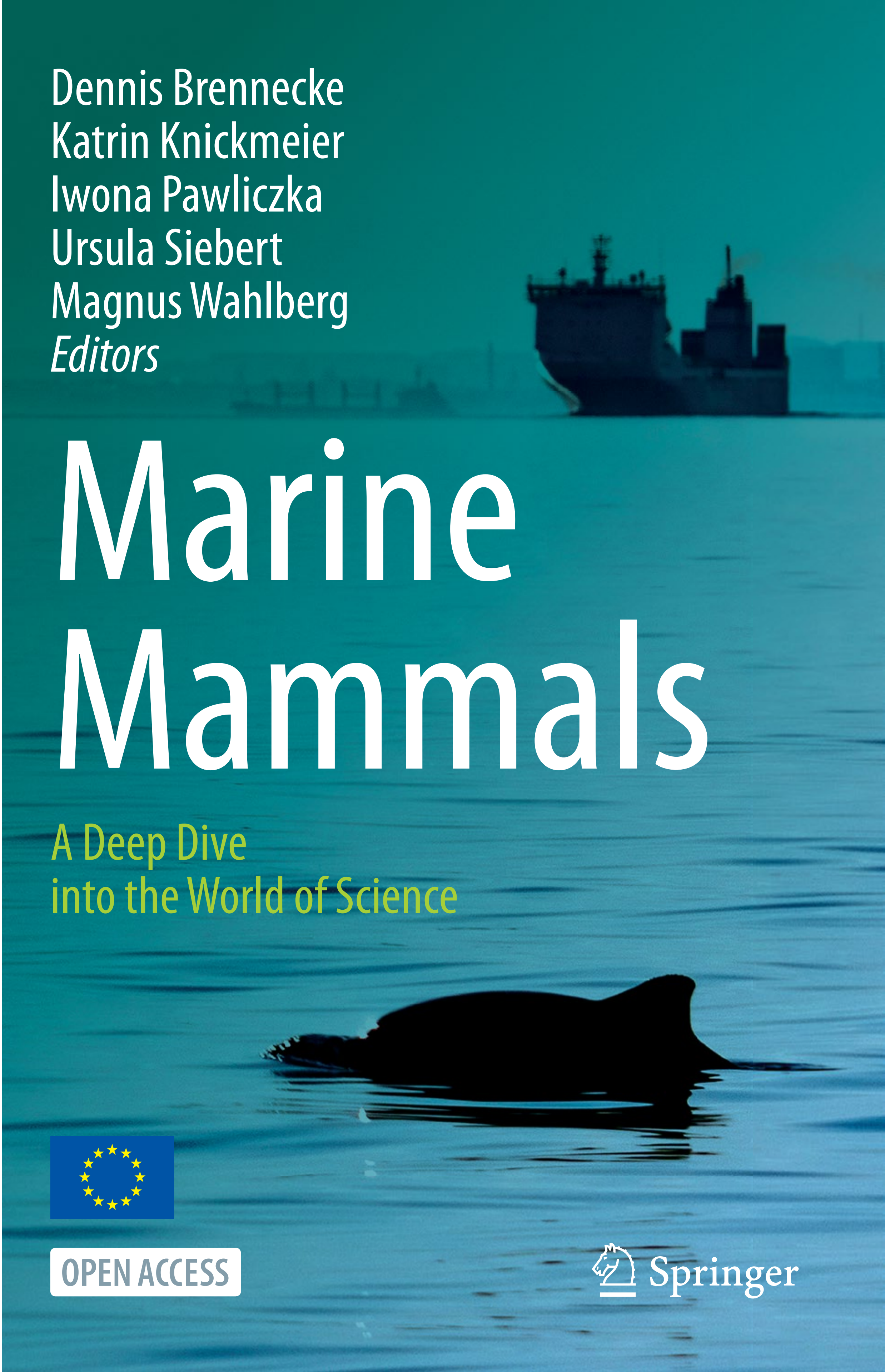

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Editors

Marine Mammals

A Deep Dive into the World of Science

OPEN ACCESS

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Preface

Science is fun, interesting, challenging and engaging. Science makes it possible to discover the marvels of the natural world. With science, we can document the lives of seals and whales, diving to great depths in pursuit of their prey and yearly travelling vast distances between breeding and feeding grounds. Science is also what makes airplanes fly and trains run. And, in the long run, science is what makes us humans able to survive on Earth, in spite of the rapidly increasing human population and the challenges we face due to environmental degradation, climate change and pandemics.

As scientists, we are engaged and full of joy when speaking about our work. Some people call us the 'last truly religious people on the planet'. We love our work, and sincerely believe that science can change the world for the better.

In spite of all the virtues of science, we predict a shortage of scientists in many western societies in the future. We will not only need more people doing research, but also engineers, technicians, veterinarians and medical doctors. There seems to be a general lack of enthusiasm among young people in taking up the challenge of studying natural science which paves the road to an interesting, challenging and fascinating future with relatively well-paid and attractive jobs.

Why is that? The major problem may be the way we try to inspire young people in choosing their career. There is a long way from the enthusiastic 'mad scientists' you meet at universities, to the rather dry presentation of science in many secondary and high school textbooks. Even though modern science centres and media platforms are doing a great job to inspire visitors and viewers to learn about research, more tools are needed to catch the interest of the next generation in science.

Marine mammals easily arouse the interest of students. They are sentinel species in many of the current debates about environmental issues: they are affected by fisheries, plastics in the oceans, environmental pollutants, anthropogenic noise and climate change. Understanding how marine mammals are affected by human activities opens up exciting discussions around many different scientific disciplines, such as biology, chemistry, physics and oceanography.

The book is written to be an inspiration and guide for teachers to expand their way of teaching biology and other natural sciences in secondary and high schools. The book is also intended for students to learn more about the natural world. We have collected a series of topics, all related to current research in marine mammals, with focus on species found in the Baltic and North Sea. We hope that whales and seals will work as a portal to entice students to become interested not only in marine mammals and marine biology, but also in animal conservation and nature protection, and many other scientific topics.

The book is divided into chapters covering topics such as marine mammal biology, sound and hearing, plastics, pollutants and fisheries. Each chapter introduces the topic and gives important background facts that the teacher can use in introductory presentations. At the end of each chapter, there is a small section of current hot topics in marine mammal research that can be used to spur the interest of students when seeing themselves as future scientists with all the excitement such work brings. Finally, we suggest several teaching modules that can be directly implemented in hands-on activities, inside as well as outside the classroom. At the end of a book is a glossary, explaining many of the specialized and perhaps unfamiliar words used in the chapters. Other words, that are not explained but that we expect the reader may have to look up in e.g., Wikipedia, are indicated in italics.

This book is the result of the EU H2020-funded MARINE MAMMALS project, which was launched in 2016 and ended in 2019. Within this project, we developed teaching materials and tried it out on teachers and students. Now is the time for you to explore the result of these efforts. We hope that teachers as well as students will find the material interesting, and also that teachers will develop the material according to the needs of their students. We also hope that we can challenge the teachers' thinking about teaching, and also that we can help making students more interested in science.

Each chapter has been through extensive reviews by acknowledged experts in marine mammal biology as well as experienced teachers. We thank Jay Barlow, Annalisa Berta, Rune Dietz, Peter Evans, Jamileh Javid Pour, Sara Königson, Morgan Martin, Felix Mittermayer, Paul Nachtigall, Filipa Paiva, Joseph Schnitzler, Martin Thiel and Peter Tyack for reviewing individual chapters, and Alejandro Acevedo-Gutierrez, Niels Dohn, Carl Kinze, Kristine Pape, Ulf Saure, Volker Smit, Janto Schönberg, Ewa Wink and Bernd Würsig for providing full-book reviews.

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Who Are the Marine Mammals?

Krishna Das, Helen Sköld, Anna Lorenz, and Eric Parmentier

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
Homeo-thermy	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

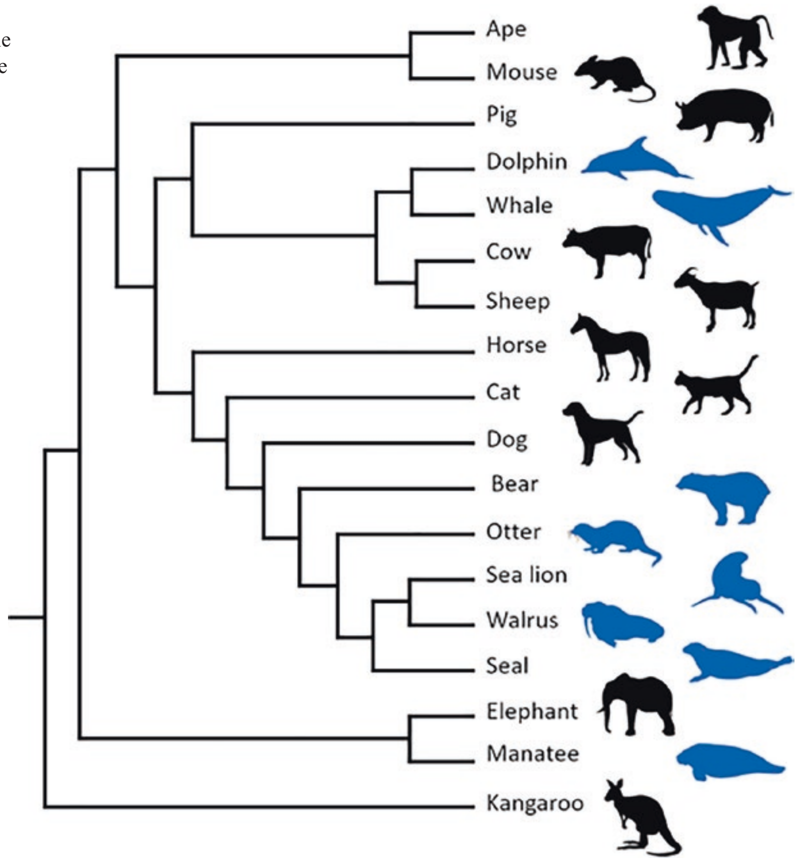

Fig. 1 Simplified phylogenetic tree showing the relationships between marine mammals (in blue) and their closely related terrestrial groups (in black)

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.

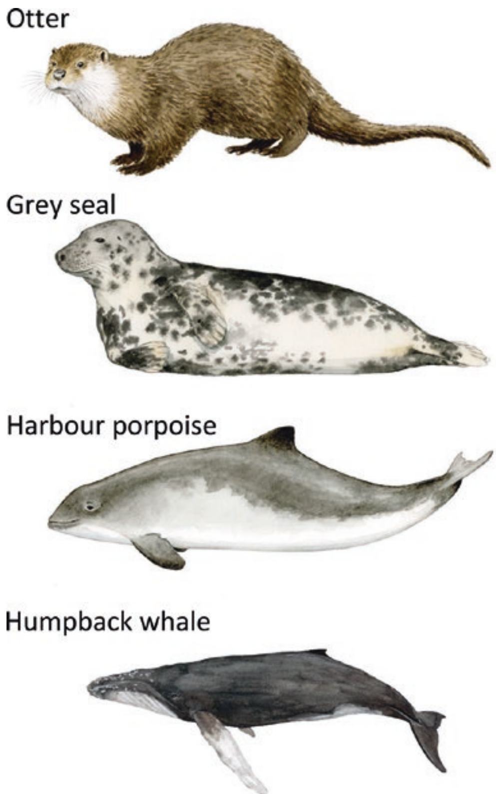

Fig. 2 Different marine mammals. Not to scale. Drawings by Annika Toth

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-

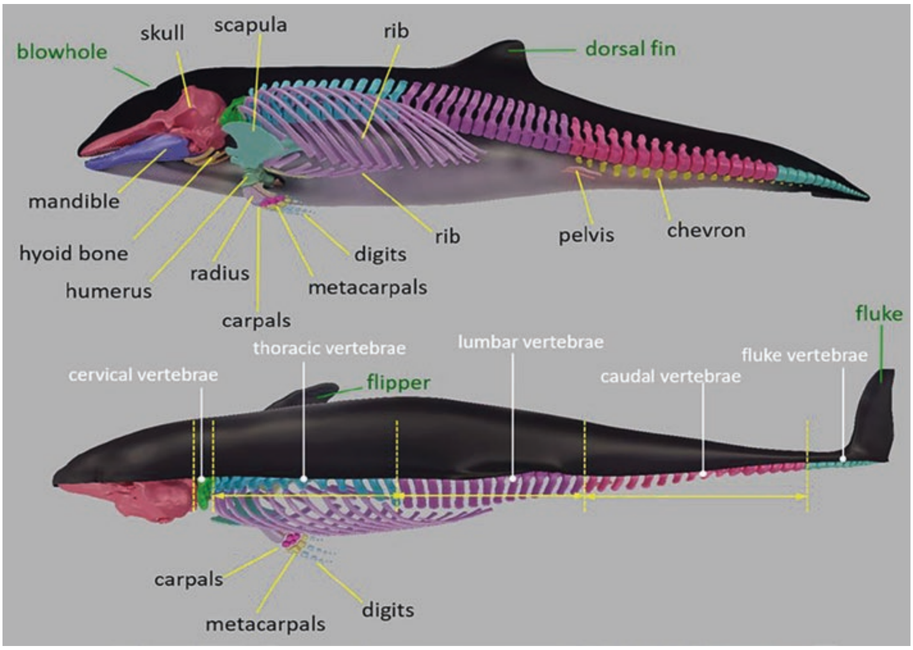

Fig. 7 Skeleton of a harbour porpoise, *Phocoena phocoena*

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

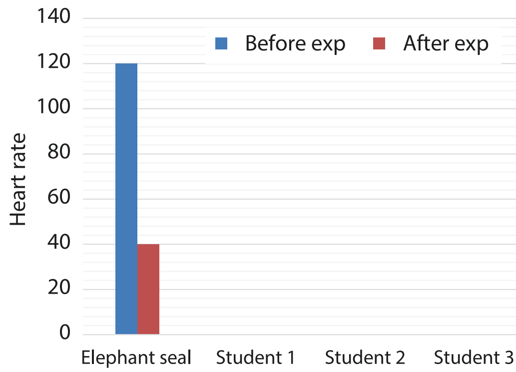

Table 4 (▶ Exercise 1.4) Results: Thermoregulation. Complete the table

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.

Marine Mammal Acoustics

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Contents

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Learning goals

- Understanding acoustics and its importance for marine mammals
- Knowledge about the diverse ways marine mammals use sound
- Understanding how human-made sounds can affect marine mammals

1 Introduction

We live in a world of sounds: both natural and human-made (anthropogenic) ones. So do the animals with which we share this planet. Many of them depend on their abilities to navigate the *soundscape* to survive. Marine mammals use sound both for sensing their surroundings and to communicate, sometimes over long distances. Knowledge of bioacoustics and the physics of sound are important, both when trying to understand the lives of marine mammals and also when trying to protect them from human disturbances.

The underwater world contains many different sounds, which can have natural causes like thunder, winds, animal sounds and rain, or be man-made. Marine mammals are well adapted to natural sounds; they react appropriately to sounds of interest to them. 'Noise pollution' is the sum of all additional, unnatural sounds which disturb animals. Sounds are not heard equally well by all animals. An acoustic signal which is important to one species may be without interest or disturbing to another. It is difficult to assess the impact of noise on animals, as we often need to address the effects on different species separately.

2 The physics of sound

Sounds are waves, somewhat similar to ocean waves you can see rolling in on a beach or that you create yourself in your bathtub. Sound waves can be generated by, for example, a vibrating membrane. Particles of the surrounding medium are set in motion by the membrane and move from side to side, condensing and relaxing the medium. Sound wave propagation is therefore dependent on the oscillation of matter surrounding the sound source. Accordingly, sound needs a medium to propagate. The medium can be a gas (such as air), liquid (such as water) or a solid (such as the seafloor). In outer space, where there is no medium, sound cannot propagate.

The particles in the medium do not actually travel with the sound wave. They oscillate and end up in the same location where they started after the wave has passed. For an animated graphic of sound propagation click ▶ here and ▶ here.

A sound wave is a *longitudinal* wave. The medium's particles move back and forth parallel to the direction in which the sound wave travels. In contrast, in a *transverse wave* (such as an electromagnetic wave), the particles or field move perpendicular to the direction in which the wave is travelling. Water waves are more complicated: here, the particles move in a circular fashion.

Check online supplementary animated graphic ◘ Fig. S1.

The easiest described sounds are 'pure tones', or sinusoidal waves. They can also be called signal 'atoms', as any kind of sound can be constructed out of sinusoidal waves. Sinusoidal waves are defined by their amplitude, frequency and phase (◘ Fig. 1).

Amplitude

Amplitude measures the local pressure fluctuation created by the movement of the particles, measured in pascals (Pa; or newton/m^2, N/m^2; ◘ Fig. 1). One pascal equals the pressure generated by 1 newton over an area of 1 m^2. In air, one pascal is a very high sound level, similar to noise generated by cars on a highway at a close distance. Compared to the atmospheric pressure, which is around 100 kPa at the surface of the Earth, the pressure fluctuations generated by most sounds are small.

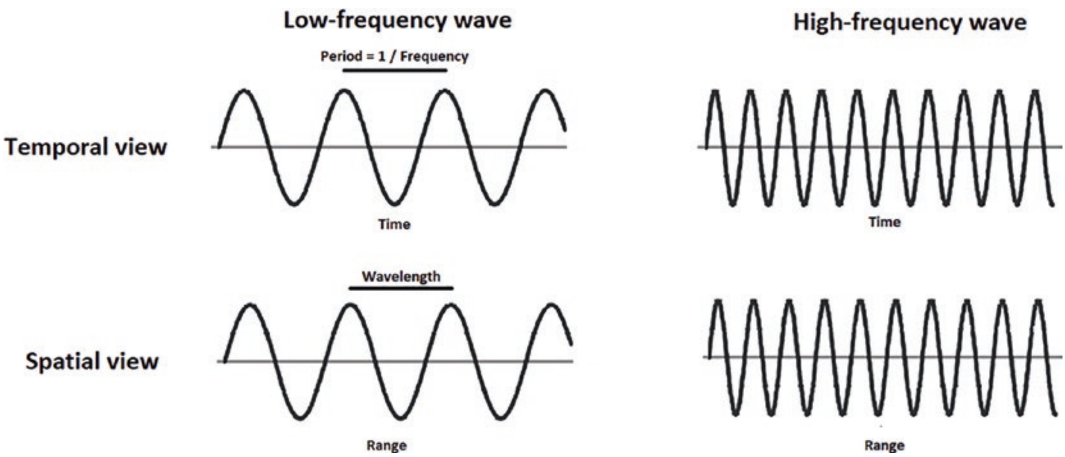

Fig. 1 Left top: A sound wave, depicted as a function of time (recorded at a certain position). Left bottom: The same sound wave, depicted as a function of range (recorded at several locations). Right top and bottom: a sound wave of higher frequency, depicted as a function of time and range. A sinusoidal sound wave is characterized by its 'height' (amplitude), frequency and phase (determining at which time the peak occurs)

Frequency

Frequency is defined by the number of wave cycles in 1 s, measured in hertz (Hz). Thus, 1 Hz is one cycle/sec, while a kilohertz (kHz) is one thousand cycles per second.

The frequency is closely related to the wave's *pitch*, which is the animal's perception of how 'high' (*treble*) or 'low' (*bass*) the sound is. Decreasing the frequency lowers the sound's pitch and makes it more 'bass-like', while increasing the frequency raises it (making the sound more 'treble-like'; Fig. 1). Different species of animals have their best hearing at different frequencies: humans hear best at 2–4 kHz, while porpoises hear best at 100–140 kHz.

Intensity

Another useful unit is the *intensity* of the wave, which is defined as $I = p^2/(\rho c)$, where p is the sound pressure (measured in Pa), ρ is the density of the medium (in kg/m^3) and c is the speed of sound in the specific medium (in m/s). Intensity is measured in units of W/m^2 (watts/metre^2). Intensity is related, but not identical to, how loud humans and other animals perceive sound (for humans, the latter is called the *loudness* of the sound).

It is important to understand the basics of pressure and intensity before we move on to discuss how well animals hear. When comparing hearing in air and underwater, it makes a difference if we report hearing thresholds (i.e. the weakest sound an animal can here) in pressure or intensity units. As we will see below, when measured in units of pascals, underwater hearing thresholds seem higher than aerial ones. However, this does not necessarily mean that marine mammals hear worse underwater than terrestrial mammals hear in air. The difference is to a large part a matter of the composition of the medium in which the sound propagates. Because water is denser than air, a pascal of sound underwater carries less intensity than a pascal of sound in air. Thus, comparing in-air and underwater sound levels is by no means trivial. When reporting thresholds in units of intensity, some marine mammals (such as seals, which live a semi-aquatic lifestyle) have similar hearing thresholds in air and underwater, while others (such as dolphins, which are entirely aquatic) have poorer hearing in air but extremely sensitive hearing underwater.

Sound levels expressed as decibels

Because the span in sound pressures that can be observed in nature is huge, the sound amplitude scale is often compressed into a logarithmic scale, known as *the decibel scale*. Decibels are calculated as

$$dB = 20 \log_{10}(p / p_0)$$

where $\log_{10}$ is the base-10 logarithm, p is the measured pressure (in Pa), and p_0 is the so-called *reference pressure*, which is p_0 = 20 μPa (micropascals) for airborne sounds, and p_0 = 1 μPa for underwater sound. The reference pressure in air is close to the human hearing threshold at 1 kHz. In this way, the hearing threshold of humans at this frequency is 0 dB re 20 μPa (try to calculate this yourself). The underwater reference pressure does not have any biological meaning but has been hand-picked by a scientific committee. To indicate which reference pressure is used, in-air sound pressure levels are reported as dB re 20 μPa and underwater as dB re 1 μPa (Fig. 2).

Because of the differences in reference units as well as in speed of sound and density of air and water, it is not easy to compare in-air decibel levels with underwater ones. A sound signal of equal pressure in both media is 26 dB higher in water than in air (due to the different reference pressures), and a sound of equal intensity is 62 dB higher in water than in air (due to different reference pressures and impedances).

Let's compare the decibel scales in air and underwater (Fig. 2). In air, the scale of audible sounds spans from the hearing threshold, which for most mammals is lower than 20 μPa up to about 100 Pa, around the *threshold of pain*. This means a difference of 6–7 orders of magnitude between the lowest and highest point of the audible scale. In decibel units, the biologically relevant in-air scale is from a bit less than 0 dB to more than 130 dB re 20 μPa. In water, the lowest hearing thresholds of marine mammals are about 100–1000 μPa (which in decibels become 40–60 dB re 1 μPa), while the threshold of pain is probably beyond 1 or 10 kPa (180–200 dB re 1 μPa). The loudest sounds that can be produced in air, such as sounds from rifle shots and jet engines, can be up to around 180 dB re 20 μPa. Beyond this sound level, the air molecules cannot maintain the extremely large particle motions and start to behave in ways not easily described by physics. Underwater, the loudest animal sounds are produced by sperm whales, which sometimes click at about 240 dB re 1 μPa, if recorded at a distance of 1 m. Even louder sounds exist, but these are mainly of human origin, such as the sounds from sonars and underwater explosions. Remember though that to directly compare the sound intensity in air and underwater, you have to subtract 62 dB from the underwater decibels.

Another important feature of a sound wave is its frequency content. Young humans can hear from about 20 Hz up to 20 kHz. With age, the upper hearing limit is rapidly decreasing so most people older than 50 years have a hard time hearing sounds above 10 kHz. Humans hear best at 2–4 kHz, which is significantly higher than the frequencies where we emphasise our speech, at a few 100s of hertz (Fig. 3).

► Example

Human hearing is not fine-tuned to the frequencies at which we communicate. But why do we speak at different frequencies than our best hearing occurs? A crowded bus ride may give you a hint. You can easily continue talking to your friend nearby, in spite of all the noise of other people talking around you. If a baby starts crying however—and babies cry in the 2–4 kHz range where humans hear best—you may stop your conversation to see if any help is needed or soon consider switching to another bus to continue your conversation. Our hearing seems to be evolutionary tuned to listen in for infants that need to be comforted. ◄

The speed at which a sound wave travels is different for every medium. It depends on the density, temperature and a few other parameters, like ambient pressure and (for underwater

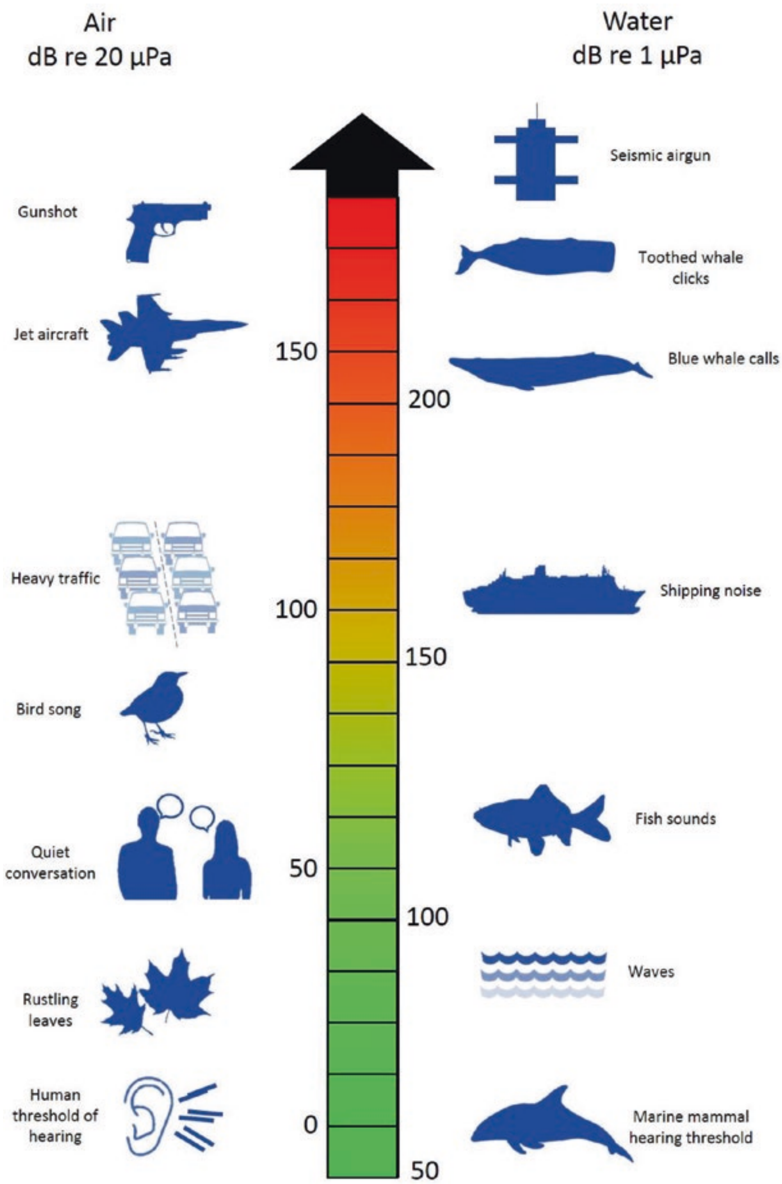

Fig. 2 In-air and underwater decibel scales. The reference pressure for airborne sounds is dB re 20 µPa, while dB re 1 µPa is the reference pressure for underwater sounds. The water dB scale is shifted by 62 dB, so that in-air and underwater sounds at the same vertical location have the same acoustic intensity

sound) salinity. In air, the speed of sound is 330–340 m/s, and in water 1450–1500 m/s. Thus, sound travels about 4.4 times faster underwater than in air.

The different acoustic properties of air and water have implications for the way we perceive sound in the two media. For example, an important cue when listening for sounds is to determine their direction. Many animals, and humans, do this primarily by gauging the difference in timing or intensity of the sound received at each ear. Both timing and intensity differences will become smaller in water. Due to the high speed of sound transmission underwater, sound is received at both ears closer in time than for airborne sounds. Furthermore, for a signal with a certain frequency content, the wavelength is longer

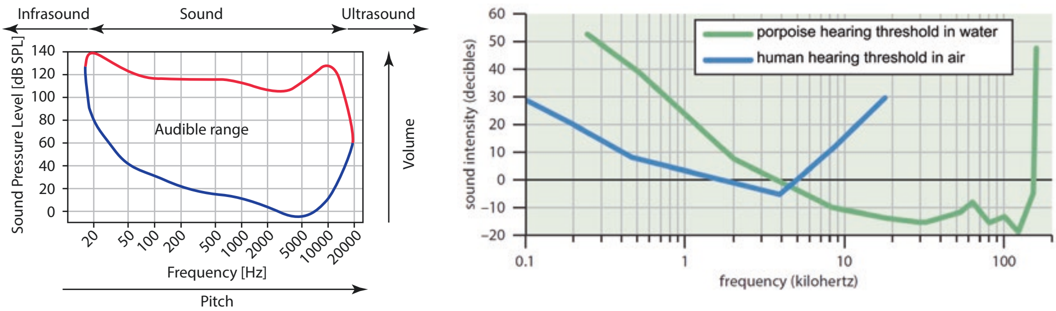

Fig. 3 Left: the human hearing threshold in blue, and threshold of pain shown in red. On the right, the audiogram of a harbour porpoise (green) is compared to a human audiogram (blue). The audiogram thresholds have been shifted so that the intensity level is the same for the underwater and in-air hearing thresholds. Left figure from Larsen and Wahlberg (2017), right figure from Wahlberg et al. (2015)

underwater than in air, as the wavelength is the ratio between speed of sound and frequency. Due to the longer wavelengths, and the similarity of flesh, bone and water density, the animal's head is less efficient in shielding signals underwater than in air. Therefore, intensity difference cues between the two ears to determine the direction of a sound source become less efficient in water. Terrestrially adapted animals, and humans, have a very hard time determining the direction of a sound source underwater. Marine mammals, however, have certain anatomical and physiological adaptations to tease out the direction of underwater sounds. Porpoises, for example, have acoustically decoupled inner ears: they are detached from the skull and surrounded by air compartments.

3 Hearing and sound production

Marine mammals use sound to communicate over short and long distances, to acoustically sense their surroundings and navigate underwater, locate prey and mating partners, and to avoid predators.

Depending on the species, the upper hearing limit differs tremendously. Seals can hear well up to about 20 kHz in air, whereas their underwater frequency range is more than doubled, up to 50 kHz. Their hearing is adapted to life both in air and water. Toothed whales hear well underwater but poorly in air. Many of them can hear even higher frequencies than seals. The record holder are small odontocetes such as the harbour porpoise, which can hear frequencies higher than 140 kHz. Porpoises hear best in the frequency range where they produce their echolocation signals (Fig. 4). Their hearing sensitivity at these frequencies is among the best sensitivities found in any aquatic mammal.

Marine mammals produce a large repertoire of different sounds. In most cases you can quite easily detect the difference between sounds from a seal, a dolphin and a baleen whale. Seals produce sounds both in air and underwater in the same frequency range as humans, mainly for communication and during mating activities. Dolphins produce clicks, burst-pulsed sounds and whistles. Some of these signals are produced in the frequency range audible to humans, but they often also contain higher, so-called *ultrasonic*, frequencies. Baleen whales produce extremely low-frequency sounds. Blue and fin whales regularly sing below 20 Hz, which is the lower frequency limit of human hearing; sounds below this limit are called *infrasound*.

Sound is one of the most useful ways of communication, above and especially underwater. Many marine animals have good eyesight, but even in the clearest tropical waters, visibility is restricted to a few tens of metres. Sound on the other hand travels much further. Many low-frequency sounds may be often heard over very large distances. Many

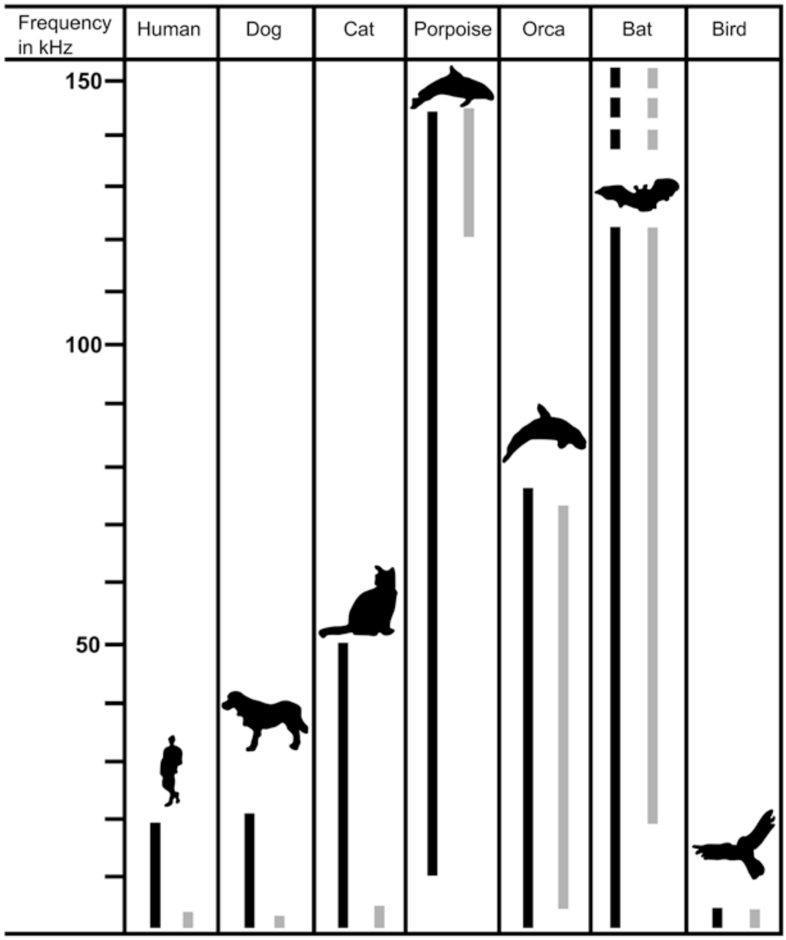

Fig. 4 Hearing (in black) and sound production (in grey) ranges in a selection of animals

marine organisms have developed ways to produce and detect sound. Whales, for instance, have developed distinct communication strategies and orientation systems, which allow them to find prey and communicate with conspecifics over great distances. For example, blue whale calls have been heard at ranges of tens or even hundreds of kilometres.

Toothed whales (odontocetes) use echolocation. They produce very high-frequency sound waves by forcing air past so-called *phonic lips* into the air sacs of their nasal passages. The clicks are transmitted through sound conducting acoustic fat of different densities in the front of their head (the *melon*), directing the sound in to a narrow beam. The emitted sound waves travel through the water until they reach an object, such as a prey item or an underwater obstacle. The object reflects some of the sound energy, creating an echo. The returning echoes are mainly received through the whale's lower jaw, containing fat which channels the perceived sound towards their inner ear complex (Fig. 5). Thus, by emitting ultrasonic sound pulses, odontocetes listen for echoes and can detect objects underwater. They can basically 'see' their environment through the sound waves they produce, in some ways similar to the echo sounder on board a ship.

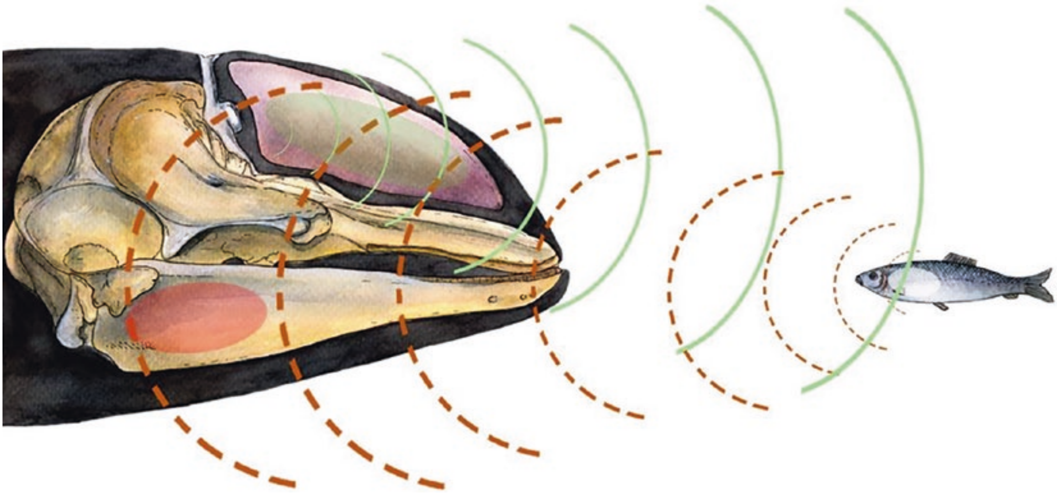

Fig. 5 Sound production and reception in a harbour porpoise. The purple structure in the forehead is the acoustic fat of the melon, which channels the emitted clicks (green). The sound is reflected by the fish (orange dashed line) and mainly received through the lower jaw. The red shading indicates the mandibular acoustic fat close to the ear bone. © Annika Toth

Baleen whales and seals do not use echolocation, but they still rely on sound and hearing for survival. Seals, and probably also baleen whales, produce sounds with their larynx and some additional air sacs, similar to terrestrial mammals. Besides good underwater and in-air hearing abilities, pinnipeds (true seals, walrus and eared seals) can perceive water disturbances with their whiskers to detect water movements generated by swimming fish.

► Example

Marine mammals have evolved adaptations that allow them to use sounds both to detect prey and to avoid predators. An interesting example is the frequency range of sounds and hearing of harbour porpoises compared to one of their predators, orcas. Orca sounds consist of a wide range of whistles and pulsed calls, with fundamental frequencies as low as a few kHz and harmonics beyond 100 kHz. Their best hearing is around 40 kHz. Harbour porpoises hear best between 120 and 140 kHz but can also hear sounds as low as a few kHz. Harbour porpoise signals, on the other hand, do not contain much energy at frequencies below 100 kHz and are centred around 120–140 kHz, where they hear best. It is believed that porpoises have adapted their sound production to higher frequencies, which are out of the hearing range of orcas. This prevents orcas from hearing sounds from their potential prey. Porpoises, on the other hand, can hear the sounds from nearby orcas and may therefore be able to avoid being captured. However, orcas have highly specialised hunting strategies and often stop making sounds before starting a hunt, making it more difficult for their prey to evade the attack.

Some of the strongest reactions to sounds played to marine mammals occur when a playback signal sounds like a natural predator. Again, orcas are an interesting example. There are different types of orcas: some feed on marine mammals, while others only eat fish. The different orca types also have different sound repertoires. Orca sounds were played back to Canadian harbour seals, which are regularly preyed upon by orcas. The seals responded aversively to sounds from mammal-eating orcas, but they did not respond to calls of fish-eating orcas. ◄

4 Impact of noise pollution on marine mammals

There are many ways humans utilise the oceans, and many of these activities introduce sound into the natural environment. Underwater noise pollution is caused by, for example, recreational boats, commercial shipping, windfarms, oil rigs, underwater exploration for oil and gas, and military activities. Highly utilised areas often have particularly high levels of underwater sound. Noise pollution may however be just as bad or even worse in quieter areas due to a smaller degree of *habituation* (become accustomed to a behaviour or condition) in animals living in such environments.

Because many marine mammals use acoustics as an important way to detect prey, to communicate or to orient themselves, a functional hearing system is of uttermost importance to them. To a certain degree, marine animals can increase the sound level or frequency range of their communication signals to make them more audible under noisy conditions. If communication sounds are masked by anthropogenic noise, they may not be able to hear calls of conspecifics to find mating opportunities or food. This can potentially play a major role in individual or species survival.

Noise can also disturb the animals' natural behaviour, make them leave their known habitat to find more silent locations, interrupt feeding, change diving behaviour, maybe even cause reproductive impairment through acute and chronic stress, and lead to temporal or permanent changes in distribution. Loud continuous or impulsive noise can damage hearing at certain frequencies, temporarily or permanently, which can result in failure to hear important signals, such as an approaching ship or a certain frequency component of mating calls. Additionally, certain types of anthropogenic noise, like military sonar, can lead to death when deep-diving whales attempt to escape or evade the sound by ascending too quickly.

Hearing impairment is caused by exposure to loud sounds, also to less intense but continuous noise over longer periods. If temporary hearing impairment occurs, it is called temporary threshold shift (TTS). A TTS is a passing increase in the auditory threshold resulting in momentary hearing impairment. We humans know this phenomenon as the 'discotheque effect', as our hearing is temporarily reduced after exposure to loud music. A permanent hearing threshold shift can occur as a result of repeated TTS events or from a single exposure to an intense sound. Both humans and marine mammals can become permanently less sensitive or even deaf to sounds of certain frequencies after loud or long exposure of sound.

► Example

Another problem that can be investigated with bioacoustics is collisions between ships and whales. The *International Whaling Commission* runs a global ship strike database (► http://iwc.int/ship-strikes), and it shows an increasing number of records over the last years. Why do whales and manatees get hit by vessels instead of avoiding them?

One of the reasons may be that the main noise source of a boat is the engine, which is situated in the stern of the boat. The hull is shielding the engine noise towards the front, so straight ahead of the boat the noise level is substantially reduced. If the animal approaches the boat sideways, the noise level drastically increases, making it aware of the approaching danger. If an animal forages or sleeps straight ahead in the ship's pathway, it may not perceive the sound of the engine and propellers, making it more vulnerable to collide with the ship, while whales startled by noise tend to surface rapidly, putting themselves in greater danger for collisions at the surface. The animal may even seek out a location straight ahead of the boat, to avoid too much noise from the approaching vessel. Additionally, underestimation of vessel speed, and maybe also hearing impairment, could also explain why animals are increasingly colliding with boats. Also, the number of fast-moving boats in waters frequented by cetaceans and manatees are constantly increasing. ◄

Continuous stress through noise pollution can supress the immune system and make marine life more vulnerable to infectious diseases and parasitic infections. Many marine mammals hear and communicate at frequencies different from the ones used by humans. They may therefore be affected by sounds that we cannot hear. Thus, when evaluating noise effects on marine mammals, it is important to use broadband recordings and analysis systems that can detect sounds also outside the hearing range of humans.

We need more research on the current levels of noise in the oceans, and how noise affect marine fauna. Politicians and decision makers need to take the results from such research into account when judging if mitigation measures are needed. The environmental impact assessment of new marine activities should include potential effects of noise emission. When needed, successfully tested sound mitigation measures should be implemented. Such measures could include effective animal warning devices used prior to military sonar, or so-called 'bubble curtains' used during construction work (see Exercise 5). One could also envision the development of quieter ship engines, changing shipping routes and harbour entry lanes, or speed reduction zones.

Tip

Buying more local goods instead of having everything shipped from abroad is another way to improve the current situation of extensive shipping (if you want to learn more about the marine traffic density in your area, you can search on the internet for links displaying marine traffic in your country's coastal zones or exclusive economic zone). Thus, by adjusting our personal behaviour we may improve the situation not only for marine mammals but also for the marine environment in general.

Current topics of acoustic and noise pollution research on marine mammals

How can we use acoustic research to protect marine mammals and to learn more about them?

We still do not know much about how marine mammals communicate and orientate themselves underwater with sound. Researchers work with trained animals, sometimes blindfolded to ascertain they only make use of auditory cues during the experiments. In this way, it can be shown that, for example, blindfolded toothed whales are able to find their way through a maze or detect and catch prey. This is considered the classical evidence of their ability to echolocate.

We can also investigate the hearing abilities of trained animals by hearing tests. This can be done in the same way as with humans: When a sound is played during an experiment, the animal is trained to indicate if it heard the sound by putting its snout on a certain *response symbol*. The hearing abilities of stranded individuals can be checked through measurements of their *auditory brainstem response* (ABR), small electrical potentials originating from the brain in response to auditory stimuli. The electrical potentials are recorded from the skin of the animal with electrodes embedded in suction cups, which are attached to the head. In this way we can measure if animals can hear a certain sound without being trained for a hearing test. The same methodology is used to detect hearing problems in newborn human babies. In stranded marine mammals, ABR measurements are sometimes used as a health parameter: The animal needs to be able to hear the species-specific frequencies to be released back into the wild.

Another approach to study the impact of noise pollution on marine mammals is using acoustic data loggers that can be deployed in critical habitats or along shipping channels. The data loggers record calls of the target species and ambient noise. In this way, scientists can better understand species distribution and habitat use without having to be continuously present on a boat for observations. Real-time passive acoustic sensors can transmit the sounds of seals and whales via satellite or radio links to a unit, which informs captains that animals are present, and that caution has to be practiced once an alert has been sent.

If you want to learn more, *Discovery of Sound in the Sea* offers great further learning materials and updated information on their web page ► https://dosits.org/ (only in English).

5 Teaching materials

Exercise 2.1: The frequencer

Have you ever wondered why some people hear sounds that others cannot hear? What are the frequency limits of your hearing, and are both of your ears equally sensitive to sound?

By listening to sounds of different frequency and intensity, you can register the frequency limits of your hearing. You can then compare your hearing limits with the ones of other animals (such as marine mammals; see an example in ◘ Fig. 3) to better understand in what ways our hearing differs from theirs.

Required materials

- Frequency sheet, available as online ◘ Supplementary file S2.
- Sound files, available as online ◘ Supplementary file S3.
- Loudspeaker and device to play sound files
- Headphones

Tasks

1. Listen to the sound files (always use the same volume); start with the lowest frequency (20 Hz).
2. Mark down when you hear the sound on the spreadsheet and leave the spot blank if you do not hear it.
3. After filling out your audiogram, you can repeat the exercise using each side of your headphones separately. This way you can create audiograms for both your right and your left ear and compare them.

Results

The result will be your own, personal frequency limits of your hearing.

Compare your results to other students and repeat the experiment with people of different age classes, like your parents and grandparents. Can you see differences in the hearing limits?

The results will not be as accurate as an audiogram measured by professional audiologists, as the played back sound level will depend on the type of loudspeaker.

Exercise 2.2: Human echolocation

Imagine you are trapped in a dark room you are unfamiliar with. How could you orientate yourself? Do you think you could teach yourself *human echolocation*?

Not only bats and toothed whales use echolocation—humans can also learn to echolocate, and some can become quite good at it. Visually impaired humans sometimes spontaneously learn to echolocate to compensate for their lack of vision. This phenomenon was formerly called 'facial vision' but is now known to be echolocation. Interestingly, one of the best human echolocators known, Daniel Kish from California, remembers learning this skill while being only a few years old. He only understood that he was using a method comparable to bats and dolphins when 20 years old. If you want to know more about this technique, check out ► https://visioneers.org/.

Required materials
- Several large wooden
- Plastic or cardboard panels (A0 or similar sizes)

Tasks
1. All students should try to practice emitting click sounds with their tongues prior to the experiment by using their own hand as a barrier to see if the clicks they emit are effective. It might take some time to produce efficient sounds, but it is a fun group exercise.
2. The students need to stand in a circle, facing the middle, shielding themselves with the panel 'walls'. During the experiment, all students should be silent to get the best experimental effect.
3. Position a blindfolded student inside the circle. The blindfolded student needs to emit click sounds while slowly walking towards the classmates, without stretched out arms, just relying on the sound of the returning echoes (Fig. 6).

Results
When approaching a wall, the blindfolded student will notice a change in the returning echo of the emitted click sound. This should cause the student to stop or to turn, instead of walking into the wall. When stopped in front of a wall, the student should slowly reach out for them to appreciate the actual distance. You can also leave an opening in the shielded circle, that has to be found by echolocation. Afterwards, the students can disperse in the room and the blindfolded one can try to locate them by echolocation and find a way to navigate around them. Additionally, if the students are trained to echolocate, different materials can be tested, since harder surfaces (e.g. a white board) reflect sound in a different way than softer ones (e.g. cardboard) do.

Exercise 2.3: Name the sound
How much do you know about animal, environmental and anthropogenic sounds? And how much do you know about underwater sounds? Do you think you can discern natural from man-made underwater sounds

Fig. 6 Human echolocation (► Exercise 2.2). The students stand in a circle, shielding themselves with panel 'walls', while a blindfolded student is standing inside the circle. The blindfolded emits click sounds while slowly walking around, trying to figure out where the 'walls' are by listening for returning echoes

easily? You have surely listened to songbirds, and you may have tried to identify them by their song. There are many more natural sounds to explore. In this exercise, we focus on some underwater sound examples that are completely unknown to most people. Can you guess the origin of those sounds?

Required materials

- Game file -loudspeaker
- *Name the sound* game, available as online Supplementary file S4

Tasks

1: Listen to the automatically played sound and repeat it by clicking on the small speaker symbol.

Guess its origin before continuing to reveal the four provided possible answers.

Was your first guess represented in the four answer options?

If not, choose A, B, C or D as your answer.
If so, was your answer correct?

Results

You will see how easy or difficult it is to discern natural and man-made sounds from each other. Probably animals often have the same difficulties as we do.

Exercise 2.4: Build your own hydrophone

Do you think that there is a simple technological way for us to hear sounds inside natural bodies of water? If so, what do you think you will hear down there?

Hydrophones are underwater microphones that can be easily built from a few components. With a hydrophone, you can listen for animals, such as whales and seals communicating with one another, or just the general underwater soundscape, sounding so eerie and unfamiliar to most of us 'land dwellers'. And with the right materials, it only takes 30 min to build your own hydrophone.

Required materials (Fig. 7a)

- This exercise includes soldering, so proper safety precautions need to be in place and care is advised. A fume hood or other ventilation system is needed, students have to be extra cautious while the soldering iron is connected and accordingly need supervision for the soldering part of the task. If soldering is considered too dangerous or unfeasible during a class exercise, this part can also be prepared prior to the experiment.
- Piezoelectric crystal (they come in very different sizes and shapes, depending on the desired frequency response and sensitivity. For example, guitar piezos are fairly cheap and appropriate for the experiment. Crystals can be ordered online, or contact a company directly and ask for a crystal that can be used in the audible frequency range, since product types change over time and vary among companies).
- Solder with low melting point (e.g. solder containing silver) and soldering iron (preferably with the possibility to regulate the temperature manually).
- A shielded cable with two exposed final strands (long enough to be lowered into the study waterbody).
- A small plastic bottle (about 3 ml) with a plastic lid.
- Vegetable oil (olive, sunflower, or similar).
- A high-impedance amplifier (this can be bought relatively cheap online).
- A pair of headphones or a small loudspeaker.
- A connector to attach to the hydrophone cable (e.g. a so-called BNC connector that can be bought online).
- Sinking weight.

Tasks

1. Pierce a small hole into the lid of the plastic bottle, run the cable with its exposed final strands through it and attach a connector to the other cable end (outside the lid).
2. Solder one of the cable's two strands on the inside and the other on the outside of the piezoelectric crystal under a fume hood. It is best to use solder with a low melting point. Ideally, the soldering iron temperature should be kept below 250°C to avoid damaging the

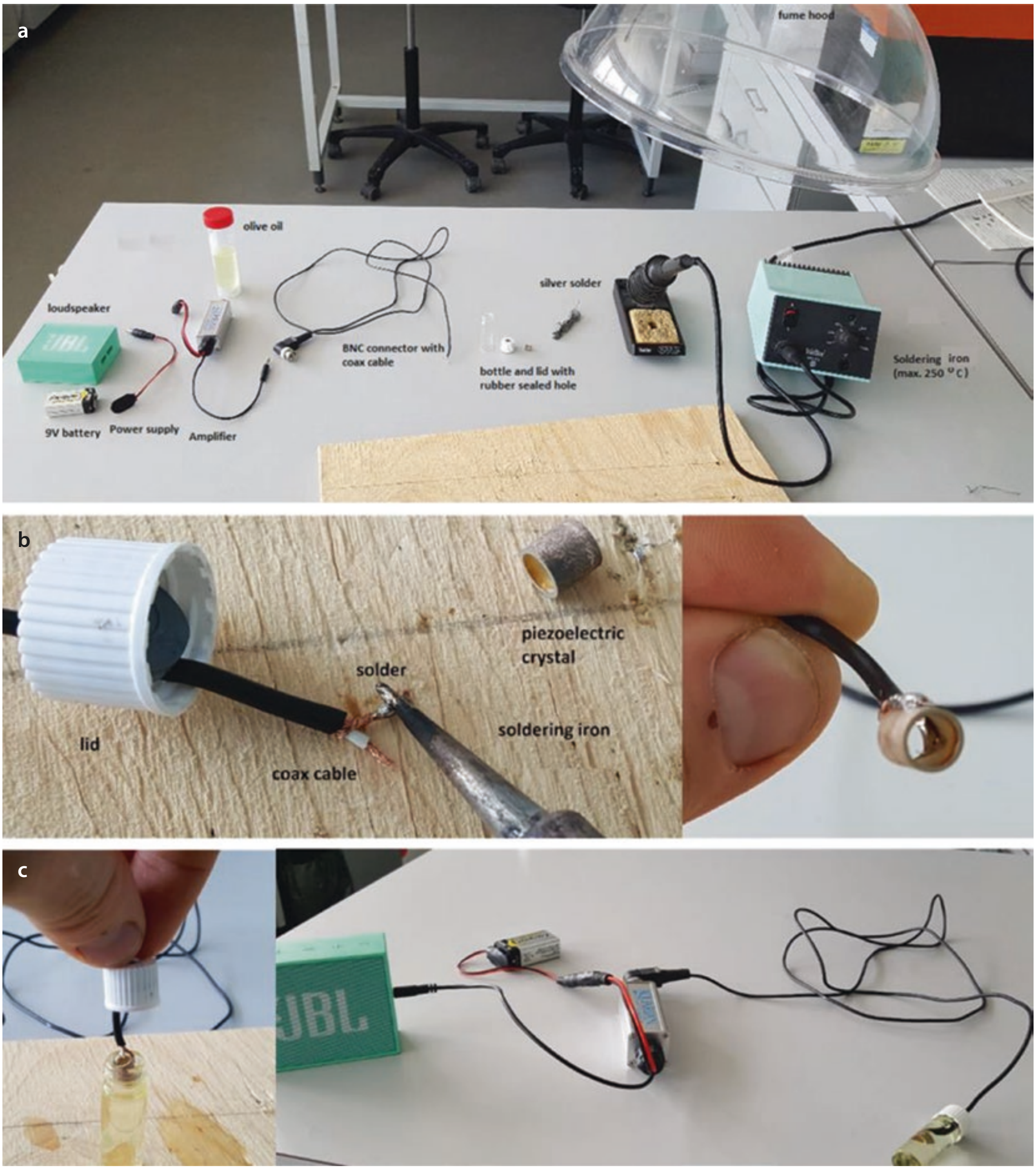

Fig. 7 Build your own hydrophone (▶ Exercise 2.4). **a** All necessary materials laid out on the working desk. **b** Soldering the cable, one strand on each side of the piezoelectric crystal. **c** After placing the crystal in the oil filled container, everything is connected and tested

sound-sensitive crystal. Always take caution not to inhale solder fumes (Fig. 7b).

3. Attach the amplifier to the connector, connect the output of the amplifier to the loudspeaker or headphones and switch it on. Now perform a ‘tap test’: tap gently on the crystal—you should hear a sharp noise through the loudspeaker.
4. Waterproof the crystal by pouring vegetable oil into the small plastic bottle and placing the crystal attached to the cable inside. Then, tightly seal the lid and attach the sinking weight to the hydrophone so it does not float.
5. Now the hydrophone is ready for use (Fig. 7c).

Results

The vegetable oil does not conduct electricity, but it conducts sound waves: therefore, the underwater sound waves can reach the piezoelectric crystal. The crystal transforms the pressure into voltage. The voltage is picked up by the cable strands and gets amplified before being transmitted to the loudspeaker. Thus, sound can be transmitted to the speaker without short-circuiting the crystal.

Tip

Bring the hydrophone out to a dock by a lake or by the sea and sink it into the water. Take caution to keep the rest of the electronics dry. Now, listen to the sounds. You can also splash the water surface with your fingers or throw a small stone into the water. You can hear if you can detect fish or other natural sounds, or perhaps you can hear a passing boat?

Exercise 2.5: Build a bubble curtain

Imagine you want to build an offshore wind farm, to generate renewable, clean energy. How would that effect aquatic life in the area? What can be done to protect them from harmful noise impacts?

Bubble curtains are noise mitigation measures that are used to dampen and absorb sounds of underwater constructions to prevent extensive hearing loss and noise harassment of marine mammals close to the construction location. Sometimes, huge bubble curtain systems are built around construction sites and activated when necessary. If you are interested in more information and pictures regarding this topic, search the internet for, for example, *The Big Bubble Curtain* by BBC.

In this experiment, we will build a miniature bubble curtain to show the effectiveness of such a mitigation device.

Required materials

- Air compressor (it can be a very simple, cheap aquarium pump, but the stronger the compressor, the better the result).
- Air bubble tube (use a commercially available bubble tube for aquaria).
- A 1.5 m hose to connect the pump with the air bubble tube.
- A waterproof sound device (e.g. a panic alarm or similar).
- An aquarium, a container or a bucket full of water.
- *Suction cup* tube holders or weights to prevent the air bubble tube from floating in the aquarium.

Tasks

1. Flex the bubble tube in tight loops, so that it results in almost two full rings. Make sure the end of the bubble tube is blocked (clamped or glued), so no air can escape that way (Fig. 8a). All air needs to flow through the holes along the tube for the bubble curtain to function properly. Then, mount the coiled tube with the *suction* tube holders or weights inside the aquarium, so that it stays at the bottom.
2. Connect the bubble tube with the compressor or aquarium pump by using the extra hose (Fig. 8b). The hose needs to be long enough to ensure that the bubble tube is fully submerged on the aquarium bottom, while the pump can safely be stored outside and connected to a power circuit. Then, fill the aquarium with water.
3. Place the sound-producing device in the middle of the air bubble tube rings, freely floating in the water column. If the device is in contact with the walls of the aquarium/bucket, they may function as sound transmitters and the experiment will not work, as the produced noise will be dispersed equally by all container walls.

   The students should be silent during the entire experiment.
4. Begin the experiment: start the sound device underwater and let the students listen to the sound of the freely submerged device for a moment.
5. Start the aquarium pump to initiate the bubble curtain and listen for changes (Fig. 8c). Do not let the experiment run for too long, since our ears adapt to the volume of the sounds and after some time noises appear louder to us again.

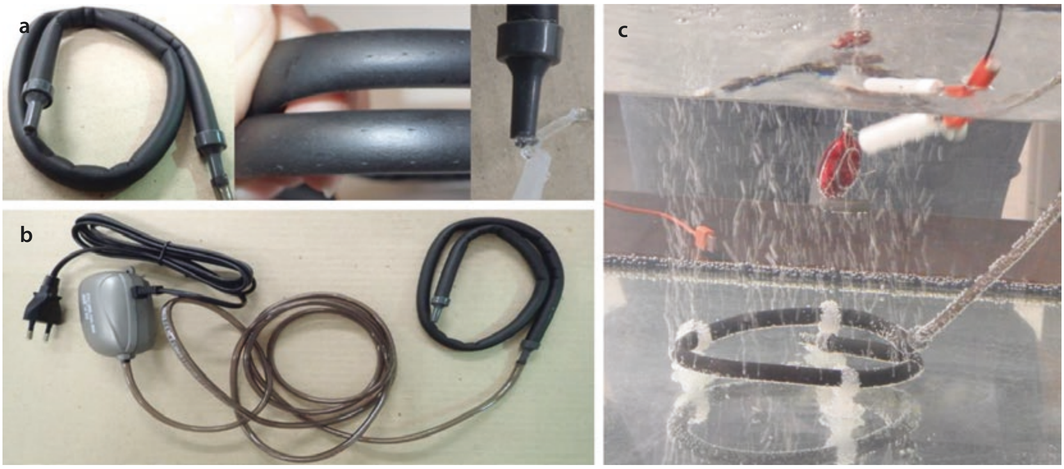

Fig. 8 Build a bubble curtain (▶ Exercise 2.5). **a** Air bubble tube for aquaria, the air holes are clearly visible. The end needs to be sealed; here we use glue. **b** Complete bubble curtain setup with aquarium pump, connective hose and air bubble tube. **c** Running bubble curtain experiment. The red alarm functions as free-floating underwater sound source. The white, self-built hydrophone is used to measure sound levels inside and outside the curtain for comparison

6. Think about the implementation of a bubble curtain on a large scale. Which materials are needed to make it work? Are there other problems that could be caused by using a bubble curtain?

Results

When the bubble curtain appears, there should be a clearly detectable drop in the sound level. Due to the limited amount of air holes in the commercially available tubes or depending on the strength of the used compressor, the effectiveness of this experiment is often not huge, but the students can get a good feeling for how effective it can be if more air bubbles and dual or triple layers are used.

For Task 6, additional ship traffic around the construction site, electricity supply to the construction site and running of loud generators should be considered, as well as huge hoses on the sea floor, likely damaging plants and microhabitats. Still, the impact of pile-driving is usually considered more dangerous and needs mitigation measures, even if they come at additional environmental costs.

Tip

By submerging the active sound device in the water, you can try to explain a hard sound barrier and sound reflection. The density difference between the two media (air and water) is several hundredfold; therefore, the two media form a *boundary* and we cannot hear what is happening underwater while we listen in air. This is why bodies of water usually appear silent to us. In this case, we still hear the sound of the panic alarm, because it is loud and the container walls transmit the sound back into the air. To prove this, let the alarm sink to the bottom, and the transmission of the sound will appear louder. Try the bubble curtain again with the sound device lying on the bottom. It will not work well, due to sound being transmitted by the container walls. You can also use a stethoscope to listen to the sound from inside the aquarium and better avoid the effects of the walls.

If the device would be submerged in the ocean where the sound is not redirected and transmitted, we would not hear it at the water surface. If we are submerged, we can hear more of the sounds present underwater. However, the air-water sound barrier still exists inside our ears, so we do not hear underwater sounds as good as in-air sounds. Many underwater sounds are outside the human hearing range but within the hearing range of marine life. Often, we may not think enough about the potential damage caused by underwater noise because we do not hear the noise that well.

Home Page

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Suggested reading

1. Tyack PL 1998. Acoustic communication under the sea. In: Hopp SL, Owren MJ, Evans CS, editors. Animal acoustic communication. New York: Springer-Verlag p. 163–220.
2. Wahlberg M, Linnenschmidt M, Madsen PT, Wisniewska D, Miller LA 2015. The acoustic world of harbour porpoises. American Scientist; 103:46–53. https://doi.org/10.1511/2015.112.46.
3. Au WWL 2018. Echolocation. In: Würsig B, Thewissen JGM, Kovacs K, editors. Encyclopedia of marine mammals. New York: Academic Press.
4. Nummela S, Yamato M 2018. Hearing. In: Würsig B, Thewissen JGM, Kovacs K, editors. Encyclopedia of marine mammals. New York: Academic Press.
5. Mann D, Hill-Cook M, Manire C, Greenhow D, Montie E, et al 2010. Hearing loss in stranded odontocete dolphins and whales. PLoS ONE 5(11):e13824. https://doi.org/10.1371/journal.pone.0013824.

Whaling, Seal Hunting and the Effect of Fisheries on Marine Mammals

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Contents

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Learning goals

- Understanding interactions between marine mammals and fisheries, and how to mitigate them
- Gaining knowledge about the views of different interest groups concerning whaling and seal culling
- Learning how to determine the diet of marine mammals by studying fish ear bones

1 Introduction

Marine mammals are important top predators in the world's oceans. Many species are opportunistic feeders, catching the most abundant, convenient and easiest caught prey, depending on region and season (◘ Table 1). For example, Baltic grey seals (*Halichoerus grypus*) feed mostly on herring, sprat and cod in the Baltic Proper, but further north in the Bothnian Bay they also feed on whitefish and salmon.

Apart from being an important part of marine food webs, marine mammals are indicators for the state of the marine environment. This is one of the reasons why stranded marine mammals undergo extensive post-mortem investigations, including stomach content analysis and including monitoring levels of toxic substances in various tissues. Large abundances of whales or seals in certain regions indicate good environmental conditions. For example, decreasing numbers of hauled-out seals could indicate that various human activities and environment alterations prevent them from thriving. Additionally, if marine mammals maintain a low *fertility rate* (having very few or no offspring) or a high level of diseases in a particular region, it is likely that their environment and prey are contaminated with toxic substances. Common toxic substances are persistent organic pollutants such as pesticides (for example DDT) or industrial chemicals (such as PCB). Similarly, the presence and good health status of marine mammals indicate a marine environment of high quality.

Overlap in human and marine mammal diets can lead to competition and result in bycatch, catch depredation and fishing gear damage. To study such issues, it is essential to know the diet of marine mammals in the area of interest. The identification and size of fish prey can be derived by measuring *otoliths* (fish ear stones; see ► Exercise 4.1 and ◘ Fig. 4) often found in the stomach or faeces of marine mammals.

◘ Table 1 Daily food consumption for adult Baltic and North Sea seals and harbour porpoises

Grey seal	Harbour seal	Ringed seal	Harbour porpoise
5–9 kg/day	3–5 kg/day	4 kg/day	3–6 kg/day

Sources: Bergman (2007) and Rojano-Donate et al. (2018). The food consumption is affected by body weight, diet composition and season

2 Bycatch

Fisheries operate in many areas that are natural foraging grounds of marine mammals. This inevitably leads to interactions and conflicts between fisheries and marine mammals. One type of interaction is incidental entanglement and death of marine mammals in fishing gear, called bycatch. Another major issue is gear and catch damage caused by marine mammals.

In the Baltic and North Sea region, bycatch is one of the major anthropogenic threats to marine mammals, although quantitative estimates of mortality in fishing gear are scarce. A few extensive reports suggest that the bycatch rate can be higher than reported in official statistics. For Baltic grey seals, the yearly bycatch may be higher than 2300 individuals. For some species, there has luckily been a documented reduction in bycatch: In the 1990s, the estimated bycatch was 7,000 harbour porpoises (*Phocoena phocoena*) in the Danish part of the North Sea. Nowadays, the estimated porpoise bycatch is lower due to altered fishing efforts as well as the use of *acoustic deterrent devices* (so-called *pingers*). Still, bycatch remains one of the largest threats to marine life, including marine mammals, in many regions, including the North Sea and the Baltic.

Bycatch

Incidental catch of non-target marine species in fishing gear. Marine mammals, fishes (non-targeted species and undersized specimens), birds and turtles, as well as invertebrates constitute a substantial part of bycatch in certain fisheries.

The main fishing gear responsible for marine mammal bycatch are gillnets, which are anchored on the sea bottom. Gill nets form very long, nearly transparent walls in the water column, constituting traps for marine mammals and other animals. Unfortunately, incidents of marine mammal bycatch, although fairly numerous in certain regions, are rarely reported by fishermen and not always adequately monitored, which makes a proper assessment of this threat difficult. Frequently, stranded cetaceans show characteristic net marks around their heads or other parts of the body, indicating previous entanglement in fishing nets (◘ Fig. 1). Post-mortem examinations often reveal a full stomach and bleeding in several organs, most likely caused by death struggle. Net wounds around the neck, snout or flippers are also observed in seals. Even though scientists sometimes judge bycatch as a likely cause of death, they are often unable to obtain information on the location, date and type of fishing gear in which the animal may have been caught. Such data are crucial for the implementation of effective conservation measures for the species in question.

Changing fishing gear to newer types known to be less harmful to marine mammals does not always provide an environmentally responsible or economically feasible solution. For instance, bottom trawling (dragging a trawl over the seafloor) has little direct impact on marine mammals but causes severe damage to *benthic* communities, as well as it may result in a large bycatch of juvenile fish and invertebrates. Thus, switching to 'marine mammal friendly gear' will not always solve the overall problems.

The worldwide demand for fish will increase in the coming decades. Due to overfishing and the huge quantity of bycaught and discarded smaller sized fish, the amounts of fish obtained by fishing no longer meet the global need. Therefore, most of the fish consumed today is farm-raised, not wild. Aquaculture is regarded as a solution to the burning issue of ocean overfishing. The main advantage of aquaculture is that, unlike fishing, it relies on bred and harvested fish, not on depleting wild fish stocks. Prospects of aquaculture are promising, but some types, such as offshore open systems, pose serious environmental threats, resulting in unhindered interactions between farmed fish enclosed in cages or netting systems and the surrounding environment. Aquaculture can spread diseases, parasites and chemicals (e.g. antibiotics) into

◘ **Fig. 1** Left: Bycaught harbour porpoise with net marks around the snout. © Katarzyna Jęczkowska. Right: Stranded grey seal entangled in fishing net. © Mateusz Puzdrowski the wild. Faeces and nutrients released into the environment may cause the rise of algal blooms and eutrophication. Damaged cages result in farmed fish escaping. Escapees of farmed fish not belonging in a certain habitat can compete for food and place with indigenous species. The escaped fish can also interbreed with the wild stocks, which may lead to questionable mixing of gene pools. In addition, aqua-cultured fish needs to eat. To grow them to harvestable size, a large amount of additional smaller fish is needed, which is usually wild-caught. Thus, there are both positive and negative sides of marine fish aquaculture.

3 Seal-safe fishing gear and catch damage

Marine mammals can cause catch loss or gear damage by feeding on fish caught in nets (Fig. 2). Since the 1990s, the conflict has escalated between Baltic fisheries and grey seals. The grey seal population of historically about 100,000 individuals suffered a drastic decline in the 1970s after decades of hunting and exposure to pollution. After being protected in the 1980s, the Baltic grey seal population have recovered, reaching over 40,000 individuals in the late 2010s. Meanwhile, the biomass of several commercial fish species has decreased in the Baltic for various reasons, and seals have increasingly been perceived as being in competition with fisheries. The seals may affect the fish stocks not only by directly feeding on them but also through the spreading of parasites, for which seals and fish are part of the life cycle.

The most severe gear damage and catch loss due to Baltic grey seals is reported from the Gulf of Bothnia. The problems are worst in coastal fisheries using static fishing gear, such as salmon traps, as well as in gillnet fisheries for herring and whitefish. Fisheries using active fishing gear, such as trawling, are less affected. Various methods have been tested to minimise the seal-fishery interactions. One option is financial compensation for seal-induced catch damages. However, this solution is short-term and does not solve the actual problem. Additionally, it does not take the seal mortality in fishing gear into account, unless special constructions preventing seals from becoming entrapped in the gear are used voluntarily by fishers. The implementation of so-called *alternative fishing gear* may both reduce catch and gear damage, as well as bycatch of seals.

4 Bycatch mitigation measures

There are four main approaches to reduce bycatch of marine mammals:
- Reduce fishing efforts,
- Use pingers or other acoustic deterrent devices,

Fig. 2 Marine mammals, in particular pinnipeds, can cause severe catch loss or gear damage by feeding on fish entrapped in fishing nets. © Annika Toth

- Implement time restrictions and area closures for fishing, and
- Use alternative fishing gear.

The most effective way to curb bycatch is to reduce fisheries that incidentally catch marine mammals. Implementation of he total allowed fishing effort using, for example, gillnets, is nowadays made.

Acoustic deterrent devices of the so-called *pinger* type (Fig. 3) are effective in minimising bycatch of harbour porpoises. Pingers emit acoustic signals of rather low intensity, with frequencies between 10 and 180 kHz. They are attached to gill nets at a few hundred metres distance from each other. According to EU legislations, fishing vessels above 12 m length using some types of gillnets in certain areas are obliged to use pingers. Unfortunately, gillnets are widely used in Baltic waters, and the areas and gill net types where pingers are mandatory does not always overlap with the areas having the highest abundance of harbour porpoises.

Pingers can almost entirely eliminate bycatch of harbour porpoises, when used properly. However, it is unclear if porpoises habituate to pingers in the long run. Also, pingers may not scare off but instead attract grey seals to the nets. This complicates the efficiency of pingers in regions where seals are abundant, since the pingers may act as *dinner bells* for seals and thereby intensify seal depredation. Since seal depredation is already a large problem in the Baltic Sea, Baltic fishermen are reluctant to use pingers. Currently, there are attempts to develop pingers that are inaudible to seals but audible to porpoises.

Temporal and spatial closure of fisheries is another way to successfully reduce bycatch. The deployment of gillnets could be banned during certain times of the year and in locations important for marine mammals. Proper implementation of such regulations requires thorough information on the distribution of marine mammals and an in-depth understanding of the needs of fisheries in the designated area.

Another way to reduce seal-induced catch loss is the development of new fishing techniques. There are different types of alternative fishing gear that have been introduced in the Baltic Sea, for example, *pontoon traps* and *cod pots*. The construction of alternative fishing gear aims to protect the fish catch from the seals, but also the seals from being bycaught. In addition to new fishing devices and techniques, traditional fishing gear could be modified by using stronger net materials, and wire partitions or grids in the entrance of traps and fyke nets.

Fish and seafood consumers need to be aware of the impact their *shopping behaviour* have on adequate bycatch protection of marine mammals. Various official certificates have been introduced to ensure that labelled fish was caught using techniques that minimise bycatch. Choosing a certified instead of

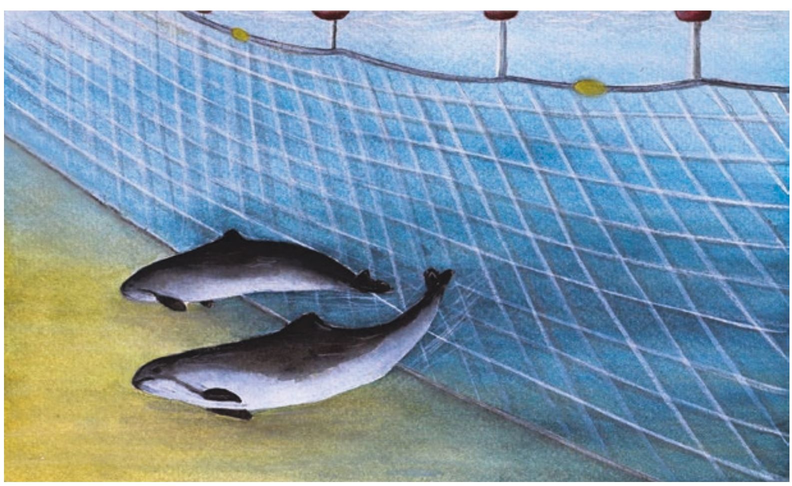

Fig. 3 Yellow acoustic deterrent devices, so-called 'pingers', are attached to a fishing net in order to minimise bycatch. Harbour porpoises are scared away by the sounds the pingers produce. © Annika Toth

an uncertified product helps ensure that bycatch caused by traditional and more harmful fishing techniques will finally be replaced by modern and marine mammal-friendly gear, limiting bycatch.

> Seafood certification schemes span from self-certification to third-party ecolabelling schemes. Some of the most well-known certifications of fisheries are the international *Marine Stewardship Council (MSC) and* the *Friend of the Sea (FOS)*. Some countries have their own certifications, such as the Swedish *KRAV* and German *Naturland*. Out of the 50 or more seafood ecolabelling schemes that are out there, MSC and FOS cover over 25% of the global seafood certifications.

Seafood certification schemes

The *Marine Stewardship Council (MSC)* assesses if wild capture fisheries are sustainable and well-managed. MSC was established in 1997 as a partnership between WWF and the food company *Unilever*. A certain amount of marine mammal bycatch is accepted under the condition that it is sustainable and only has a small impact on populations. The certification is carried out by third-party certifiers. About 15% of the world's fisheries are covered by MSC programmes. Assessments of fisheries is based on scientific verification of the sustainability of targeted fish stocks, the ecosystem impact and the quality of management of the fishery. In the future, MSC will adjust its assessment methodology to FAO (*The Food and Agriculture Organisation*, United Nations) guidelines for the ecolabelling of fish and fishery products.

Friend of the Sea (FOS) was founded in 2006 by the Earth Island Institute's 'Dolphin Safe Project', which has been managing the 'Dolphin Safe' label. FOS is one of the most diverse seafood ecolabels and certifies both aquaculture and fisheries. The sustainable fishery criteria require no overexploitation of target stock, not more than 8% discards, no bycatch of endangered species, no impact on the seabed, compliance with regulations, social accountability and gradual reduction of the carbon footprint. The 'Dolphin Safe' label played a role in the reduction of dolphin bycatch in tuna fisheries. Despite these efforts, the affected dolphin populations have not recovered, which indicates that both fishery management and the 'Dolphin Safe' label are not effective enough. Dolphin-safe catch methods may be used by the industry primarily as a marketing tool rather than a genuine attempt to protect dolphin populations. Consumers should look for actual certified labels on tuna cans rather than general 'dolphin friendly' prints. Also note that some dolphin-safe fishing practises can have a substantial bycatch of other threatened species of, for example, sharks and turtles.

The Swedish *KRAV* label for organic food has implemented a system for the certification of sustainable fisheries. Sustainability is evaluated using three criteria: safe fishing methods, sustainable stocks and *traceability*. Safe fishing methods require the use of fishing gear that eliminates capture of non-targeted species or undersized individuals. Sustainability ensures that fishing is carried out on stocks that can be maintained in the long term. Traceability allows checking the location of fishing vessels, ensuring they only fish from approved stocks in authorised areas.

Naturland was founded in Germany in 1982 as an organic farming certification scheme. It later developed certification schemes for aquaculture and fisheries. Naturland standards on sustainable fishery focus on the careful use of fish stocks while protecting entire ecosystems, avoidance of harmful fishing methods, and supporting fair working conditions for fishermen.

Seafood certification schemes are not without flaws. Scientists and NGOs have been objected to some fisheries certifications. For example, a substantial part of seafood certified by MSC or FOS lacks stock status information. Target species are sometimes overfished and therefore not worthy receiving the label. Some of the MSC certifiers have been paid by the fisheries. Still, we believe it is sensible to purchase certified seafood, as the fraction of less exploited or healthier fish stocks is 3–4 times higher in certified than in non-certified products.

5 Whaling and seal hunting

5.1 Whaling

Whaling is the practice of hunting whales, dolphins or porpoises. In some parts of the world, whaling started at least 3,000 B.C., mainly as a food resource. In the 1800s, whales were also hunted for blubber (which was used for, lamp oil, lubrication and soap) and baleen (*whalebone*, used for, corsets and umbrella ribs). During the era of industrial whaling in the twentieth century, many larger whale species were hunted for meat to near extinction. The industrialised hunt had such an impact on populations that several species of large whales are still listed as endangered. Nowadays, whales are protected by several national laws and international conventions. The *International Convention for the Regulation of Whaling* was ratified by many countries in 1946. Even though most countries have banned whaling, there are still a few countries hunting whales (◘ Table 2).

Table 2 Examples of modern whaling operations, regulated by the IWC

Type	Purpose	Where?	Concerns
Aboriginal subsistence whaling	Cultural and nutritional requirements of remote aboriginal communities	Alaska, Chukotka, Greenland and Bequia	May also have commercial purposes by selling whale meat to tourists. Traditional killing methods are often less efficient than modern ones
Scientific whaling	Research	Japan (until 2019)	If meat is sold, these operations are not only scientific but also commercial
Commercial whaling	Economic	Iceland and Norway; Japan	These countries object the IWC moratorium. They have established their own catch limits, not regulated by IWC

IWC and ASCOBANS

The IWC (*International Whaling Commission*) manages whaling and is involved in cetacean research and conservation. The IWC regulates commercial, scientific and aboriginal subsistence whaling. Membership of the IWC is open to any country that formally adheres to the 1946 Convention. In 1986, IWC implemented a *whaling moratorium* on large whales, pausing commercial whaling. The moratorium has given many whale populations a chance to recover from the extensive exploitation during the nineteenth and twentieth centuries.

The moratorium was affirmed in 2018 and is still effective. A few countries object to the moratorium and pursue whaling, targeting, for example, minke whales (*Balaenoptera acutorostrata*, e.g. Norway) and fin whales (*Balaenoptera physalus*, e.g. Iceland). In addition, some countries are allowed to pursue *scientific whaling* to evaluate the status of certain populations. However, scientific whaling has been suspected to be used as a 'loophole' to pursue commercial whaling under the moratorium. Japan is an important country in these discussions. After having conducted scientific whaling sanctioned by IWC for decades, Japan resumed commercial whaling and left IWC in 2019.

ASCOBANS (Agreement on the conservation of small cetaceans in the Baltic, North East Atlantic, Irish and North Seas) was ratified in 1991 and extended to its present extent in 2008. The objective of ASCOBANS is to restore or maintain a favourable conservation status for cetaceans in the area covered by the agreement. Working groups of scientists and conservationists within ASCOBANS develop area- or topic-specific management strategies for the protection and recovery of local populations of marine mammals, such as harbour porpoises.

During the twentieth century, the era of industrial whaling, almost 3 million cetaceans were killed. Measured as total biomass, this constitutes one of the largest animal harvests in human history. In the North Atlantic, over 280,000 cetaceans were killed, in the North Pacific 560,000, and in the Southern Hemisphere an estimated 2,000,000 animals. These are only the officially documented numbers; the real numbers are likely much higher.

Once stocks of larger whales had been depleted, the whalers moved on to hunt other stocks, and eventually smaller species. Sail-powered whaling ships took around 300,000 sperm whales (*Physeter macrocephalus*) between the early 1700s and the end of the 1800s. Technological advances of the late nineteenth century made whaling extremely efficient. Engine-driven vessels and the *exploding harpoon* were introduced, as well as factory processing on huge ships or at whaling stations. In the first 60 years of the 1900s, the same number of sperm whales were caught as during the previous two centuries. In the following decade (1970s), the same number of sperm whales were again harvested, this time due to a special interest in the waxy fluid inside their heads, called spermaceti.

5.2 Seal hunting

Seal hunting also goes back several thousand years of human history. Seal bones and teeth are found in human-made deposits in Northern Europe from stone, bronze and iron ages. Seals have been hunted for fur, blubber and meat. They have also been hunted as pest control to reduce competition with fisheries.

During the past few hundred years, the two main target species for seal hunting in Northern Europe were the harbour and grey seal. In the late 1800s and early 1900s, a bounty system was established in several countries as an attempt to reduce seal stocks and their influence on fishing. The bounty system led to an overexploitation of both species. With the additional detrimental effects of DDT, PCBs and other toxic substances, the populations plummeted in the 1950s and 1960s. Both grey and harbour seals have been protected from hunting since the 1980s in most Northern European countries. Since protection, the populations of Northern European seals have steadily increased, except for a few viral disease outbreaks with a high mortality in harbour seal populations in 1988 and 2002. Today, the abundance of both harbour and grey seals has reached a sustainable level. Still, the nutritional and health status of individual seals have not reached a satisfactory level.

Limited seal hunting (mainly for fishing gear protection, but in some areas also for food) is allowed in several Baltic countries, including Finland, Sweden and Denmark. In Germany, harbour seals belong to huntable game, but they have been exempted from this practice since 1974. Officially appointed and trained seal hunters help the German authorities to collect dead animals, and to decide if seals in a poor health condition found alive on the beach should be sent for rehabilitation or *euthanised* with a rifle.

Current topics of seal- fishery interaction research

Improved Fishing Gear

Grey seals exhibit remarkable adaptability and cognitive abilities. In regions of high abundance, like the Baltic Sea, they locally create conflicts with commercial fisheries by eating fish from nets and destroying gear. To protect catch, fishermen may replace traditional fishing gear (such as gillnets) with alternative seal-safe gear (e.g. pontoon traps or cod pots). Despite the large progress that has been made in preventing seal-induced catch damage, none of these new types of gear are 100% seal safe. Seals quickly improve their skills in raiding fish traps, and therefore constant modifications of fishing gear are essential. It is necessary to continue the development of effective and sustainable seal-safe fishing methods, while at the same time prevent damage caused by seals. In order to improve fishing gear and to test new prototypes, a close cooperation between scientists, fishing gear technologists and fishermen is required.

At the Swedish *University of Agricultural Sciences* (SLU) in Lysekil, Dr. Sara Königson and her student, Jasmine Stavenow, investigate conflicts between seals and fisheries. The aim of their research is to develop seal-proof fishing gear. In one of Sara's research projects, she has developed and tested pots as an alternative to gill nets used for cod. Sara and Jasmine attached waterproof cameras to the pots so that they could study both fish and seal behaviour around the pots. They spent many hours on the pier or in small boats preparing the pots for the experiments, as well as in front of their computers, analysing the footage and summarising the results into reports and scientific publications. Some of Sara's and Jasmine's seal-proof pots are now commercially available. Sara and Jasmine continue to invent or improve other types of fishing gear.

You can watch the video of their typical day of field work and a video showing the behaviour of grey seals visiting fishing gear here ▫ Videos S1 and S2.

6 Teaching materials

Exercise 4.1: Fish dissection and otolith examination

Did you know that bony fish have *ear stones*, which can be used for species identification? How can you determine the age of a fish?

Bony fishes have a sensory organ to detect gravity, balance and movement. Within this

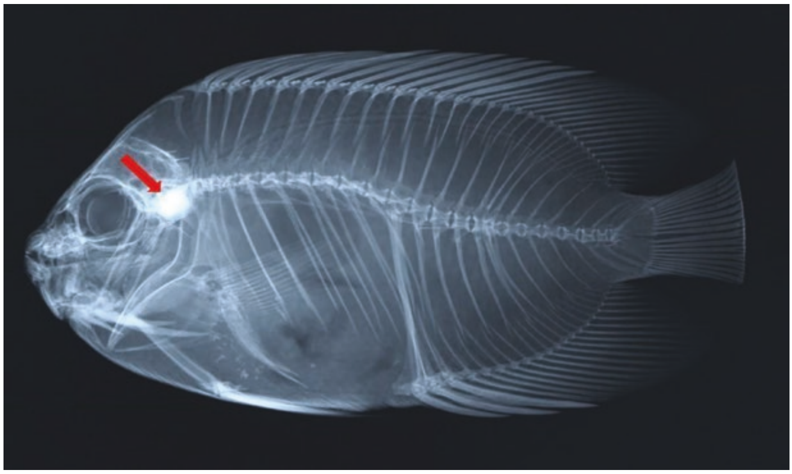

Fig. 4 X-ray image of a marine angelfish showing the location of an otolith (indicated with an arrow). © Frédérich Bruno

organ, the fish ear is also located. No external ear (such as our *pinna*) is necessary for fish to hear underwater. Essential to fish hearing is the *otoliths*, meaning ear- (oto) stones (liths). Each otolith is made of calcium carbonate crystals. Bony fish have six otoliths, three on each side of the head in posterior end of the cranial cavity (Fig. 4). Some of them are small, and usually only two of them (which in some species can grow very large, with a length of several cm) can be seen without a magnifying glass. When the fish is rocked in a sound field, the otoliths lag slightly behind due to their higher density, and the relative motion between fish and ear stone is picked up by sensory hair cells.

Otoliths show *annual growth zones*, very much like growth rings on trees. Therefore, they can be used to age fish. In herring and flat fish, the annual growth zones can be seen without any kind of special preparation. In other species, such as cod, the otoliths must be prepared before the growth zones are visible. These otoliths are sectioned, polished or washed in weak hydrochloric acid solution in order to enhance the contrast between the different growth zones. Sometimes it is also necessary to break the otolith and burn the cracked surface with a burner or candle before age determination is possible.

There are many other applications to these stones besides age determination. Their toxic content may indicate ecosystem pollution. The growth layer in which toxins are detected may indicate at what age fish encountered toxins. Otoliths are shaped differently depending on species, and they are therefore used for taxonomic studies and species identification. Even though otoliths found in marine mammal stomachs and faeces may be eroded by digestion, they still provide useful information on prey species. Such data can also enhance our knowledge on the magnitude of competition between wildlife and fisheries. Consequently, analysing otoliths makes it possible to study fish, their predators, ecosystems, fishery interactions and environmental contamination.

In this exercise, you will learn how to remove otoliths from herring.

Required materials

- Dead herring
- Petri dish
- Small scissors (e.g. nail or surgical scissors)
- Tweezers
- Disposable gloves
- Paper towels
- Binocular microscope or smartphone microscope

Tasks

1. Cut carefully through the top of the head with small scissors and expose the brain. The otoliths are located near the bottom of the brain case.

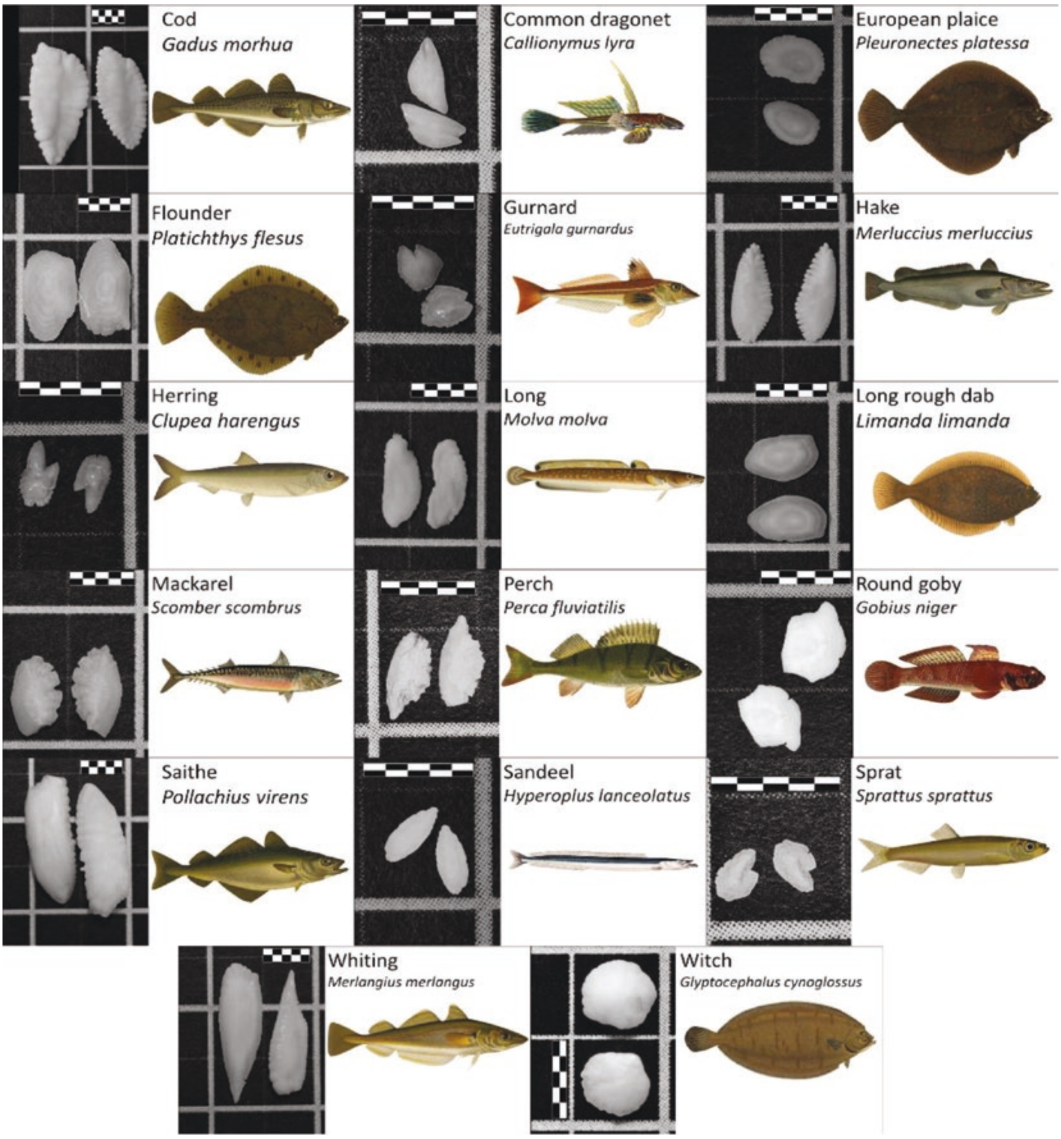

Fig. 5 (► Exercise 4.1) Otoliths of different fish species. The black-and-white scale on top of each otolith is 5 mm long. Fish illustrations under public domain (CC0) © Wilhelm von Wright, Gervais and Boulart

2. Use tweezers to push the brain out of the way or extract it completely so that the two largest otoliths can be removed on each side of the head.
3. Place the otoliths on a petri dish and observe them under a binocular microscope, or with a smartphone microscope. What do you see? Are the edges smooth or rough? Do you observe any layers? Compare Fig. 5. to the otoliths you just extracted.

Exercise 4.2: Whose scat is it?

Have you ever wondered how scientists determine what aquatic predators eat? Why are dietary studies of marine animals important?

In this exercise you will investigate marine animal scat. You learn how scientists identify marine animals through the help of otoliths and other animal parts found in scat. This information is used to understand the feeding behaviour of marine mammals, their health status, their habitat range, the abundance of fish and other animals within their local habitat, and much more. For example, in a study from 2013 the scientists used stomach contents to predict how much giant squid is eaten worldwide by sperm whales each year. The result was an astonishing 131 million individuals!

- **Required materials**
  - Information on marine animal feeding preferences, provided below
  - A compilation of different fish species and their otoliths (Fig. 5)
  - Pictures of scat samples (either from Fig. 6 or collected by you)

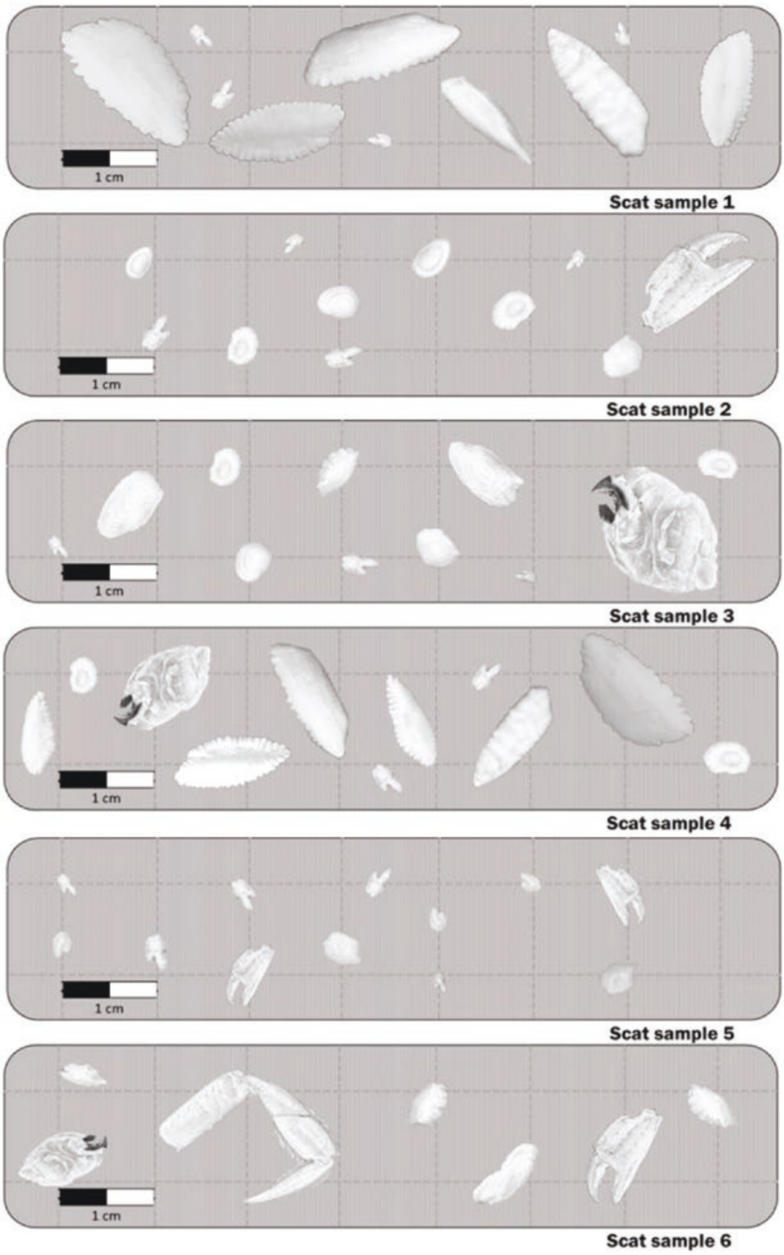

Fig. 6 (► Exercise 4.2) Scat content examples from six different marine mammals and birds. It is possible to determine which animal each scat originates from by using the marine animal feeding preferences (provided in ► Exercise 4.2), and Fig. 5

Tasks

Your task is to identify the consumed fish species by its otoliths and the bony fragments you found in the scat sample, and to identify the most likely predator by the prey remains present in their scat.

1. Identify the otoliths and animal parts in your scat sample (Fig. 6) by using the provided information on fish and their otoliths (Fig. 5). Some animal parts are not depicted; in these cases, you have to guess what it is. Write down your results; try to identify the entire content of the scat sample. Otoliths are species specific, but there can be a natural variation in their shape between individuals. Try to match the sample to the most likely otolith in Fig. 5.
2. Once you have identified the content of your scat sample, use the information on marine animal feeding preferences below to see if the scat content matches the feeding preferences of a certain species of marine mammal or bird. Remember that there is an overlap in feeding preferences between species, so it could be that several animals fit the criteria. In this case, you need to find the most likely species.
3. Write down your answer and describe how you identified the species. If you are using Fig. 6. for your scat sample, then check if your answer is correct here: link.
4. Start over again using a different scat sample and see if you can figure it out faster.

To identify the predator, here is some information on marine animal feeding preferences.

Grey seals
Often eat herring, cod, haddock, dab, sprat and whiting
Sometimes eat hake, plaice, salmon, crustaceans and molluscs
Harbour seals
Often eat plaice, herring, dab and gobids
Sometimes eat crustaceans and molluscs
Ringed seals
Often eat herring, round goby and sprat
Sometimes eat crustaceans and molluscs
Porpoises
Often eat herring, sprat, cod
Sometimes eat round goby, saithe and sandeel
Herring gulls
Often eat crustaceans, echinoderms, herring, mackerel and molluscs
Sometimes eat saithe and sandeel
Common guillemots
Often eat herring, sandeel and sprat
Sometimes eat dab, sticklebacks and whiting
Great cormorants
Often eat eelpout, perch, roach and sticklebacks
Sometimes eat common ling, mackerel, molluscs and crustaceans

Exercise 4.3: Whaling role play

You have probably heard about discussions about whaling in the news. Did you ever consider why it is so difficult to pass a ban on whaling, and why some people and nations are opposing it? Should whaling be continued in order to preserve cultural heritage? Can humans use whales as a source of food, just like we use many other types of animals?

Here, in a panel discussion, stakeholders from different interest groups with different opinions debate whether or not there should be a worldwide ban on commercial whaling.

There are very few countries that still pursue commercial whaling. Whale meat for human consumption is usually sold on local markets. The IUCN (*International Union of Conservation of Nature*), the worldwide authority on the status of nature, lists the minke whale, the major target species of whaling, as being of least concern. Countries that are objecting to the IWC's moratorium decision and establish their own catch limits must provide information on their catches to the IWC, while Japan is no longer obliged to report to the IWC as a non-member.

Required materials

- Role cards

Moderator

You lead the panel discussion and examine the topic as comprehensively as possible. You should remain independent, neutral and not biased towards one opinion throughout the entire discussion, and you are in charge of controlling a fair distribution of the voiced contributions. You are also responsible for calling the different stakeholders to reason if the discussion gets too heated, and you should encourage active participation by more reluctant participants through direct questions.

To begin the discussion, you ask the participants to present themselves and to outline their position on commercial whaling. Watch the time during the introductions: Each participant only has 2-3 min. If you feel they would have needed more time to explain their views, you can always ask them questions during the debate.

Subsequently, you will start the discussion. Here are some ways to get started:

- Ask a pro-whaling participant what they think of the anti-whaling opinions, or the other way around,
- Ask the whaler why he is whaling in spite of a large international opinion being opposed to it,
- Ask an anti-whaling participant for valid reasons to make exemptions from a ban on whaling.

Make sure to engage all stakeholders in the discussion by giving alternative suggestions or asking about their opinion on that matter. If the discussion comes to a standstill, keep the conversation going. You may, for example:

- Ask a pro-whaling participant whether he or she can imagine an alternative to whaling,
- Ask an anti-whaling participant if he or she thinks we have the right to enforce a ban on whaling for indigenous people, and
- Ask about ethics behind whaling, and about the necessity of whaling to sustain a livelihood; point out examples of a whaling nation that was successfully transformed into a whale-watching nation.

Stakeholders

Whaler: Whaling is my job. I need to earn my money to feed my family. It is what I learned and what I grew up with. I don't have a university degree or much other working experience; I don't think I could provide for my family if I would have to stop this job. I don't understand why most people are so angry about my job. Compared to what humans do to other food production animals, the whaling I practice is much less harmful. Our modern methods guarantee a quick and humane death. Whaling is sustainable; there are plenty of whales out there in the ocean and the stocks keep growing. The whales have a good life, are free and happy and get killed without any notice. They had a better life and a better death than many animals raised for their meat in farms.

Pro-whaling fisherman: Fishing is our livelihood, and the whales eat too much fish. We are not able to use our fishing quotas any longer due to whales. Fish remains our main export businesses. We need to reduce the whale population in order to fulfil our fishing goals. Some whales even eat fish directly out of our nets!

Anti-whaling fisherman: Fishing is our livelihood, and the whales support us because they are ecosystem engineers. Many people believe that they eat fish and thus compete with our catches, but that is not true. The larger whales eat plankton and small fish that is not our target species. They defecate in the water, which enriches the ocean with nutrients and gives small plankton and krill food, which again serves as food source for larger creatures. Whales basically help the fish—that we want to catch—grow. Additionally, whales that feed on the same species that we fish always know where the highest fish abundance is. We just need to go where the whales are and we will have good catches.

Local politician: This is a sovereign country making its own decisions. Foreigners do not rule it, and neither does IWC. We decide ourselves whether whaling should be carried out or not. Whaling has a long tradition here, and we are a traditionalistic country. We value our history and our ancestry. Additionally, whaling is sustainable. Why is it OK to slaughter millions of cows, pigs and chickens for food, but not a couple of happy, free-living whales? That is hypocritical.

Whaling industry economist: Whaling has a long tradition in this country. My family has been whaling for centuries. Whales have been an accessible, healthy and sustainable food source for decades. Additionally, it is worth a good amount of money to sell whale meat. There still is a demand on whale meat because people grew up eating it. We are a small business, targeting only species that are abundant. Therefore, our practice is sustainable and our takes are not leading to a population decline or extinction.

The conservationist: The world's oceans are vast. There is no international police force operating on the high seas. If commercial whaling is permitted to start up again, there will be no way to control international trade of whale meat and blubber. Each large whale might be worth hundreds of thousands of dollars. Illegal and unregulated whaling could once again drive the large whale species to the brink of extinction, just like it happened in the past.

Animal welfare advocate: We think that commercial whaling must be halted. No one knows how populations of whales will be affected by hunting, on top of other daily threats they face. Whaling is unethical, and whales are not suitable for human consumption. Whales live long lives and reproduce slowly. They cannot be killed in an ethical manner. Explosive harpoons often miss the right area on the whale's body, subjecting them to suffering a long, slow and painful death.

Scientist: Whales have been recognised as ecosystem engineers (their faeces enrich the ocean with nutrients, which feeds plankton and thus substantially supports the bottom of the food chain). Many whales have fixed migration routes, and we often notice that the same animal is mistaken for several. Therefore, populations can be misinterpreted as being larger than they really are. One species may be divided into subgroups, ecotypes or even completely different species, which we are not yet aware of and that we may exterminate through whaling. Additionally, whales are on top of the food chain, and with their extensive blubber reserves and their longevity, they accumulate all kinds of toxins. The accumulation of pollutants in stranded whales can be so high that they have to be disposed as toxic waste. Whaling nations give out warnings that pregnant women should not consume whale meat. This is clearly not healthy food.

Citizen Robinson: Only few citizens eat whale meat. I myself grew up never tasting whale meat and I have no ambitions in doing so. Whaling is an outdated tradition that should stop. Many tourists coming here don't like the fact that we are a whaling nation, and we probably have economic losses from people who decide to boycott this country due to our whaling activities. In my opinion, whaling harms our country by degrading its economy and reputation.

Citizen Johnson: Whaling is a tradition in this country and therefore we take a lot of pride in it. Many citizens of this nation support whaling because it is sustainable, healthy and good for the economy. Whale hunting creates jobs and provides a locally sourced food source. Also, whale meat is better than farmed meat, because the whale lived a happier life than a cow or pig. Why can't you have both whaling and whale safaris going on in the same country? In Sweden, people are hunting moose, and there are also moose parks where people can enjoy them.

Tourism expert: Tourism is one of the most important and fastest growing businesses in our nation. Tourists come to see our nature and also for whale watching. It is absurd that we keep killing whales, but the behaviour of tourists is as baffling to me. Some whale watching tourists even eat whale meat. But other tourists boycott our country as a holiday destination due to our whaling reputation.

■ Tasks

1. In this role play, the participants will assume characters of different parties involved in this conflict of interest. Choose one of the potential roles (or have one assigned by your teacher) and collect arguments for your position in order to

develop a basis for the discussion. Multiple students can form groups of parties. However, make sure that the number of stakeholders in each party of interest is equally distributed. Some additional reading material for more information can be provided by the teacher or obtained from the internet (e.g. the IWC and the IUCN websites). Prepare yourself for your stakeholder position and for possible *counter arguments*. One contestant (teacher or a student) is the moderator of the discussion and should be especially aware of the instructions given above for this role.

2. Prepare your arguments for about 15 min with your *stakeholder colleagues* before presenting them to the other participants/parties of interest.
   - What is your position on whaling?
   - What are your main arguments?
   - What compromise could be proposed in the interest of yourself or your organisation?

   Choose one person of your stakeholder group to represent your party of interest during the discussion.
3. The moderator will start the discussion. Before the panel discussion begins, participants present themselves, their position and their arguments in 2–3 min. All participants are thus given the opportunity to get to know each other and their positions on the topic. After the introduction, the moderator will take the lead on the discussion between the different parties of interest and keep the debate alive.
4. In the end, all students should collectively summarise all pro-whaling and anti-whaling arguments and see if the class can come to a differentiated and objective consensus on their opinion on commercial whaling.

Suggested reading

1. Calamnius L, Lundin M, Fjälling A, Königson S 2018. Pontoon trap for salmon and trout equipped with a seal exclusion device catches larger salmons. PLoS ONE 13(7):e0201164. https://doi.org/10.1371/journal.pone.0201164.
2. Dawson SM, Northridge S, Waples D, Read AJ 2013. To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. Endangered Species Res. 19:201–21. https://doi.org/10.3354/esr00464.
3. Hansson S, Bergström U, Bonsdorff E, Härkönen T, Jepsen N, Kautsky L, Lundström K, Lunneryd SG, Ovegård M, Salmi J, Sendek D, Vetemaa M 2018. Competition for the fish—fish extraction from the Baltic Sea by humans, aquatic mammals, and birds. ICES J Marine Sci. 75(3):999–1008. https://doi.org/10.1093/icesjms/fsx207.
4. Rocha RC, Clapham PJ, Ivashchenko YV 2017. Emptying the oceans: a summary of industrial whaling catches in the 20th century. Marine Fisheries Rev. 76(4):37–48. https://doi.org/10.7755/MFR.76.4.3.
5. Varjopuro R 2011. Co-existence of seals and fisheries? Adaptation of a coastal fishery for recovery of the Baltic grey seal. Marine Policy 35:450–6. https://doi.org/10.1016/j.marpol.2010.10.023.

Plastic Debris and Its Impacts on Marine Mammals

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Contents

Supplementary Information The online version contains supplementary material available at [https://doi.org/10.1007/978-3-031-06836-2_4].

D. Brennecke et al. (eds.), *Marine Mammals*, https://doi.org/10.1007/978-3-031-06836-2_4

Learning goals

- Understand plastic pollution problems in our oceans.
- Detect and quantify plastics in our environment and everyday products.
- Obtain knowledge-based ideas to reduce plastic pollution.

1 Introduction

The *United Nations Environment Programme* defines *marine debris* as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment." Marine debris consist of many different materials, such as metal, glass, processed wood, and last but not least, plastics. Due to its durability and lightness, plastics make up a large share of all marine debris and can be found also in remote places.

"Plastics" refer to synthetic materials made primarily of crude oil. These materials have many interesting properties, such as lightness and durability. They can be hard, soft, elastic, persistent and formed in any imaginable way. These features make plastics usable almost everywhere. We have a hard time imagining our daily lives without plastics. Plastic materials are used for, for example, clothing and for food packaging and many other products. In the form of nylon, it is also used in fishing nets and fishing lines.

One problem with plastics is that they are not readily *biodegradable*. Together with the large quantities produced, as well as insufficient ways of disposal and recycling, this means that we find plastics everywhere in the environment. In 2020, more than 360 million tonnes of plastics were produced globally. It is estimated that 4-13 million tonnes make their way into the oceans every year. Scientific expeditions have revealed that more than five billion pieces of plastic with a total weight of more than 250,000 tonnes are floating around in our oceans. This enormous amount of plastic has severe consequences for marine life. Animals become entangled in drifting garbage and fishing nets, and they confuse plastic items with food. Plastics which have been ingested by smaller animals is transferred to large animals by predation. Different size classes of plastics cause different threats. For marine mammals, studies of the impact of plastics have so far focused on larger debris causing entanglement or ingestion, whereas information on the impact of small plastic items is scarce.

2 Plastics: A problem with many sources

There are many sources of marine plastic debris. A major input comes from land with rivers and beaches. Plastic waste from agriculture, industrial production, construction sites, or from people carelessly dropping waste accidentally ends up in the environment and is transported to rivers and beaches by wind and rain and end up in the oceans. Interestingly, 70% of global debris entering the oceans originate from only ten larger rivers.

Large amounts of plastic debris are mainly caused by poor waste management. But, even in regions with well-developed waste management, debris ends up in rivers and is then transported to the ocean.

Nearly 2.4 billion people (about 40% of the world's population) live within 100 km from the coast. In many countries, waste is still placed in large waste disposal sites that may be situated close to the sea. Strong winds blow large quantities of waste into the oceans. Many plastic items are only used once and then they are thrown away; this includes bottles, bags, cups, straws, and spoons. These items may end in the environment due to the carelessness of consumers or poor recycling systems or problematic waste disposal sites: Even if they are properly disposed in garbage cans, they may still end up in the oceans.

Every time you wash your clothes, thousands of plastic fibers are released into the wastewater. The fibers are too small to be filtered out of wastewater at treatment facilities and therefore make their direct way to the ocean.

Thousands of ships and boats navigate our seas and rivers. Shipping containers may be lost at sea and—although it is nowadays strictly prohibited—rubbish may be thrown overboard. Sea-based sources, including shipping and offshore industry, contribute with 20% of marine debris. During fishing operations, nylon nets, lines and ropes are accidentally lost or dumped at sea. Abandoned fishing nets may stay active catching fish for a long time period: They are known as *ghost nets*. *Dolly ropes* are orange or blue plastic threads that are used to protect bottom trawling nets against wear and tear. Every year, thousands of kilos of dolly ropes end up in the sea.

3 Where does plastics end up, and what are the consequences for marine life?

Oceanic water is always in motion. Water is transported around by the huge currents that link all ocean basins. Surface and deep ocean currents belong to the same transportation network that work a bit like conveyor belts move water around the world. The atmosphere and the ocean currents influence one another. Some ocean currents form giant gyres spanning several hundred, even thousands of kilometers in diameter. Once entering the oceans, marine debris circulates in these current systems for decades, perhaps even for centuries, and get concentrated within *gyres* created by the currents.

In 1997, scientists discovered a large area with marine debris in the North Pacific, named the *Great Pacific Garbage Patch*. The total weight of all man-made objects in this area was estimated to be 80,000 tons, or the same weight as 500 jumbo jets.

It may take hundreds of years for plastic to degrade. Plastic items are disintegrated into smaller parts by wind and sun. Older objects become brittle and then fragment into smaller and smaller pieces ending at so-called micro- and nanoplastics. Plastic objects either sink to the seabed or keep floating at the sea surface or within the water column. The weight of floating plastics is enhanced when colonized by small organisms, such as barnacles, mussels, and bacteria. This promotes the sinking process.

The ocean currents transport plastics and its inhabitants over large distances into new regions. Bryozoans, barnacles, hydroids, and molluscs hitch-hike on plastic litter. For *invasive species*, they may reproduce more rapidly in a new area and outcompete native species. This can change the composition of ecosystems and interfere with existing food chains.

During the past decades, scientists have observed impacts of plastic ingestion or entanglement in more than 550 species of marine animals, ranging from invertebrates to mammals. Marine mammals, turtles and seabirds become entangled in discarded fishing gear, restricting the animals in their movements, as well as in feeding or reproduction activities (◘ Figs. 1 and 2). Marine mammals entangled in submerged and anchored "ghost nets" are unable to surface for breathing and drown. A fishing rope tangled at the base of a tail of a whale can cut off blood circulation and eventually the entire tail.

In the North and Baltic Seas, marine debris cause severe health problems for wildlife. Marine mammals such as harbour porpoises, harbor seals and grey seals have shown a variety of impacts associated with entanglement and ingestion. This includes inflammation of organs and suffocation. There has been a drastic rise in the number of reported events during the past decades. Still, there is no satisfactory understanding of the significance of marine debris for marine mammals.

Another problem is that many animals mistake plastic fragments with food. By eating plastic fragments, animals may acquire a full stomach without gaining any nutrients—they can starve. Scientists investigated sperm whales which accidentally ended up in beaches along the North Sea in early 2016. In 9 out of 30 whales, a variety of plastic debris was found in their stomachs. The animals had engulfed nets, ropes, foils, packaging material, and even a large plastic part from a car engine (◘ Fig. 3). One animal was found with 24 kg of marine debris in its stomach.

Fig. 1 A humpback whale caught in a net. The whale was completely covered with the net and one of its pectoral fins was stuck. Several attempts were needed before the whale could be released. Many whales which cannot be helped die—often because they are no longer able to reach the surface to breathe. © Gary Freitag

Fig. 2 Gannets at a breeding colony on the island of Helgoland. Many Gannets are found dead due to entanglement in net fragments. © Abbo van Neer

Fig. 3 (**a**) A fishing net found in a stomach from a sperm whale, stranded in the North Sea. (**b**) The net was 13 m long. Reprinted with permission from: Unger B, EL Bravo Rebolledo, R Deaville, A Gröne, LL IJsseldijk, MF Leopold, U Siebert, J Spitz, P Wohlsein, H Herr 2016. Large amounts of marine debris were found in sperm whales stranded along the North Sea coast in early 2016. Marine Pollution Bulletin 112(1–2): 134–141

In 2018, a dead young male sperm whale was found with 29 kg of plastic trash off the coast of Spain. A necropsy revealed that the animal had ingested, for example, trash bags, polypropylene sacks, ropes, and net segments. Some months later, in 2018, another sperm whale was found washed ashore in Indonesia. Scientists found hundreds of plastic items in its stomach, including cups, bags, and sandals. In 2019, scientists opened the stomach of a young dead whale in Sicily and found many plastic bags inside. In 2019, in the island of Mindanao, Philippines, a young Cuvier's beaked whale was found having 40 kg of plastic bags, including 16 rice sacks, in its stomach.

Investigating the stomach contents of stranded whales plays a crucial role in understanding the effects of plastic ingestion on cetaceans. However, stranded animals may be diseased and emaciated for other reasons than plastics ingestion and therefore not representative for healthier, free-ranging individuals. Furthermore, animals dying without being washed ashore or investigated, remain unregistered.

4 Microplastics: Small particles with specific problems

Once in the ocean, plastic waste is exposed to waves, salt, abrasion, and sunlight, breaking up larger objects into small pieces. The materials become brittle and break into smaller fragments. The pieces become smaller and smaller, and at some point they are invisible to the naked eye. However, this does not mean they disappear. Experts assign the tiny particles to different categories according to their size and study their effects on wildlife.

Definition

- Microplastics: Plastic fragments smaller than 5 millimeters
- Mesoplastics: Plastic fragments with a size of 5 mm to 2.5 cm
- Macroplastics: Plastic fragments larger than 2.5 cm

There are many ways that plastics end up in nature. Synthetic fibers are released from clothes when being washed. Tiny plastic beads are added to cosmetics in shower- or peeling gel. Large amounts of these small plastic particles may enter the marine environment. The fragments can be sufficiently small to pass filter systems and thus enter the environment. As car traffic increases, there is an inevitable increase in microplastics from tire abrasion ending up in the environment. Scientific studies show that the abrasion of car tires is one of the largest contributions to microplastics. Almost every part of our mobility sector contributes to the microplastic amount that enters the environment.

Similar to macroplastics, microplastics is mistaken for food by smaller animals. Animals filtering water for plankton, such as mussels, consume microplastics and are unable to digest it. Therefore, plastic fragments are deposited inside the body. When the filter feeders are consumed by other animals, the plastic particles are assimilated inside the predators. They are transported higher and higher up the food webs, where they are found in larger and larger concentrations.

Can 5 mm plastic items affect huge filter-feeding baleen whales? In 2012, high concentrations of pollutants and chemicals added during plastics production were detected in Mediterranean fin whales (*Balaenoptera physalus*). Due to the way of feeding, baleen whales are susceptible to high levels of microplastics ingestion and exposed to associated toxic compounds. In addition, microplastic particles have been documented in the feces of northern fur seals (*Callorhinus ursinus*) and in the digestive systems of stranded dolphins and monk seals.

An additional problem is that seawater contains many *persistent organic pollutants* (POPs) such as DDT and PCBs. The POPs enter the sea via rivers and beaches. They are insoluble in water, and microplastic fragments adsorb these pollutants. As a result, plastic fragments become floating pollutant carriers. Once the particles have been ingested by marine organisms, the pollutants can enter tissues. POPs are usually deposited in the fatty tissue of the organism. These toxic substances can affect the hormone and immune systems, as well as cause cancer. In addition, pollutants enter the food web and are transferred from one trophic level to the next.

Around 99% of macroplastics entering the oceans do not reach a plastic gyre. The plastics eventually break down into microplastics and sink to the sediment. Also, the polar ice contains high concentrations of microplastics that will be released by increased melting due to climate change. Macro- and microplastics have even been discovered in the *Challenger Deep of the Mariana Trench*, the deepest part of the world's oceans.

5 Mitigation efforts: What can be done?

Our attention toward the marine debris problem is growing. Projects for raising awareness in the public are essential for reducing usage and thus risk of disposal into the marine environment. It is important that our behavior and habits change rapidly.

Both NGOs (*non-governmental organizations*) and people being part of different social groups and professions are focusing on the impact of the environment and searching for solutions. Currently, many efforts are focusing on getting debris out of the ocean. Technologies that are trying to clean the oceans, using filtering ships or swimming baskets, are developed globally. These technologies focus on removing macroplastics. There is a more difficult task ahead of us: to remove microplastics from the oceans, where it makes up the largest portion of all plastics.

An effective method to alleviate the marine debris problem is to reduce plastic consumption. Large contributors to plastic debris that enters the oceans are part of our everyday use. Different ideas to reduce plastics in our wastewater are attempted. Non-wrapped groceries are introduced, offering reduced prices for bringing reusable cups to coffee shops, as well as utilizing only materials which can also be used for other purposes.

Scientists and engineers around the world investigate potential solutions to the debris problem. One focus is on the main sources of marine debris and its trajectories, on its way to the oceans. Another important part of current research is finding substitutes for plastics, or developing biodegradable forms of plastics while meeting the demands in their usage. However, these substitutes, for example, made from soya or corn, will also generate contamination due to intensive agriculture practices.

Everyone can help to reduce the amount of plastics in the oceans. Use *the three R rules* "Reduce," "Reuse," and "Recycle" to cut down on consumption you don't need. Avoid single-used products like plastic cups or plastic bags. The EU parliament is banning disposable plastic products from 2021, including drinking straws, disposable crockery, and cotton buds. In addition, EU member states are obliged to recycle 90% of all disposable plastic bottles. These rules will give more responsibility to the industry for dealing with plastic waste.

To effectively change attitudes to the use of plastic products, the problem has to be addressed in schools. The issue is already part of the content of a few textbooks, and a larger number of student projects have been established for science competitions that deal with the issue of marine debris. The problems with plastics will last for future generations, which underlines the necessity to educate school children in reducing their plastic consumption.

In recent years, civil engagement in scientific research has become increasingly important in Europe. In citizen science projects, locals have the opportunity to be part of a scientific investigation and to advocate for marine protection. The data collected by the participants are evaluated, either by scientists or together with the citizens. They contribute to steering decision-making processes. Citizen science projects also offer great potential for school education. The students are actively part of the scientific inquiry, deal with a topic and have the opportunity to reflect their own behavior and develop awareness.

One example is a citizen science project dealing with marine debris on the yearly *International Coastal Cleanup Day* (ICC). The ICC day is arranged on the third Saturday in September. On this day, coastal sections of rivers, lakes, and oceans are cleaned of debris. Data are collected at the same time, to be used for scientific purposes.

The ICC day is the largest voluntary marine conservation campaign in the world. For the participating students, it is certainly a positive feeling to be able to contribute to marine conservation. Meanwhile, there is also a smartphone app of the Ocean Conservancy, "Clean Swell," which is currently available in English language only, for the ICC.

Current topics of plastic pollution research

Debris, and especially plastics, have a profound impact on the environment. Many studies have investigated the impact plastic debris has on the marine environment, where organisms of different sizes entangle in debris or ingest it. More recent studies have shown that the majority of debris reaches the oceans by rivers. However, quantities, composition, and sources of debris within rivers or at estuaries have not been well studied and most investigations consider few sampling sites. Sampling a larger area over a longer time span is challenging but may be essential to understanding distribution patterns, transport mechanisms, and sources of riverine debris.

The German citizen science initiative "Plastic Pirates" fills some of these gaps. "Plastic Pirates" involve school children and teachers to sample a river of their choice for different types of debris. The participants use a sampling protocol to document quantities, composition and sources of debris items, and a small net to fish for microplastics. The data is subsequently sent to a team of international experts for analysis.

The analysis of the first dataset revealed that about 33% of the collected debris consisted of plastics, and that another large share of garbage is cigarette butts—with a high potential of polluting freshwater. One principal source of debris is people visiting the riverside to meet for having a barbecue or a picknick. Future sampling campaigns with the "Plastic Pirates" aim at investigations of single-use plastics and continue to sample microplastics to cover a larger time span.

6 Teaching materials

Exercise 4.1: How different debris objects might affect marine mammals

All kinds of plastic items can become marine debris, and later encountered by marine mammals. Some items found in marine mammals are listed in ◘ Table 1.

Table 1 (▶ Exercise 4.1) Possible threats of marine debris

Debris item occurring in the ocean	Possible origin	Possible threatened marine mammal species	Possible encounter	Possible impact on marine mammal species
Plastic coverage of a car engine (size: 30 × 20 cm)	*Landfill*	*Sperm whale*	*Mistaken for food*	*Internal injuries such as perforations of gastrointestinal tract due to sharp edges, blockage of digestive tract leading to starvation*
Gillnet anchored at seafloor				
Net floating at surface				
Microplastic fragments				
Food wrappings				
Broken bucket				
Ropes				
Tires				
Flip-flops				

Tasks

1: Fill in Table 1. How might plastic debris items have entered the oceans? Which marine mammal species could be most affected, and why? What are the possible consequences for the species?

Exercise 4.2: Searching for microplastics in everyday products

Plastic microbeads are added to many cosmetic and personal hygiene products. The aim is to improve the cleansing effect of, for example, facial scrubs. Although they are very small, microbeads pose a risk to marine wildlife. Due to chemical properties, harmful organic substances can attach themselves to these tiny particles. If they are then mistaken for prey and eaten by plankton-feeders or other animals, they can be absorbed by the organism and in this way enter the food chain.

Required materials

- Round microsieve (100 or 300 µm mesh size or coffee filter)
- Petri dish
- Water tanks (plastic aquarium, bucket around 10 L)
- Cosmetic products (body peeling, shower gel)
- Wash bottle
- Binocular microscope

Tasks

1. Put a small quantity of the cosmetic product into the microsieve.
2. Rinse the sample in the microsieve. For this, put the microsieve in the water tank and use your fingers. It should be rinsed until the sample no longer foams up.
3. Using the wash bottle, transfer the rinsed samples to a clean Petri dish. Observe the samples with the binocular microscope.
4. Repeat the process with various cosmetic products.

   Possible extension:

5. Download the smartphone app “Beat the microbead” or “Codecheck” on your smartphone. Scan your cosmetic products

at home and in your local supermarket for microplastics ingredients.
6. Write a request and send it per email to the costumer services of the producing companies.

Exercise 4.3: How long does it take for plastic bags or fishing lines to degrade?

We hardly ever question the fact that we use plastics. Plastic is a synthetic material that nowadays comes in many different forms with all kinds of properties. What all plastics have in common is that they are made primarily using crude oil. Plastics have many practical properties. Plastics have become a daily essential material present in a wide range of products due to several outstanding characteristics. They are malleable, hard, elastic, not very breakable, long-lasting, and can be changed in almost any way. As they can also be produced relatively cheap, they are found all around the globe.

- **Required materials**
  - Degradation timescale (Fig. 4)
  - Various items (aluminum can, plastic bottle, paper towels, newspaper, fishing line, cotton rope, wool socks, cardboard box, plywood, Styrofoam plastic cup, milk carton)
  - Arrange before, who is bringing along which of the listed materials

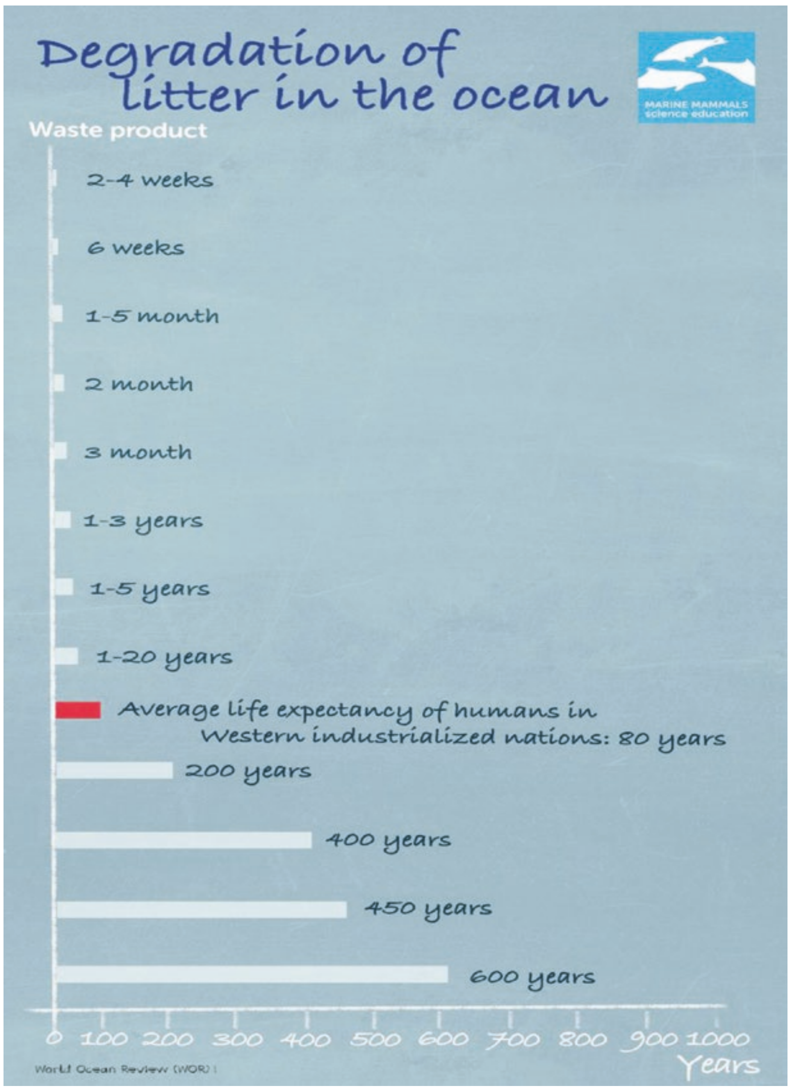

Fig. 4 (▶ Exercise 4.3) Estimated timescales for degradation time of different debris items: aluminum can, plastic bottle, paper towels, newspaper, fishing line, cotton rope, wool socks, cardboard box, plywood, Styrofoam plastic cup, milk carton. Try to fill in which debris belongs to which degradation time, from your readings on the internet © Adapted from: World Ocean Review

■ **Tasks**

1. Estimate with the diagram on the poster how many years it takes for the items inside to degrade in the ocean.
2. Find the data on the internet—if data vary between sources, discuss why this might be the case.
3. Discuss consequences concerning the different duration of degradation of litter debris in the ocean.

? Exercise 4.4: Floating plastic

We will now study the behavior of plastic waste in seawater. This knowledge is essential to find out where plastic waste may cause significant problems to gray seals in the area. A key question is how plastic waste is spread. Alongside the different types of plastics, its form and density play an important role for its "behavior." This determines whether a plastic object floats on the surface, drifts within the water column, or sinks to the seabed.

■ **Tasks**

1. Collect three items of plastic waste each. Choose the three plastic objects that you find most often in your household waste or recycling bin.
2. Consider the factors that may determine the floatability of the plastics.
3. Develop a series of experiments that you can use to study this property. You can use entire plastic objects or cut out small samples. You can investigate the following questions:

   What items float in the water and how do they behave in water?

   - Closed bottles with a lid and open bottles without a lid
   - Closed and filled bottles
   - Bottles with different volumes (e.g., 250 ml, 500 ml, and 1000 ml)
   - Bottles colonized by species such as barnacles (can be simulated using organic modeling plasticine)
   - Bottles made from different types of plastic (e.g., drinking and shampoo bottles)
4. Carry out the experiments with other plastic types (e.g., plastic bags or yogurt pots).
5. Which marine organisms are affected by floating and sinking plastics? Find examples on internet.

? Exercise 4.5: Mystery game

Situation: In 2016, 30 sperm whales stranded at various North Sea locations. All individuals were young bulls (males) around the same age. Several research groups from the countries being involved are trying to explain the strandings (◘ Fig. 5).

◘ **Fig. 5** Uwe Piatkowski from GEOMAR and Ursula Siebert from the University of Veterinary Medicine Hannover investigating the stranded sperm whales' unfortunate deaths.

Scientific approach

In addition to experimenting and searching for answers to scientific questions, the publication of results in specialist journals on the scientific process and the presentation of the results at conferences are also essential. This step is important to make information accessible globally and to find solutions together. In many cases, it is also possible that several research groups are conducting research on the same problem. Every team, of course, wants to be the first to publish their findings.

Required materials

- Mystery game cards

Tasks

1. You are one of the research groups from Germany, the Netherlands, France, and the United Kingdom. You and your colleagues will try to find a plausible explanation for the stranding in the North Sea by using the cards. Create a logical sequence of incidents, explaining the phenomenon.

   Start with card number 7 and use at least five more. If you find a plausible explanation for the strandings, you can publish it.
2. All mystery game cards are available as online supplementary date file: ▶ pdf chapter4 Nov 2022.pdf
3. Read all the Mystery game cards and group them in categories. Sort the cards in a logic sequence and eliminate cards that are not relevant for the stranding of sperm whales. Look for similarities and differences and try to find relationships between the cards.

Exercise 4.6: Microplastics beach sampling

Plastics are currently accumulating on beaches worldwide and can pose a risk for many animals. How much microplastic can be found on sandy beaches?

Required materials

- Sieve (mesh size 1 mm)
- Tray
- Rope (20 m long)
- Mini-shovel

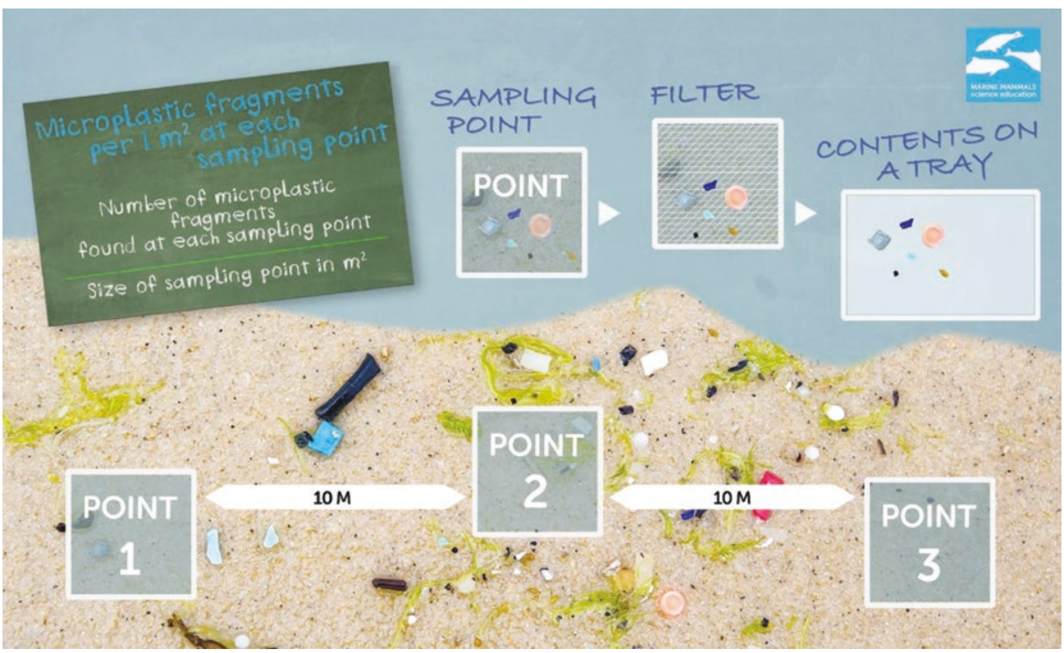

Fig. 6. (▶ Exercise 4.5) Overview sampling points to quantify microplastic fragments on beaches.

Tasks

1. Go to a beach and identify the high-water line (the point at which wet and dry sand meet). If you cannot find this line, take samples within the first meter of the beach from the waterline.
2. Put a 20-meter-long rope along this line and mark out three points (POINT 1, 2 and 3 in Fig. 6)—at the start, middle, and end of the length of the rope.
3. Measure a 50 × 50 cm square at each of these points in the sand.
4. Go to the first square. Remove all larger natural objects (e.g., stones, algae, plants, wood). Use a mini-shovel to dig about 2 cm into the sand within the square and deposit it on a tray.
5. Filter the sand on the tray with the sieve. If the sand is wet, do not sieve it on the beach, but let it dry. Label the bag with the number of the sampling point (1, 2, or 3), close it tight, and take it with you back to your school/group room to dry your sand in an appropriately labeled tray and filter it as soon as it is dry.
6. Now study the contents of the tray carefully. Sort microplastic into one corner of the tray; count the plastic fragments and pellets.
7. Calculate the size of your sampling squares in square meters:
8. Side a in meters × side b in meters = ... m^2
9. Calculate the number of microplastic fragments per square meter at each sampling point: Number of microplastic fragments per square meter found at each sampling point.

Exercise 4.7: Plastic waste diary

You are familiar with various plastic products. It is hard to imagine everyday life without them. An average European, for example, uses more than 100 kilograms of plastic each year. The global increase in the consumption of plastic materials has given rise to huge quantities of waste. Think about how much plastic you use and dispose of every day.

Table 2 (► Exercise 4.7) Plastic diary: Do you know how much plastic you use every day?

Day of the week	Number of plastic waste items	Type of plastic waste items
Monday		
Tuesday		
Wednesday		
Thursday		
Friday		
Saturday		
Sunday		

Tasks

1. Keep a plastic waste diary for 1 week. Note the quantities of plastic waste that you personally generate each day. Make a list of all the plastic items that you throw away (Table 2). Ask your parents to do the same for 1 week.
2. What do you notice? Compare your results with others.
3. Now try to reduce your plastic waste for a whole day. Count it again. What has changed? What can you do differently in the future to reduce your plastic waste further?

Exercise 4.8: What can I do?

Humans have been using rivers, lakes, and oceans since the beginning of mankind. These habitats give us a great deal of resources. But instead of caring for them, we pollute and exploit them. Fortunately, there are also people and organizations who actively campaign to protect the planet. There are many ways of protecting the environments and its inhabitants. Each and every one of us can contribute to that. In order to reduce plastic consumption, you can apply to one or even more of the three R rules.

1. Reduce

   Here, the aim is to cut down on things that you do not actually need. Do you really need the latest smartphone or yet another pair of shoes? If you are now thinking about throwing away everything that is surplus to requirements, then this would be the wrong approach. You can get rid of unnecessary items in other ways, such as by getting them to places where they can still be used. Therefore, you should sell, give away, donate, or swap your items instead.

2. Reuse

   Before buying something new, why not use something that you already have and spend your money on things that you will use more often? One example would be shopping bags that can be reused many times. If you think carefully on a day-to-day basis, you will find all kinds of disposable items that can be replaced with alternatives.

3. Recycle

   Separating waste is essential when it comes to recycling. Not all rubbish items can be recycled. In some countries, container deposit schemes, where the consumer pays a small deposit for items such as bottled drinks, which they then get back upon returning the bottles, are an example of where recycling works well.

Tasks

1. Find at least one other example for each R. Furthermore, search for other R words to add the list above and find examples for them.
2. How could you change your everyday routine in order to produce less plastic waste?
3. Think about ways in which you could raise public awareness of the problem of plastic waste pollution in the oceans so that more people are informed. What initiatives could you carry out so that lots of people get involved? What can people who do not live in coastal areas do to help protect seas and oceans?

   You may find the following questions useful:

   Who produces a lot of waste in your area?

   Who is still not aware of the waste problem?

   How can we present the results?
4. Put the project into practice and document every step with photos.
5. Inform the local press or the city administration about your project.
6. Start to investigate the waste problem in your school life. How can you create less waste in your school? What is done in your school to contribute to a more sustainable development towards plastic consumption? What are ideas from other schools? What are the pupils' opinion toward plastic consumption? What could be improved?

   Develop a small survey for your school and start to initiate changes to show other pupils that everyone can improve something.

Home Pages

Ambsdorf J et al. 2017. Meeresatlas: Daten und Fakten über unseren Umgang mit dem Ozean. ► https://www.boell.de/en/oceanatlas.

Suggested reading

1. Cole M, Lindeque P, Halsband C, Galloway T 2011. Microplastics as contaminants in the marine environment: a review. Marine Pollution Bull 62:2588–97. https://doi.org/10.1016/j.marpolbul.2011.09.025.
2. Gutow L, Gerdts G, Saborowski R 2017. Mikroplastikmüll im Meer. In: Hempel G, Bischof K, Hagen W, editors. Faszination Meeresforschung. Springer. ISBN: 978-3-662-49714-2.

3. Lebreton LCM, van der Zwet J, Damsteeg J, Slat B, Andrady A, Reisser J 2017. River plastic emissions to the world's oceans. Nat Commun 8:15611. https://doi.org/10.1038/ncomms15611.
4. Unger B, Bravo Rebolledo EL, Deaville R, Gröne A, IJsseldijk LL, Leopold MF, Siebert U, Spitze J, Wohlsein P, Herr H 2016. Large amounts of marine debris found in sperm whales stranded along the North Sea coast in early 2016. Marine Pollution Bull 15112(1–2):134–41. https://doi.org/10.1016/j.marpolbul.2016.08.027.

Chemical Pollution and Diseases of Marine Mammals

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Contents

Supplementary Information The online version contains supplementary material available at [https://doi.org/10.1007/978-3-031-06836-2_5].

D. Brennecke et al. (eds.), *Marine Mammals*, https://doi.org/10.1007/978-3-031-06836-2_5

Learning goals

- Understand how different pollutants affect marine mammals.
- Learn how biomagnification and bioaccumulation affect marine life.
- Learn how to monitor wildlife health by post-mortem examinations.

1 Introduction

Many organic and inorganic chemicals are manufactured by humans and end up in our oceans. As stated by marine scientist C. M. Reddy of the Woods Hole Oceanographic Institution in 2008: '*During the course of the 20th century, the planet became and is now chemically different from any previous time*'. These chemicals are synthesised or formed by natural processes through human activities.

Many different types of human-made compounds cause problems for wildlife. There are toxic *persistent organic pollutan*ts (POPs), which are industrial compounds, and toxic *trace elements*, previously known as *heavy metals*. POPs and trace elements occur in nature in increased abundance because of human activities. Previously, POPs were used as pesticides, industrial chemicals, solvents and pharmaceuticals. They are chemically stable and do not easily degrade through natural processes.

The *biological half-life* describes how quickly a chemical compound (including medications) is reduced to half of its initial concentration in, for example, body tissues. Usually, POPs dissolve well in lipids (but not in water) and are therefore soluble in *fatty tissues*. They are poorly metabolised (and therefore have a long biological half-life). Because they easily bind to the surface of solid particles, they are easily ingested and assimilated as a part of the animal's nutrition. Because of all these features, POPs are prone to dietary accumulation—so-called bioaccumulation, or biomagnification—in fatty tissues, with potential adverse health impacts.

With more humans inhabiting coastal regions, the health of oceans becomes a more important issue for everyone. At higher temperatures, POPs volatize and reach the atmosphere, where they can travel long distances before they are finally re-deposited. Therefore POPs may accumulate also in areas far from their emission, like Antarctica. Hence, environmental contamination by POPs is extensive, and they will often remain in the environment for decades (◘ Fig. 1).

Marine mammals can be used as early indicators for negative trends and impacts linked to anthropogenic (human-made) activities. Such *sentinel species* will also permit us to better characterise and potentially manage negative impact on human and animal health because of us polluting our oceans.

Bioaccumulation of contaminants

Organisms take in toxic chemicals through contaminated food, water, and/or air. The gastrointestinal tract concentrates ingested stable and hydrophobic (low affinity to water) chemicals. When these substances are stored in fatty body tissues, they increase in concentration inside the organism. This is known as *bioaccumulation*.

Biomagnification trough the food web

Biomagnification (also known as *bioamplification*) causes toxic compounds to be found at higher concentrations in tissues of organisms belonging to a higher level in the food chain. With each step upwards the food web, the concentration of pollutants increases up to ten times in animal tissues. The toxic compounds are transferred from smaller to larger organism, from prey to predator. Because the compounds are easily assimilated but have a long biological half-life, they accumulate within the tissues. The higher the trophic level an animal feeds at, the more chemicals build up within the body. The amount of increase depends on the biological half-life of the substance, and how easily it is assimilated, metabolised or excreted by the organism.

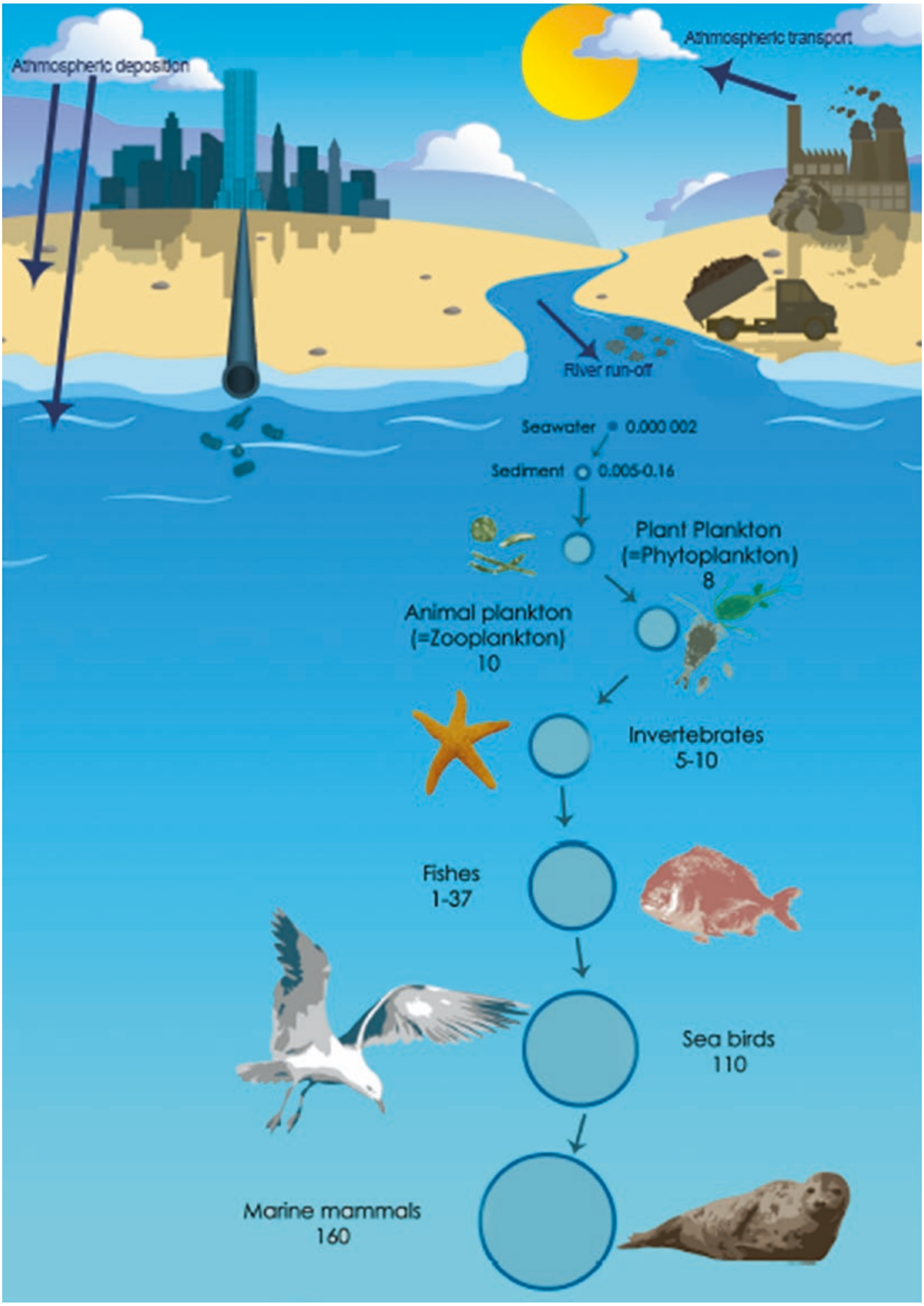

Fig. 1 Illustration of PCB bioaccumulation in the marine food chain. Pollution and the related biomagnification within organisms are a global problem. The numbers associated with the shown media/species refer to a constructed mean contaminant concentration within these, to show the significant effect of biomagnification. © Guillaume Bolterys

Marine mammals and contaminants

Marine mammals accumulate high levels of toxic POPs and trace elements in their tissues (blubber, liver, hair) because of their unique biological and ecological features:

- Marine mammals have extensive fat stores in which *lipophilic contaminants* (easily dissolved in fat) accumulate.
- They are at the top (or close to the top) of marine food webs.
- They are *homeothermic* (warm-blooded) animals, eating large quantities of food containing pollutants.
- Marine mammals have a long lifespan, and pollutants accumulate over time.

2 The use of marine mammals as bioindicators

The distribution of chemical pollutants in the marine environment is not homogeneous, and a considerable variation of concentrations may occur regionally and temporally. It may therefore be difficult to assess the full environmental impact of pollutants. As a supplement to measurements of the contaminant levels at different sites, *bioindicators* can be used to monitor pollution. Bioindicators are living organisms used to assess the levels of pollutants in the ecosystems where they live. Marine mammals are highly suitable bioindicators of the marine environment. Due to their position at the top of the food webs, their long lifespan and the long biological half-time of pollutants, marine mammals accumulate high levels of different toxic chemicals.

The interest in studying contaminants in marine mammals was boosted by past large-scale die-offs or impaired reproduction abilities of pinnipeds and cetaceans living in polluted regions, and the discovery of high contaminant levels in these animals. In many cases, *morbillivirus* infections were the primary cause of disease outbreaks in these animals. Famous examples are the harbour seal mass mortalities in the North Sea in 1988 and 2002. Scientists investigate if environmental pollution plays a role in mass mortalities, as toxic chemicals may suppress the immune system.

3 How harmful are pollutants?

Several chemical pollutants, such as DDT, PCB, TBT (*Tributyltin*) and metallic trace elements, are *endocrine disrupting chemicals* (EDCs), meaning they affect the hormonal system. Hormonal disruptions can influence many systems in the body, such as the endocrine system itself, reproduction (cause birth defects and developmental disorders), immune cell generation, as well as causing tumours.

Endocrine disrupting chemicals may interfere with the hormone synthesis in the endocrine gland, the hormone transport or the hormone's metabolism and excretion within its target cells. Since many hormones regulate reproductive functions, exposure to EDCs often has negative consequences for reproductive health. Embryos, foetuses and newborns are especially vulnerable to EDCs, causing future problems in brain function, immunity, metabolism and reproductive abilities.

Furthermore, EDCs can alter the synthesis of steroid hormones and have adverse effects on the mechanisms of molecules operated by genes and proteins. Pollutants most likely promote disease and mortality by supressing the immune system. Alterations to energy metabolism can lead to obesity, diabetes, and cardiovascular disease development, as well as have adverse effects on the immune system. Additionally, synergistic effects between various contaminants may amplify the toxicity of different chemicals. Interactions with environmental factors, for example, pathogens, starvation, and climate change (changes in water temperature, pH and salinity) could also amplify the contaminant toxicity and bioavailability.

Trace element pollutants, such as mercury, cadmium, and lead, have especially high cell toxicity and accumulation characteristics. Mercury and PCBs are potent *immunosuppressants* in terrestrial and aquatic animals, altering host resistance to disease. Animals with high contamination levels seem to be more susceptible to diseases than animals with lower toxin burdens. Since EDC effects are usually subtle and more chronic than acute, it is often difficult to link certain health impairments to specific exposures.

► Example

A well-studied case of contamination effects comes from the St. Lawrence River Estuary beluga whale (*Delphinapterus leucas*) population in Canada. These belugas live at the southernmost limit of the species range, are geographically isolated from other populations and were listed as endangered in 2014 by the *Committee on the Status of Endangered Wildlife in Canada*. Pollution and human disturbance have reduced food resources and caused habitat degradation, which seem to contribute to the decline of this species.

The St. Lawrence River Estuary receives water from one of the world's most industrialised regions. The belugas are heavily contaminated by trace elements, PCB, DDT and PAHs (*polycyclic aromatic hydrocarbons*). Exposure to highly toxic discharges from local aluminium smelters led to elevated contaminant levels in the tissue of the belugas and had toxicological effects. From studies made between 1983 and 2006, 16% of 175 stranded belugas had at least one terminal cancerous tumour. Some of the cancer types found in belugas are related to the presence of PAHs, suggesting that these compounds are involved in the cause of cancer in the SLE belugas.

These effects of pollution are not restricted to belugas only. The human population living by the St. Lawrence River Estuary is also suffering from higher cancer rates than other Canadians.

Contamination is considered a serious threat to the SLE beluga population recovery. Despite reductions in the discharge of some toxic chemicals, pollutant concentrations in tissues do not decrease quickly. Some effects on contaminants may first develop 20 years after exposure. The belugas could be affected by contaminants for many decades to come. ◄

4 Post-mortem examinations

A *post-mortem examination* is the examination of a dead animal. For humans it is also called an *autopsy*, whereas for any non-human animal it is called a *necropsy*. The aim is to determine the cause of death, how and when the animal died and to obtain a better understanding of how diseases spread. Often, a proper health assessment of living marine mammals is not possible. Therefore, we rely on post-mortem examinations of animals that are stranded or caught in fishing nets to obtain information of animal health and diseases.

Post-mortem examinations elucidate the cause of death and common diseases of the species investigated. We also learn about transmissible pathogens between humans and animals (so-called *zoonoses*) and the influence of anthropogenic activities on wildlife. Additionally, necropsies are the main source of samples used for toxicological analysis, which helps researchers to associate contaminant loads with clinical observations and pathologic health impairments. This helps us to identify how different pollutants and their concentrations affect the health of marine mammals.

A full post-mortem examination includes:

- Measurements of body size (length and girths), weight and colouration
- Macroscopical examination of all organs with the naked eye
- *Histological* assessment of all organs using microscopy
- *Bacteriology* (investigating bacteria and their connection to disease)
- *Mycology* (study of fungal infections)
- *Parasitology* (study of parasites and their interactions with the host)
- *Virology* (study of viruses and their connection to disease)
- *Toxicology* (study of adverse effects of chemical substances)
- *Serology* (detect antibodies caused by infections in serum)
- Age determination
- Genetics

For a small animal such as a harbour porpoise (*Phocoena phocoena*), a necropsy lasts 2-4 h, depending on the animal's decomposition status. For a larger whale, necropsy may last for several days, depending on available work force and technical equipment, as well as the stranding location.

Some extra examinations can be undertaken depending on financial means, which species is investigated, and under which circumstances it was found. Additional examinations may include *immunohistology* (the microscopic study of tissues with the aid of antibodies that bind to tissue components and reveal their presence), *electron microscopy*, bone density measurements, and analysis of stomach content and reproductive organs. Such examinations are complex and time consuming, and analysis may take several months.

The cause of disease and death may be determined, and the general health status of the individual can be assessed. This may also inform the health status on the population and the habitats frequented by the animal. However, it is not always possible to determine a cause of death. Some cases remain unsolved even after a thorough post-mortem examination.

Disease can be a major cause of population decline in marine mammals, and the reasons for many stranding events remain poorly understood. New sequencing technology, virological and microbiological studies can identify pathogens and diseases and help in surveillance.

For watching a short video about the necroscopy of a harbour porpoise, see: (▶ https://wissen.hannover.de/en/Institutions/University-of-Veterinary-Medicine-Hannover/Looking-into-Animals-Necropsies-at-the-TiHo).

5 Common diseases of marine mammals

Marine mammals, just like any animal, can suffer from different kinds of diseases. These can affect their health adversely, cause pain, distress and even death, and therefore have negative implications for the entire population.

Diseases can be caused by different reasons:

- Infectious diseases by viral, bacterial, parasitic and fungal infections
- Non-infectious diseases by toxins (from pollutants or algae), starvation or predation

For any cause of disease there is often secondary bacterial and parasitic infections, most common in the lungs.

A high load of parasites (e.g. pulmonary roundworms, *gastrointestinal nematodes* and tapeworms, liver and *gastric flukes*), pneumonia, acute traumata (from bleedings or fractures), chronic disease and direct anthropogenic impacts are common for stranded marine mammals. Impaired hearing, as well as disruption of the hormonal and immunological system, can also have severe, adverse impacts on individual health.

Chemical pollution may play a role in the *pathogenicity* (the ability of an organism to cause disease) of several types of diseases of marine mammals. Pathogenic viruses have been associated with meningitis, bronchopneumonia, skin diseases and changes in the reproductive system. Different influenza A virus strains have caused at least five larger die-offs of seals in the past 40 years. There is a risk that these diseases can be *zoonotic* (being able to transfer to and infect humans).

A deteriorated health status from an increased pollutant burden can lead to devastating viral epidemics. Huge morbillivirus die-offs were caused by the *Phocine Distemper Virus* (PDV) in 1988–1989, 1990–1991, and 2002 in harbour seals in the North Sea and Kattegat, and by a dolphin morbillivirus in 1990–1991 in striped dolphins (*Stenella coeruleoalba*) in Mediterranean waters. The *epizootic* (disease event in an animal population, analogous to an epidemic in humans) PDV outbreaks killed thousands of animals, and the disease susceptibility of the infected individuals was probably caused by contaminant-induced *immunosuppression*.

Exposure to a mixture of different PCBs decreases the immune response and increases the risk for virus infections. If other environmental factors also favour virus replication and their rapid spread, combined effects may lead to epizootic outbreaks. Furthermore, PCB exposure indicated a contaminant-related disruption of hormone function of free-ranging harbour seals and harbour porpoises, leading to reduced reproduction.

Contamination in the Baltic Sea from the 1970s and 1980s

Elevated POP levels in Baltic grey seals (*Haliocherus grypus*) and ringed seals (*Pusa hispida*) in the 1970s and 1980s were linked to reproductive failure and several different tissue lesions, causing the so-called *'Baltic Seal Disease Complex'*. Affected seals had smaller *thyroid glands* (responsible for secretion of hormones regulating growth and development) and enlarged adrenal glands (producing a variety of hormones, including adrenaline, cortisol, and sexual hormones). The uterus experienced *stenosis* (abnormal narrowing), *occlusion* and tumours, resulting in impaired reproduction. There were also claw lesions, loss of bone structure in the skull and reduced bone mineral density.

High concentrations of organochlorine are associated with a low mineral density in *trabecular bone* (porous, internal skeletal bone tissue found at the ends of long bones, in the pelvic bones, ribs, skull, and vertebrae). Measurements of bone mineral density provide insights into the bones' health and can determine the risk for fractures. Severe intestinal ulcers and increased parasitic burdens have also been associated with high loads of DDT and PCB.

Zoonotic diseases can be dangerous for people encountering dead or sick marine mammals. People working with marine mammals have the highest risk of acquiring zoonotic diseases. Therefore, marine mammal researchers, rehabilitators, trainers, veterinarians and volunteers must be extra careful. People encountering captive or wild marine mammals during, for example, vacations should also be careful. Zoonoses caused by bacteria, fungi or viruses are easily transmissible. Luckily, the majority of transmissions from marine mammals to humans have only resulted in localised skin infections that can resolve spontaneously or with appropriate medical therapy. However, some zoonoses can lead to life-threatening systemic diseases. When encountering dead or alive marine mammals, always keep a safe distance and call appropriate authorities.

Growing amounts of anthropogenic influences and utilisation of the marine ecosystem constantly increase the pressure on marine mammals, their habitat and the associated stress and disease risk. Marine mammals may face more infectious diseases in the future, enhanced by the prevalence of contaminants in the environment and in the food chains.

Current topics of chemical pollution and diseases of marine mammals research

Chemical pollution affecting marine mammals is an important topic for current research, since it includes many unanswered questions. Even though there is knowledge on intake pathways, bioaccumulation and biomagnification, as well as on geographical and temporal contaminant trends, data is lacking on the implications on marine mammals.

There have been many questions regarding the impact of plastics and other debris on the marine fauna, including marine mammals. This includes the transport of contaminants to coastal ecosystems (persistent, bioaccumulative and toxic chemicals attach to plastics) and impacts of macro as well as micro plastics. It is still unclear if ingested plastics add significantly to the existing contamination load. Plastics are nowadays such an important topic, so that this book dedicates a whole chapter to them.

Many studies are conducted on diverse species and different known and measurable pollutants. However, this does not mean that all potential pollutants are known and tested for. There is still a wide grey zone of unknowns, including newly emerging contaminants, their accumulation within the environment, impacts they have on different species, and potential human exposure.

Many of the current studies on cetaceans focus on organochlorine contaminants and their reproductive implications, particularly in endangered species and subspecies, since they are especially vulnerable. This focus may change over time with new analytical methods. Orcas are on top of the trophic food chain and a very long-living species. Thus, they are highly susceptible to contaminant biomagnification and consequential reproductive impairment, since immunosuppression can have detrimental effects on offspring (embryos during pregnancy, calves receiving large amounts of contaminants through nursing) and population survival.

Stable isotopes and *biomarkers* are used to assess contaminant exposure as a feeding ecology tool and to assess the bodily response to environmental pollutants. Stable isotopes are non-radioactive variations of chemical elements. Measuring and analysing their distribution, amounts and proportions in samples can be used to trace the origin, history, source, chemical interactions, and carbon and nitrogen cycles of the studied sample. Biomarkers are characteristic biologic traits that can indicate normal or pathogenic processes associated with stress (e.g. environmental pollution or diseases) within organs, cells, genes, gene products, or hormones of the studied organism. Since the primary reason for wildlife contaminant exposure is their feeding ecology, effective new tools for diet determination and habitat use are key elements of many eco-toxicological studies.

Another important topic for current research is the individual and population health effects of oil exposure on marine mammals. An example is the extremely long and large oil spill caused by *Deepwater Horizon* in the Gulf of Mexico in 2010. Many cetaceans have succumbed to different disease complexes associated with the spill and suffered from reproductive failure and abortions. Establishing a link between the massive oil spill and its effect on wildlife is crucial for preventing future disasters and establishing appropriate management plans for similar human activities.

We need to consider effects of both older pollutants such as PCBs, which are banned in Europe and North America but are still long-lasting in the food chains, as well as newer chemical pollutants. We need to improve pollutant management and design effective conservation measures. It is also crucial to develop sampling and analysis methods for new contaminants, to generate new mitigation measures to prevent further contamination, as well as develop functional cleaning methods. Last but not least, we need to tackle these issues on a global scale to prevent further entries of pollutants into the environment.

Apart from PCBs and trace metals, pharmaceuticals (including human and veterinary drugs) are another important class of contaminants entering the world's waterways. Thousands of tons of pharmacologically active substances are used annually worldwide. Unfortunately, they receive relatively little attention as possible environmental pollutants. Up to 90% of consumed pharmaceuticals can be excreted unchanged, while environmental bacterial action can convert utilised metabolites into active drug compounds. Additionally, unused medicines are often disposed through the sewage system, and many pharmaceuticals are only incompletely eliminated at sewage treatment plants. The possible effects of the presence of drugs in aquatic systems are widely unknown.

A major concern has so far been that antibiotics found in effluent sewage may cause increased resistance among bacterial populations exposed to these drugs. There are currently several studies looking for multi-drug-resistant bacteria in marine life. However, most aquatic organisms are continually exposed to a whole range of different substances. Especially in coastal regions, pharmaceuticals may suppress the immune response and hormone production of aquatic organisms.

Several studies have shown that many aquatic animals are affected by marine environment polluting drugs: Oysters from two different bays in Canada contained traces of medications such as antibiotics, *antihistamines* (used for allergy treatment) and pain relievers. 'Intersex' fish, with both male and female reproductive organs caused by *endocrine disrupters*, have been found worldwide. Scientists believe that artificial hormones from birth control pills may contribute to this problem. *Antidepressant* and *antianxiety* medications are also found globally in the environment. They accumulate in wildlife tissues, and their potential to disrupt normal biological systems and behaviours is extensive.

Many aquatic organisms spend their entire lives in polluted environments, affecting their immune system, feeding habits, behaviour, metabolism, and movement patterns. *Prozac* (a common antidepressant used for the treatment of depression) causes shrimp (*Echinogammarus marinus*) to leave their natural, hidden habitat and head towards more luminous locations, making them vulnerable to predators. Small amounts of cocaine can have adverse health effects on critically endangered European eels (*Anguilla anguilla*). Cocaine-exposed eels were hyperactive and suffered from muscle damage. These problems do not end in our rivers or oceans: When we eat seafood, the pharmaceuticals and contaminants return to our bodies, affecting our physiology and starting a new vicious circle.

6 Teaching materials

Exercise 5.1: How can different types of pollution affect marine mammals?

Have a class discussion:

- Identify sources of, and solutions to air pollution.
- Identify sources of, and solutions to water pollution.
- What can everyone do to fight environmental pollution?
- List at least ten ways to avoid pollution. Maybe some students already implement some of these ways and others are not. Can the students support one another to increase our efforts to reduce pollution?

Tip

Let the students collect all discarded items they find on their way to school. Discuss the potential the objects have to harm wildlife.

Some activities anybody can do to help reduce pollution:

- Walk or ride a bicycle instead of driving in a car.
- Turn off lights and unplug electronic devices when not needed.
- Switch to reusable water bottles, mugs and bags.
- Use eco-friendly and energy-efficient products whenever possible.
- Buy locally grown and produced food products.
- Use soap bars and other minimal/zero waste products.
- Reduce, reuse and recycle as often as you can.
- Properly discard expired medications.
- Plant trees, grow your own fruits and vegetables.

Be sure to share facts that will emphasise the importance of your activities and why you are doing them. For example, when you are recycling, explain that recycling just one glass bottle reduces air pollution by 20 percent and causes 50 percent less water pollution compared to making a brand-new bottle.

Exercise 5.2: Mussel filtration

Organisms get rid of contaminants through catabolism and excretion, but how does the ocean get rid of pollutants?

In this experiment, we will demonstrate the important role of mussels as waste collectors within aquatic ecosystems by showing their ability to clear water.

Marine mussels are *bivalve* (they have two hard shells) molluscs. There are among other species, blue mussels, oysters, and clams, which all improve water quality and contribute to healthy marine habitats. They play an important role in aquatic ecosystems. Mussels are filter feeders. They draw in seawater and filter out phytoplankton and sediments. A video showing the anatomy of a mussel can be found at ▶ https://www.youtube.com/watch?v=gZKSFBj--FqU.

On this 3D animation ▶ https://www.youtube.com/watch?v=7KekxV78gns you can observe filter and particulate organic matter filtration by a blue mussel (*Mytilus edulis*). The animation shows the path of water (blue) and associated food (orange) in the mussel. Siphoned material is either transferred to the mouth for digestion or sloughs off the gills and exits via the ventral margin of the shell. Digested material is used both as fuel for various life processes and excreted as faeces. The amount and rate of particulate matter removed from the water column and subsequent deposition of waste depends on species, size, water temperature and particle concentration.

Marine mussels function as bioindicators of marine pollution. As sedentary suspension feeders, mussels remove a variety of materials from the water column. These materials include pollutants that can be assimilated and bioaccumulate in their tissues.

Required materials

- Two aquaria, container or buckets full of seawater (use rain or lake water if freshwater species are used).
- Aquarium pump (you don't need a strong one; it can be a very simple, cheap model) or compressor.
- Living blue mussels. Commercially available from supermarkets; if possible, collect them with the students from a nearby harbour (if blue mussels cannot be obtained, freshwater mussels from a lake or aquarist stores are also an option).
- A planktonic algae mix (from a nearby lake, or cultivated beforehand).
- Food colouring.
- A video recording device with a timer (e.g. a smartphone).

Tasks

1. Collect the blue mussels and keep them in a well-aired aquarium around 15–20 °C. Arrange the second aquarium next to the first one in a similar way, with water but without mussels.
2. Pour the mix of planktonic algae equally into both aquariums and observe how fast the mussels are able to clear the water. Try to film the process or take a picture before and after the clearing of the seawater. If you have a photometer, you can also take measurements of the differences in light reflection between the two aquaria. ◘ Figure 2 shows the result of the experiment.
3. Put the food colouring into water of both aquaria, let it spread and see what happens.
4. Write down your observations and times. Draw conclusions and discuss them within your group.

After the experiment, the living mussels should be returned to their place of origin, or they can be kept in suitable aquarium; or a dissection can be done to view the food colouring deposition within the mussel by colouration of the organs. While the mussels are alive, you can observe the ciliary movements at the level of the gills with a binocular microscope. You should, however, consider how to humanely kill the mussels prior to dissection, for animal welfare reasons. This can be done by boiling, by bubbling carbon dioxide or adding a 20–30% concentration of magnesium sulphate into the water. Please do NOT use formaldehyde or alcohol for euthanasia purposes.

You can also watch a recording of the whole mussel clearing experiment ▶ (Video S1).

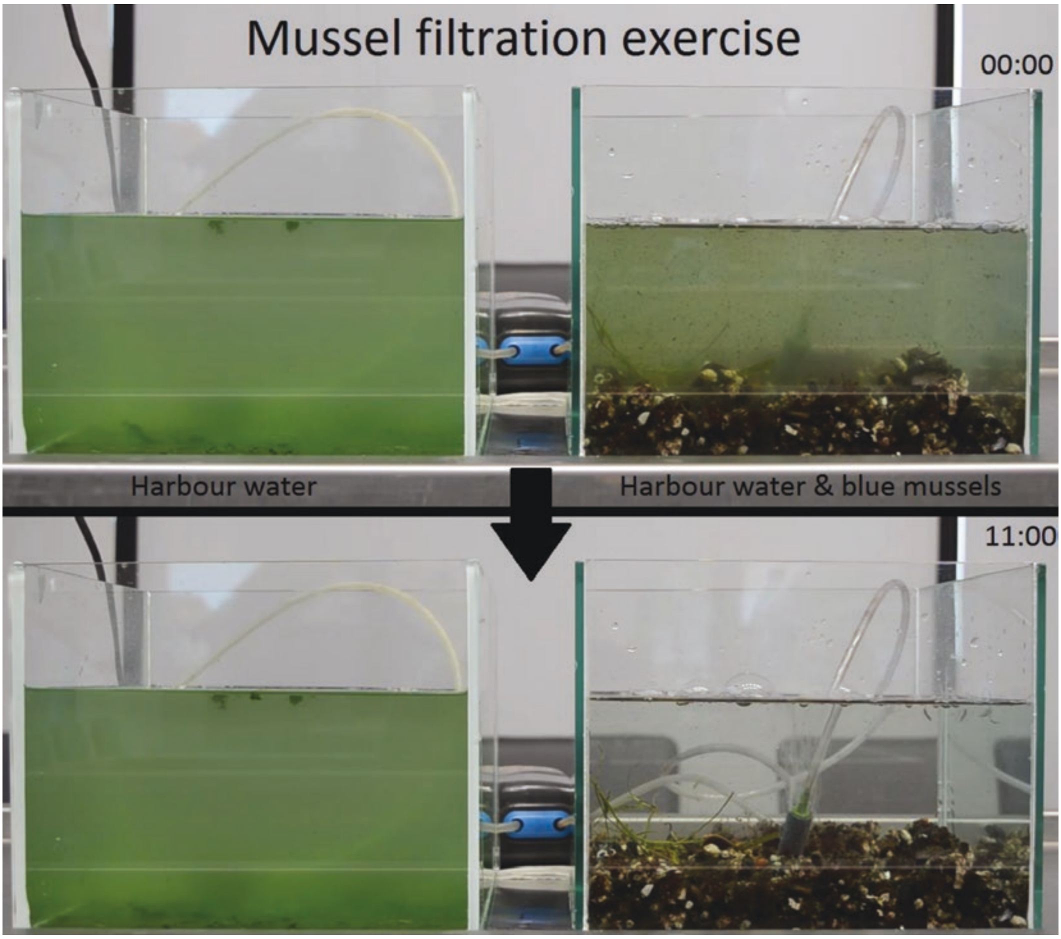

Fig. 2 (▶ Exercise 5.2) Mussel filtration experiment. The upper picture shows two aquaria with sea water, the right one also contains mussels. The bottom picture shows that after 11 min, the mussels have cleared the water completely, while the tank without mussels remains unchanged

Exercise 5.3: Bioaccumulation: The hidden dangers in the food web

The processes of bioaccumulation and biomagnification are connected. How can we visualise a better understanding of these concepts?

With this simple experiment, students can observe how contaminants accumulate and magnify in different organisms within the food chain. Through ingestion with their prey, chemicals move up through the food chain. Bioaccumulation means that even when the initial level of chemicals was low, the concentration accumulates in organisms higher up the food web, increasing their toxic potential.

Required materials

- 1 'shaker' cup
- 9 small cups (corresponding to small animal, e.g. shrimp)
- 3 medium cups (corresponding to medium fish, e.g. cod)
- 1 large cup (predator, e.g. harbour porpoise)
- 20 items of the same colour (e.g. blue sweets) as plankton
- 10 items of the same colour (e.g. red sweets) as plankton with DDT attached

Tasks

Place all 30 items in the 'shaker' to represent the population of primary producers and give it a good shake. Record the amounts of DDT

Fig. 3 (▶ Exercise 5.3) Top: game requirements (differently sized cups, a 'shaker' and 'plankton' items of two different colours); Bottom: playing the game—simulation of bioaccumulation by emptying the contents of two randomly chosen small 'sand lance' cups into one of the medium 'cod' cups

(number of, for example, red sweets) per producer (for example, 10 contaminants per 30 producers gives a total of 1/3)

1. Simulate sand lance eating some of the plankton by closing your eyes and randomly removing 3 items from the 'shaker'. Place them into one of the small 'sand lance' cups and repeat this for the remaining eight small cups. Record the amount of DDT in each sand lance (see Fig. 3).
2. Now, simulate the cod eating two sand lances. Empty the contents of two randomly chosen 'sand lance' cups into one of the medium 'cod' cups. Repeat for the remaining two cod cups. Record the amount of DDT in each 'cod'.
3. Finally, simulate the porpoise eating cod. One porpoise needs to consume two cods. Empty the contents of two randomly chosen 'cod' cups into the large 'porpoise' cup. Record the amount of DDT in the porpoise.
4. Place all items back into the 'shaker' cup and repeat the experiment two more times. Then calculate the average amount of DDT for each organism from all three trials.

Draw conclusions to marine life by using the following questions:

- Comparing all three trials, which organism contained the highest concentration of DDT?
- What happened to the amount of DDT per organism as it moved up the food chain?
- Why is DDT harmful to marine mammals?
- Name other organisms besides porpoises that you would expect to have high concentrations of DDT.
- If the porpoise population decreases due to contamination effects, which other populations of marine mammals would be affected?
- Which of the following types of sea food would be the safest to eat, concerning their content of pollutants? List them in order and explain your answer.

  Herring, Squid, Salmon, Mackerel, Orca, Mussels, Shark, Cod, Tuna

Exercise 5.4: Oil spill clean-up (Part 1)

Imagine an oil spill into a body of water—what methods or materials could be used to clean up the oil?

The ocean has been subject to many different small oil leakages and large oil spill disasters with major environmental impacts. There are chronic spills: The Niger Delta is polluted by over 13 million barrels of crude oil, with an average yearly spill of 240,000 barrels. More commonly, we hear about wrecked oil cargo ships such as the 'Amoco Cadiz' crude oil carrier spill in France in 1978 and the 'Exxon Valdez' oil tanker spill in Alaska in 1989. In this exercise, you will model an oil spill, look at the impact of oil on seabirds and test different materials for cleaning up the spill. This experiment will help you understand why an oil spill is an environmental catastrophe and a difficult task to deal with.

Required materials

- Baking dish
- Hot and cold tap water
- Blue food colouring
- Vegetable oil
- Pure cocoa powder
- Teaspoon
- Stir rods
- Beaker
- Sorbents (paper towel, kitchen towel, different textile fabrics, cotton balls, sponges, Styrofoam cup, straw or hay, shredded wheat, garden peat moss, etc.)
- Liquid dishwashing detergent
- Forceps
- Clean, dry feathers
- Three bowls or basins

Tasks

First, you have to prepare your clean water and 'crude oil'.

1. To prepare the 'ocean' fill the baking dish with cold tap water to within 2 cm of rim, add the food dye and stir it until it has a nice colour. Let the solution settle.
2. To simulate crude oil use 3 tablespoons of vegetable oil and thoroughly mix in 2 tbsp. of cocoa powder. (This experiment also works with regular vegetable oil, but the effect is clearer and more realistic with the thicker oil-cocoa mix.)
3. To contaminate fresh water, pour the simulated crude oil very slowly directly onto the surface of the freshwater dish. Be cautious: if you pour too quickly, the experiment will not work—in this case, start over!
   - What happened to the oil when you dropped it on the ocean? Record your observations and explain them.
4. To test the sorbents each student should choose ~3 sorbents to test, so that all available options are being tested. Before starting, write a hypothesis on how the different sorbents you selected will clean up oil and which of them will work best.

   Test the sorbents one at a time and record your observations thoroughly.
   - How much oil did the sorbent clean up?
   - Is the sorbent fast or slow absorbing?
   - Does the sorbent pick up water too?
   - Does the clean sorbent sink or float?
   - Does it change if oil-coated?
   - Which sorbent worked the fastest?
   - Which one worked the best overall?
   - How would you pick up oil-contaminated sorbents in a real oil spill in fresh water/the ocean?
   - How would you dispose the tons of toxic oil-contaminated material from a real oil spill?
5. Now add 2–3 drops of detergent to the oil-contaminated freshwater. Describe what happens. Would detergent be a reasonable tool to use in a real oil spill? Discuss the pros and cons with your classmates.

   Look back at your original hypothesis and write a concluding statement that recommends materials and methods for cleaning up oil spills based on your findings.

   Oil spill clean-up (Part 2)

   How are animals affected by oil and related clean-up methods?
6. To look at the way oil affects bird feathers, you will try out different clean-up methods to find out which ones work best (depending on how much detergent was used in step 5., a new oiled water preparation might be necessary for this part). Before starting, discuss how different animals are affected by an oil spill and what happens to birds and their feathers in particular.
   - What is the function of feathers for birds?
   - Which water bird species can you think of being affected by oil spills?

7. Choose some feathers and dip them in the oil to imitate what happens when a bird lands on an oil slick. What happened to the feathers? How do you think this might affect a water bird? Write down your observations and thoughts.
8. Now try three methods of cleaning feathers. Therefore, we need to set up 3 washing stations. One with cold water, one with hot water and one with warm water and detergent. Choose a washing technique for your feathers and use the same method at each station.
   (a) Cold water washing: try washing some of the oiled feathers in cold water. Write down your observations.
   (b) Hot water washing: try washing some of the oiled feathers in hot water. Write down your observations.
   (c) Washing with detergent: try washing some of the oiled feathers in the warm soapy water. Write down your observations.
9. Which method would be best to clean oily birds? Write a final statement that discusses how oil spills affect birds, what the best cleaning method would be and incorporate your own findings.

Oil spill clean-up (Part 3): Group discussion

Discuss the following points within your class and perform some online research yourself on the issue:

- Birds may ingest oil while trying to preen the oil from their feathers—how does this effect their health and survival chances?
- Aquatic animals are usually extremely sensitive creatures—is only the ingestion of oil dangerous or are there other problems related to external toxin exposure?
- Every oil spill is different, because the kinds of oil that are used vary widely—what could be a difference between a crude oil spill and a spill of highly toxic oils such as diesel or jet fuel?
- Washing birds within 8–24 h of capture is advantageous in order to reduce absorption of toxins through the skin and possible resultant liver and kidney damage. However, cleaning (restraint and handling) is a very stressful procedure for a wild bird—should birds be cleaned immediately after capture or should they not be washed until their physical and mental condition is stable (such that they are likely to survive the procedure) even if that increases the chances of intoxication through toxin absorption?
- Why is it so important to make sure the bird is thoroughly rinsed and definitely clean after the washing procedure?

Example answers:

- The ingestion of oil leads to intoxication and potential interference with internal organ functionality, decreasing their health and survival chances.
- Toxin resorption through the skin and oil contamination of fur and feathers prevent thermoregulation or swimming ability; animals can get stuck in an oil blanket.
- Crude oil is less processed and hence often less toxic than highly refined oils, but might be more difficult to clean off.
- The animal should always be stabilised prior to a washing procedure, but also be cleaned as soon as possible to prevent further intoxication damage. Distressed animals require calming before washing, which can take several days.
- Residual oil and/or detergent will interfere with waterproofing and insulation of the bird.

Exercise 5.5: Greenhouse gases in the ocean

It is often mentioned that the ocean functions as a huge CO_2 trap, which is of major importance for climate regulation, but how does it do that?

The ocean absorbs gases from the atmosphere and releases them again. Thus, the world's oceans have a major influence on the world climate and also absorb a lot of airborne contaminants. Gases like the greenhouse gas carbon dioxide or other pollutants can dissolve in the water, just like salt does. How much gas the water can absorb depends on various factors that can easily be tried out with this little experiment.

- **Required materials**
- 0.5 l bottle (transparent)
- Bowl
- Small funnel
- Tap water (optional: food colouring)
- Effervescent tablets (e.g. Alka-Seltzer tablet)
- Permanent marker

- **Tasks**

Fill half of the bowl and the bottle to the brim with warm tap water. For a nicer optic, you can dye the water with food colouring.

1. Place the funnel into the bottle and carefully position everything upside down in the bowl (bottle opening facing down). Put an effervescent tablet under the funnel and let it dissolve. During this process, carbon dioxide is produced and CO_2 bubbles fizz into the bottle. The more CO_2 is produced, the more water gets pushed out of the bottle. Once the tablet is dissolved, indicate the lower edge of the resulting gas bubble with the marker.
2. Repeat the experiment with cold water. Is the new marker in the same place as the first one?
3. What will happen if you put a second effervescent tablet under the funnel? Will the bubble within the bottle be twice as big, less or more than twice as big as in the first trail?
4. Discuss your results and gather some explanations.

   What does this mean for other pollutants and for aquatic animals?

   If you are unsure, perform an online search on sea temperature increase and its effects on ecosystems.

Explanation

In this experiment, we have to discern the invisible from the visible gas bubbles: not all the produced gas arrives at the top of the bottle, because—invisible to us—a certain portion is absorbed by the water. The gas basically 'dissolves' in it. The ability of the water to absorb gases depends on the temperature and the amount of gas already dissolved in the water: the colder the water, the more gas can be absorbed, resulting in a smaller gas bubble within the bottle (Step 2). The second effervescent tablet (Step 3) then dissolves in water, which already contains a lot of gas from the first trail (it is almost 'saturated'). Therefore, a much larger proportion of gas directly fizzes into the bottle now.

In the past, water in the world's oceans contained relatively little carbon dioxide, and large quantities of greenhouse gases could therefore pass from the air into the water at the ocean surface. Meanwhile, our oceans slowly begin to warm due to climate change caused by carbon dioxide. Due to both effects (saturation and temperature increase), the oceans are less able to absorb this gas. It is a vicious cycle.

Suggested reading

1. Desforges J-P, Hall A, McConnell B, Rosing-Asvid A, Barber JL, Brownlow A, De Guise S, Eulaers I, Jepson PD, Letcher RJ, Levin M, Ross PS, Samarra F, Víkingson G, Sonne C, Dietz R 2018. Predicting global killer whale population collapse from PCB pollution. Science 361:1373–6. https://doi.org/10.1126/science.aat1953.
2. Fabbri E, Franzellitti S 2016. Human pharmaceuticals in the marine environment: focus on exposure and biological effects in animal species. Environ Toxicol Chem 35:799–812. https://doi.org/10.1002/etc.3131.
3. Fossi MC, Panti C 2018. Marine mammal ecotoxicology: impacts of multiple stressors on population

health. London: Elsevier, Academic Press ISBN: 9780128122501.
4. Gulland FMD, Dierauf LA, Whitman KL 2018. CRC Handbook of Marine Mammal Medicine. 3rd ed. Boca Ranton, FL: CRC Press. ISBN 9781498796873.
5. Jepson PD, Deaville R, Barber JL, Aguilar A, Borrell A, Murphy S, Barry J, Brownlow A, Barnett J, Berrow S, Cunningham AA, Davison NJ, ten Doeschate M, Esteban R, Ferreira M, Foote AD, Genov T, Giménez J, Loveridge J, Llavona Á, Martin V, Maxwell DL, Papachlimitzou A, Penrose R, Perkins MW, Smith B, de Stephanis R, Tregenza N, Verborgh P, Fernandez A, Law RJ 2016. PCB pollution continues to impact populations of orcas and other dolphins in European waters. Scientific Rep 6:18573. https://doi.org/10.1038/srep18573.

How to Become a Marine Mammal Scientist

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Contents

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Learning Goals

- Become aware of different working prospects in science, technology, engineering and mathematics.
- Understand how careers in different fields can lead to a job in marine mammal science and research.
- Learn how researchers with diverse backgrounds became marine mammal scientists.

1 Introduction

There are many ways to become involved working with marine mammals as a professional career. You can become a zoologist, marine or population biologist, oceanographer, veterinarian, ecologist, physicist, engineer, underwater photographer, technician, national park ranger, naturalist, professional scuba diver, digitalisation expert, science communicator, project assistant at an institute studying marine mammals or a combination of several of these. Scientific working with marine mammals is transdisciplinary and encompasses various academic disciplines, such as biology, chemistry, physics, mathematics and engineering. An interest in topics relevant for today's environmental challenges (e.g. climate change, pollution, decrease in biodiversity, renewable energy, natural disasters and food security) can lead to studies of marine mammals. Marine mammals have a fundamental role in many marine ecosystems.

2 Marine mammal career opportunities

If you plan to become a marine mammal scientist, it will require your full devotion, time, energy and creativity. Practical field work outdoors can be equally part of a researcher's job as working on the computer or performing meticulous laboratory work. Try to find a good place to gain experience in your field of interest and a team that will give insights into their daily work. Volunteering can be important to gain knowledge and experience for a future career. If you are unsure about a certain job or work field, receiving practical insight often helps to make the right career choices for your future. For example, you could utilise your holidays to familiarise yourself with an occupation of interest, like participating in aquatic animal censuses, rehabilitation or education programmes.

There are thousands of students who want to work with marine mammals. Since you are not alone in your passion, you have to be unique in some relevant way. You can achieve this by learning certain technical skills, such as computer coding, equipment repair, or by acquiring a scuba certification, a boat handling licence or a permit to fly drones or radio control aircrafts. It is also important to educate yourself by reading specialised and scientific literature. You can read about marine animals that interest you, but also about your specific field of interest, such as diving physiology, acoustics, diseases, social behaviour, prey species and food availability.

2.1 Prerequisites learned in school

Most research positions have an academic background, so achieving good grades especially in the natural sciences, technology and mathematics is important for being accepted into a university to study your field of interest. It is important that you are proficient in English. You can improve your language skills through training courses. Scientists regularly present their research at international conferences or meet during different assemblies to exchange knowledge, project ideas and research outcomes. Meetings are almost always held in English. You report your study results in scientific publications, written in English to reach a large audience.

In some parts of the world, many people you meet are not comfortable speaking English, so you also want to pick up other languages. Latin is not a requirement, but numerous scientific terms like taxonomy or anatomical structures are Latin for global standardisation.

3 How to become a marine mammal scientist

There are many university programmes preparing you for a career in science, some of which will be touched on in this chapter. Also, non-academic professions can lead to an active career in marine mammal science and research. Scientific groups rely on employees with many practical and administrative backgrounds, such as laboratory technicians, secretaries, communication specialists, public relations managers and animal trainers.

3.1 How to become a marine biologist

Marine biologists study marine organisms, which may include either microscopic beings such as plankton, or larger animals such as marine mammals. If you want to study these organisms you may either observe them in the field (that is, in the ocean), or you can collect some individuals and bring them into your laboratory. In the laboratory, you can investigate a certain scientific question, for instance whether a certain species can survive summer heat waves, by simply increasing the temperature of the water simulating a heat wave event. During field studies, you may investigate if marine mammals are more present in pristine areas than highly human impacted areas.

To become a marine biologist, you need to gain knowledge in a broad range of disciplines. These mainly constitute the subjects of biology, chemistry, geology, physics and mathematics. Being engaged and achieving good grades in secondary school is important. Marine biology and all related careers are of a high educational level, which means you likely need to obtain a degree from a college or university to become a competitive candidate for a job.

First, you likely will need to get a university degree, which is often a *Bachelor of Science* in biology or any other natural science. There are different university programmes, like environmental sciences, marine geosciences, bioinformatics, etc. The duration of a Bachelor's programme is usually three or four years (six to eight semesters). After obtaining your degree, you can choose a field of special interest and deepen your knowledge by entering a *Master's programme* to study and specialise in, for example, marine biology, marine environmental sciences or biological oceanography.

A Master's programme usually lasts four semesters (two years) or in some countries three years. The final year or semester is dedicated to your Master's thesis, for which you choose a research topic that interests you and that you would like to focus on in your future career. Keep in mind that almost everything in the marine environment is connected and therefore of relevance, from the tiniest plankton to the largest animals on Earth, and a solid basis of knowledge is needed to understand them and any threats they face.

After completing a Master's thesis, you may continue to pursue a doctoral degree, which will give you the opportunity to develop your own research questions, and then by performing experiments or field surveys, write scientific publications and thus become a part of the scientific community. This last phase of higher education usually lasts at least three to four years, sometimes longer.

3.2 How to become a veterinarian

If you would like to become a veterinarian, you should have a general understanding of mathematics, physics, chemistry and biology. You should be interested in domestic animals, animal health, microbiology, diseases, food safety and hygiene. If you want to become a wildlife veterinarian, you should also be interested in wildlife, environmental protection, animal welfare and conservation.

To be accepted by a veterinary university, you usually need to have good grades in secondary school, especially in the natural sciences. Often, a letter of intent and an aptitude test are also required. The educational system differs depending on your country of residence, but it usually takes some 11 semesters (5.5 years) of study, including compulsory practical internships. You learn about zoology, botany, chemistry, physics, biochemistry, embryology, pharmacology, as well as more specialised topics in anatomy, physiology, pathology, animal welfare, internal medicine and surgery. You also learn about food and meat production and hygiene.

Depending on the university, you may specialise in a certain animal species during the course of study. Even so, with a veterinary degree you have a broad training and can work in many different fields. You can work in a veterinary clinic, in the food production and hygiene sector, pursue research, sell veterinary supplies, or work for the pharmaceutical or another industry. Unfortunately, there is usually little university training in topics of interest for wildlife veterinarians. You need to gain experience through internships and postgraduate studies to specialise in fields like wildlife biology, zoo animal and wildlife health, animal welfare and conservation.

As a veterinarian you are expected to see the larger picture by connecting fragmented information to form a diagnosis, to function in unfamiliar situations, to work reliably under stress and to quickly familiarise yourself with new situations and areas of work. You need to be attentive and creative, because regardless of whether you are treating a mouse, horse or elephant, you have to find a solution for each animal and situation. In addition, you can specialise in clinical fields such as reproduction, *ophthalmology* or dentistry rather than in an animal species. If you desire to work with marine mammals, you should try to engage in as many practical experiences as possible. Volunteer wherever you can and participate in relevant internships. This is a highly competitive field with very few paid positions. Therefore, you should be determined and excel at your profession to succeed in the long run.

In rehabilitation or permanent holding facilities, the veterinary care team obtains regular hands-on experience with the animals they care for. Veterinary specialists are often called in for their expertise to assist the head veterinarian with clinical cases (such as dental reconstructions, or *osteosynthesis*). For some wildlife veterinarians, marine mammal research often involves little hands-on work with the animals, as much of the work focuses on population levels or the pattern of spreading of a disease. One should be prepared for working many hours on a computer or in a laboratory. Still, working as a veterinarian is highly rewarding, whether it is helping individuals in a clinical setting or performing wildlife research on a broader scale, as in this profession you can usually see the results of your devotion and you can do a lot of good.

3.3 How to become an engineer

Advice from Principal Research Fellow Mark Johnson, PhD in electronic engineering, Scottish Oceans Institute and Marine Bioacoustics Group, University of St Andrews, and Aarhus University, Denmark.

Working on engineering methods to study marine mammals is incredibly rewarding and challenging. Most marine mammals spend little time at the surface, so much of what we know about their behaviour and capabilities comes from using electronic data loggers (records data over time and/or in relation to location). To learn something new in this highly specific field, you have to develop a logger capable of measuring something different or invent a way to analyse the data that the loggers collect, and this often requires engineering knowledge. Engineering is both a set of skills and a way of looking at problems. Engineers use maths and physics to understand how things work or to build new things. In animal biology, engineers invent ways to find out where animals are, what their environment is like, how many of them are there, and what they are doing. Some biologists working with animals take an engineering approach, for example, by applying physical models to explain how animals move or how the sounds they make radiate into the environment. Either way, the key is to look at problems from an engineering perspective and acquire enough knowledge in maths, physics, and engineering to develop the mechanical or electronic systems you need.

Many universities offer Bachelor's degrees in engineering in which you usually have to select between mechanical or computer and electronic themes. Some universities offer more cross-disciplinary themes such as industrial design or biomedical engineering which may also give you useful skills for developing systems to study marine life. A more practically oriented diploma in computer engineering may also be a possibility to help you add engineering skills to your biology training (e.g. as an evening class). There are few research groups actively working on engineering applications in marine biology, and you may need to persuade researchers across departments at your chosen university to create a cross-disciplinary opportunity for postgraduate study. However, there is such a powerful need for people with engineering skills in marine biology, that you may find that researchers are keen to create such opportunities.

Strangely, many university engineering courses do not teach you how to build electronic devices. They teach you about the theory and less about the practice. Most engineers learn about designing and building by trial and error or by working with other engineers. Some companies employ interns and this can be a good way to learn how to proceed. Another way is to reverse engineer: see how other people have designed equipment and try to adapt their work. There are a lot of hacker and engineering communities on the web that can help with advice (albeit of varying quality). But ultimately, the way to learn is to build things, test them and find out what breaks, repeatedly.

3.4 How to become a mathematical biologist

Advice from Dr. Benno Wölfing, formerly responsible for statistics and modelling at ITAW, now working in the division for Management and Monitoring of Marine Protected Areas of the German Federal Agency for Nature Conservation, Isle of Vilm, Germany.

In his autobiography, Charles Darwin 'deeply regretted that [he] did not proceed far enough at least to understand something of the great leading principles of mathematics; for men thus endowed seem to have an extra sense'. This *extra sense* has facilitated great scientific discoveries in life sciences in recent years. On the one hand, mathematical models are excellent tools for studying complex systems such as the evolution and spread of new traits in a population or the spread of disease. On the other hand, statistical methods are essential for quantifying the evidence in favour or against a scientific hypothesis and thus form the foundation for inference. The great majority of contemporary publications in the biological sciences draw on mathematical tools. To fully appreciate the evidence underlying a scientific statement, mathematical knowledge is required and every scientist should know a basis of statistics and programming. But don't worry: while statistics use mathematical concepts, they require a different set of logical thinking, and you don't have to be a mathematician to be a great statistician and vice versa. If mathematics is not your strongest suit, you can still get an understanding of statistics and be an excellent scientist, while for the more comprehensive studies and models, an interdisciplinary approach including statisticians, mathematical biologists or bioinformaticians is usually the way to go.

The requirements: Mathematical biologists are working in a field that spans disciplines as diverse as mathematics, biology and bioinformatics. Bachelor's degrees in biomathematics, biology, bioinformatics, statistics, applied mathematics or physics can all be good starting points for a career. In the end you want to achieve both a good knowledge of the biological system you are studying and a thorough understanding of the mathematical toolset. During your studies you may achieve this by participating in courses of other university departments, by selecting or suggesting cross-disciplinary assignments and research projects and by working in cross-disciplinary research groups. Programming experience is an essential skill. For graduate students and postdocs, experts in specific tools or analysis methods often offer internationally advertised courses.

Most research questions in the life sciences can only be answered in collaborative efforts. Fruitful collaborations between researchers of different disciplines require a mutual understanding of basic principles and a shared vocabulary. Mathematical biologists can be viewed as working in a continuum between mathematics and biology. You can select where to specialise on this continuum based on your personal interests and talents. If your prime interest is in developing mathematical tools, in abstraction or in exploring systems, you may choose to study theoretical physics or applied mathematics. Bioinformaticians typically focus on the analysis of data acquired in the field of molecular biology as well as genetic and genomic data. Statisticians are trained in experimental design and the analysis of experimental data. Biologists receive an in-depth training in the methods and concepts of their discipline enabling them to identify research questions from which their discipline will profit. Efforts to acquire a good knowledge in related disciplines will be important throughout your career.

4 Accounts of different career paths

■ Interview with Professor Dr Ursula Siebert, Director of the Institute for Terrestrial and Aquatic Wildlife Research (ITAW), Germany

Prof Dr Ursula Siebert is a wildlife veterinarian who specialises in marine mammals. She studied veterinary medicine at the German Justus-Liebig-University Giessen and the Ecole Vétérinaire de Nantes in France, before conducting her doctoral thesis on 'Impact of mercury pollution on cetaceans from German waters' in Brussels, Belgium and Giessen, Germany. In 2007, she finished her habilitation in zoology at the Christian-Albrechts-University Kiel and has been the Director of the ITAW since July 2011. She is a Diplomate of the European College of Zoological Medicine (ECZM) in Wildlife Population Health and a Certified German Veterinary Specialist in wild animals.

What is your main research focus?

'In my research, I mainly focus on wildlife biology and wildlife health. I supervise terrestrial and aquatic research working groups at the institute; thus, I am involved in everything the institute conducts: health monitoring on live and dead animals, acoustics, animal counts, telemetry, wildlife diseases/parasites and population decline investigations. To protect marine mammals in particular, it is necessary to know how they live and what effects human activities have on them. Only the interdisciplinary work of several research groups and professions (zoologists, veterinarians, chemists, physicists, statisticians, etc.) and the joint evaluation of data and information lead to insights into the status of a population or species. Over the past years, human threats to marine mammals have increased dramatically and researchers need to find out how the animals react to changing living conditions, form conservation management strategies, and propose protected areas. Advising politics and stakeholders is also a main part of my work'.

How did you become a scientist working with marine mammals?

'I was conducting a part of my veterinary studies in Nantes, France, where I lived close to the seaside and started to work on marine mammals. From that point on, I followed this path and kept educating and specialising myself in marine mammal science and pathology'.

What does a typical day as a research institute leader look like?

'The head of a research institute has to look after everything that happens at the institute, for example, the research projects, proposals, contracts, master and doctoral students, building and facilities, as well as everybody's safety and security. I have to keep contact with funding agencies and stake holders to inform them about the progress and outcome of our research, and recognise what type of work or project are needed next to preserve marine mammals in German waters. Because I am involved in so many different working aspects, I regularly meet with ministries, contracting authorities, working groups, national and international colleagues and potential collaborators; have to read and respond to a huge amount of emails per day; write and check scientific papers and reports; and keep an overview of everything that is going on at the institute'.

What was your best experience working with marine mammals?

'The best working experience concerning marine mammals is to teach and train people in different countries about them, including preparing young scientists for future research and protection of marine mammals. To see the excitement and interest in their eyes during a lecture or a practical class is always rewarding for the hard work we are doing'.

Interview with Associate Professor Magnus Wahlberg, Head of the University of Southern Denmark (SDU)'s Marine Biological Research Center in Kerteminde, Denmark

Prof Magnus Wahlberg is originally from Sweden and studied physics and biology at the Universities of Lund and Gothenburg. He worked with fish telemetry and sound production for the National Board of Fisheries in Sweden before starting a PhD at the University of Southern Denmark, developing acoustic localisation methods for deep-diving cetaceans, focusing on the sperm whale. As a post-doctoral researcher at Tjärnö Marine Biological Laboratory, Sweden, and Aarhus University, Denmark, he continued measurements on deep-diving cetaceans, including bottlenose whales. In 2006, he was appointed chief scientist at Fjord&Bælt, focusing on studies of harbour porpoise biosonar and hearing. He was appointed Associate Professor at SDU in 2012, and in 2015 he became Daily leader of SDU's Marine Biological Research Center in Kerteminde. His current research focuses on the hearing abilities and behaviour of marine mammals and birds.

What is your main research focus?

'My main research area is underwater hearing and underwater sound production in marine animals, especially marine mammals. I studied how fish respond to sound, how marine mammals interact with fishing gear, and also how especially porpoises find food by using echolocation. I work a lot with underwater sound, which means I am working very interdisciplinary. Acoustics by definition is a topic in physics. You need physicists to understand acoustics and you also need skilled engineers to build the equipment that you need for the measurements. We often work with engineers in our research'.

How did you become a scientist working with marine mammals?

'I started my career studying physics, actually. Then I got interested in biology and I switched to biology. But I was mainly interested in underwater sound, how animals respond to it and how they use sound underwater. For many years, I was working on different projects related to these questions. I also had a passion for marine mammals. I worked with many different scientists on some bycatch projects, I was a whale safari guide (naturalist) and very often, I helped other colleagues with their research projects just because I thought it was fun. I never ever thought I could make a career out of this passion. But I was lucky and motivated, so one thing led to the other, until I got a job at the Swedish fishery institute working with fish and seals. Later, I started my graduate work with toothed whales, and eventually ended up in Kerteminde and have continued my career here. For me, one thing has just led to the other very much by coincidence rather than following a planned career path. And I think especially in some scientific fields you have to be flexible and have very many hooks out in the sea of opportunities and then you may get efficient, competent or lucky so that one of the hooks is the big catch and then that's the way you go. In my opinion, you cannot sit down and plan your life a certain way, because the next opportunity is maybe in Canada or in Australia, or in a completely different field or with another species, you never know'.

What does a typical day as a researcher look like?

'There are no typical days for researchers. Every day is different, and I think you have to be very open minded and adaptable. We call it 'expect the unexpected'. You should always try to find out if there is something new and interesting in what you are doing; that's sort of what we are mainly focusing on. On the other hand, you have to be very meticulous, because it takes a lot of discipline to formulate good ideas for projects, plan the projects, and get funding to conduct them, and also to collect and analyse the data, and finally writing it up for a scientific publication.

Natural scientists are trying to figure out the unknown, how issues are connected or how biological life systems function. Our work is trying to find new things. And how do you do that? Well, it's not necessarily like an 8:00 am to 4:00 pm kind of job. The days usually start more or less in the same way as they do for most people: we are starting our computer and go through our emails to see if there is an immediate problem from colleagues or students that needs our attention. But otherwise every day can be very different. Sometimes we are running experiments, we have to fix technical problems, we may have some issues that we have to solve in terms of understanding an experimental result or we go out in the field to measure sounds from the wild and we have to either prepare field equipment or actually go out and take the measurements. Often, we dive into our computers to analyse the data and also write up papers and reports. On top of that, we are also teaching and supervising students at different levels. Finally, we have some administrative work to do. Basically, every day looks very different'.

What was your best experience as a marine biologist?

'I have many fantastic experiences from field work with whales and seals but maybe the best one I can think about is one in the Azores, which are some beautiful Portuguese islands in the Atlantic where a lot of whales congregate. We had been out there for several weeks listening for and also tagging sperm whales from a sailing boat. During our last night, when all tags were retrieved, we had to finish up and eventually get all the equipment back into the boat, which actually took the whole night. It was already in the early morning hours when we had everything organised. I had been able to sleep a little bit during the night whereas the rest of the crew was completely exhausted. So, I was the only one who was sort of fresh enough to sail. There I was, sitting all alone while the sun was rising, and right beneath the stunning volcanic landscape of the Azores, quietly sailing the boat back to the harbour—that was a fantastic experience!'

■ Interview with Professor Eric Parmentier, Director of the University of Liège's Functional and Evolutive Morphology laboratory, Belgium

Eric Parmentier is a fish and 3D-modelling expert who graduated from the University of Liège's animal biology department before studying Carapidae, a sound producing fish family whose members infiltrate invertebrates. With the aim of carrying out comparisons, his research expanded to other fish families capable of acoustic communication.

What is your main research focus?

'I like to work on different subjects. In the lab, we work mainly on the acoustic communication of fish. We try to understand which messages fish send, how they produce their calls and how we can use these calls to monitor the environment. If fishes are able to send sounds, they should also be able to receive them, meaning that we are also working on their hearing abilities. Additionally, we examine the feeding modes of different fish species. Being able to feed on different prey and food items means that you are able to share the same environment and different niches. This way, we can explain the biodiversity of fish in the same habitat. Our latest project in the lab concerns marine mammals. They have different sizes, anatomies and physiologies, and do not all live in the same parts of the ocean. Using the vertebrae of the backbone, we try to explain how they evolved and adapt to different environments. Our work slogan could be: show me your backbone and I will tell you where and how you live'.

How did you become a scientist working with aquatic animals?

'I simply like to be in the sea. So, I suppose, it is easy to understand that I also like to understand how creatures of the sea are living. How they communicate, how they adapt to changing situations and how they thrive. The most obvious way to find answers to these questions was to study them—so I became a biologist'.

What does a typical day as a researcher look like?

'It depends on the day, because I am a professor and I also have to teach. However, much of my time is spent in a lab, working with bones, graphics and animations. But right now, while answering these questions, I am in Guadeloupe (in the southern Caribbean Sea) for one month with my research team and it is 6 am. In twenty minutes, we go to sea. We will probably swim four to five hours to collect different fish species we suspect to be vocal. Once we catch them, we place them close to the beach in shallow water and use hydrophones to record their sounds, if possible. We also take small tail samples for genetic studies. After sampling, some fish are set free immediately, while others are kept longer for morphological studies. If the fish is vocal, we can go back to the sea to place other hydrophones allowing us to follow the fish's sonic activity for longer times. We can also use cameras to explain fish behaviour through videos. This kind of fieldwork is always very exciting, but can also be strenuous and exhausting work. Once we are home, we have a huge amount of data that needs to be analysed and interpreted, so when we leave the field the work is by no means done'.

What was your best experience as a marine biologist?

'There is no best experience, but a lot of nice experiences. Each time we visit a new place or we know we are the first people to observe something, we are excited and happy. For example, during this mission in Guadeloupe, we are the first to record and describe the sounds of ten different fish species! Before us, nobody knew these fish were even able to produce sounds. Isn't that amazing? It is also neat to communicate the experiments we have done and our research outcomes. The description of new fish species was also a great thing. So, there are a lot of nice experiences in my life as a marine biologist'.

■ Interview with Dr. Iwona Pawliczka, Head of Prof. Krzysztof Skóra Hel Marine Station, Department of Oceanography and Geography, University of Gdansk, Poland

Dr Iwona Pawliczka studied marine biology at the University of Gdańsk. She has always been interested in marine mammals but did her master's thesis on fish diet. During her studies she published her first paper on harbour porpoises as a co-author of an international team. After a couple of years spent far from the sea, she got a position at Hel Marine Station University of Gdańsk where she took care of the research and population reestablishment and stabilisation of Baltic harbour porpoises and grey seals. She finished her PhD on the biology, population status and threats to harbour porpoises in the Polish waters of the Baltic Sea. Her current research and conservation work focusses on the biology of and threats to marine mammals. She is a member of different international forums dedicated to marine mammal protection in European waters, including ASCOBANS and HELCOM expert groups.

What is your main research focus?

'Marine biology is a very multidisciplinary science. In our situation in Poland, where there aren't so many marine mammals, and at the same time not so many scientists working on them, it is very important to cover a lot of different issues in this kind of research. At Hel Marine Station the team and I try to cover not only biology, behaviour and monitoring—but also more specific research as toxicology, parasitology and microbiology. We try to find out as much as possible about marine mammal populations that live here in the Baltic Sea. At the same time, we cooperate with a lot of different international teams like the ITAW, which are specialised in their own very specific aspects in the lives of marine mammals'.

How did you become a scientist working with marine mammals?

'From the beginning of my life, I lived at the seaside. I was pretty sure that my professional life has to be connected to the sea, in some way. Growing up, I decided, that the biology of the sea was the most exciting for me. I had the chance to observe marine life from a very young age. I became more and more excited and curious about it, asked myself how marine mammals can live in the water and what adaptations they have to live in the marine environment'.

What does a typical day as a researcher look like?

'I think marine biologists and researchers, in general, are independent workers. It very much depends on how you organise your work in your office and the field. Firstly, you have to find financial support to carry out projects. You have to find co-workers and research teams, often internationally, who are also interested in the same project or research questions. Writing grant and project proposals is a large part of a researcher's life. Then you have to organise your time between fieldwork, office work, conferences, workshops, and writing publications and project reports. The first stage of almost all projects is dedicated to fieldwork. Sometimes on the ocean, sometimes at the beach, sometimes in the laboratory. Being out on the ocean or working hands on with marine mammals is obviously a prize for every researcher, which is only occasionally awarded. Often, you have to spend a lot of time inside the office or in labs. But you may also have to dedicate your time and your research to working at the university and to education, both academic and public education. It is very important to deliver the most recent data to the public, to politicians and to decision-makers, to take care of the environment and to trigger positive progress'.

What was your best experience as a marine biologist?

'This is very difficult to say. My job and being a researcher have so many facets and so many different days, and you get so many different experiences, that it is very difficult to say which one was the best. But, I would definitely say, that the happiest moments and days are when you can really observe the results of your work out in nature and how the animals live in their natural environment and not in captivity, not in the labs and not in the offices. So those are the best moments in my life as a marine biologist'.

Interview with Dr. Andreas Ruser, Deputy Director and Head of the Bioacoustic Research Group at the ITAW, Germany

Dr. Andreas Ruser is a trained physicist. He graduated from the Faculty of Mathematics and Natural Sciences of Kiel University in 2001. During his doctoral research in biophysics, he focused on analysing chlorophyll-fluorescence to determine marine algae groups and on investigations on natural water samples with flow cytometers. One of his interests focuses on the layout and construction of analogue and digital circuits and he is in charge of the development and improvement of different monitoring-systems (for water levels, currents, waves, underwater sound, animal hearing, etc.).

What is your main research focus?

'The bulk of my work is in the field of bioacoustics, where I mainly perform research on marine mammals. My working group focuses on underwater noise and hearing of harbour porpoises, harbour seals and grey seals, in particular on the impact of anthropogenic underwater noise. We examine the animals' ears to understand the physical effects of anthropogenic underwater sound on hearing, and also try to investigate how sound affects the distribution of animals within their habitat. To record sounds in the ocean, acoustic recording devices (hydrophones) are stationed underwater. Through their recordings, we can learn how severe the underwater sound input is and can determine its effects on marine animals. By analysing the recordings, we can detect whether animals are present in the vicinity of the hydrophones or not. In addition, we also tag animals with acoustic recording and GPS devices and later try to figure out how an animal behaves when exposed to underwater sound. Through our bioacoustics research, we try to answer questions regarding their normal physiology, anthropogenic influences on behavioural change and the severity of underwater noise pollution effects'.

How did you become a scientist working with marine mammals?

'The career process until I started working with marine mammals was very long. I was always interested in technology and this passion led to the decision to study physics. During my studies, I would have never dreamt of ever working with marine mammals. That was never my plan. However, I always wanted to work in the field of applied physics. Meaning no theoretical research, but something that can be measured or somehow captured and practically implemented. During my university studies, I worked in a very different area, namely in photosynthesis research. During the course of my career, I moved from basic photosynthesis research in terrestrial plants, over investigations of phytoplankton, to research on marine mammals. In fact, my research objects have slowly but steadily increased in size throughout my career. In the end, working with and on marine mammals happened just like that. I always had a natural interest in this subject, but the basis to become a marine mammal researcher was paved very early on by my fascination and orientation for applied physics'.

What does a typical day as a researcher look like?

'This morning, my day started like every other workday. With a rather unpleasant sound: the repeated buzzing of my alarm clock. Like most people working at the institute, I would rather be outside in the field watching and studying marine mammals and recording their call behaviour instead of working in the lab. The step into the acoustic laboratory is sobering; it looks like a NASA control room with banks of computers and boxes filled with equipment such as hydrophones, amplifiers, cables and sound cards. A colleague is staring at the computer screens, but he is actually listening to the sounds of blue whales the team recorded in Iceland. Sound recordings come with a collection of a gigantic amount of data. Each recorded second represents, depending on the sample rate, up to more than 500,000 data points. These huge amounts of data and many hours of recordings require many cups of coffee, the use of powerful software, excellent programming skills and proper data management. The subsequent analysis of sound is diverse and requires more cups of coffee, but statistical programmes allow data organisation, calculation, statistical computing and graphic display of recorded sounds. This means, that we will sit in front of our computers for the rest of the day, analysing the collected data, trying to refine our programmes and change statistical descriptive parameters to improve our results. Often, we let the computers calculate overnight, so that we have the next dataset analysed the next morning and we can continue working on it'.

What was your best experience as a scientist?

'Apart from a very mind-boggling experience with different plankton types during my doctoral chlorophyll-fluorescence research, my best experience as a scientist is the acoustic work with a harbour porpoise. Doing my first hearing tests and auditory experiments with porpoises was my absolute career highlight. For one, the animals are extremely special, all the porpoises I've studied so far have their own personality, which is amazing and relatively unbelievable. They may not look like it, but porpoises are simply highly fascinating, remarkable animals. It is just something completely different to work with a large animal, compared to researching microscopic plankton structures that are barely visible to the naked eye. Moreover, every field investigation is a new challenge, always extremely complicated. You have to think about and consider an incredible amount of possibilities and in the end, everything has to work in the field. Something that is easily done in a lab is usually a challenge on site and fieldwork is always complicated and often nerve-racking. Even if you have tested the entire equipment and the measuring system worked perfectly a few hours ago, the conditions in the field are always different. Suddenly, an electronic system that was previously running flawlessly for weeks in the laboratory shuts down without a reason while you are working on a porpoise. Adrenaline kicks in and you have to find a fast and easy solution to the problem to still get reliable results at the end of the day. That is why a good day out on the water, where everything works and you get good results is so satisfying. When all your hard work is rewarded with aspired data, the whole team is happy, the examined porpoise is healthy, has good hearing abilities and can happily swim off—that is always a great feeling and the best motivation one can think of'.

Supplementary Information

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Glossary

Acoustic deterrent device A device that plays out loud sounds to make seals avoid predating on fishing gear and fish farms. For porpoises, sounds of less intensity is used to avoid bycatch; these devices are known as *pingers*.

Acoustics *Science of sound*, including sound production, propagation and reception.

Additives Substances that are added in small quantities during plastic production to induce or enhance specific properties.

Alternative fishing gear Fishing gear developed to mitigate bycatch and depredation by marine mammals.

Anthropogenic sound Sound caused by human activities.

Aquaculture Raising fish, crustaceans, mussels or algae in controlled conditions, such as tanks and ponds, or off the coast in net pens or cages, or (for algae and mussels) on lines.

Baleen Long and slender structures attached to the upper jaw of baleen whales. Baleen is made of keratin, a fibrous protein also found in human hair and fingernails. While foraging, water is pushed through the baleen and captures, for example, krill or schooling fish.

Bioacoustics Scientific topic combining biology, engineering and acoustics. Bioacousticians investigate, for example, sound production and reception, how sound is used by animals to communicate, find food and orient themselves in their environment, and how animals react to man-made sounds.

Bioaccumulation Gradual build-up of chemicals or toxins in an organism. Bioaccumulation refers to the combined toxic uptake from food, water, air, etc. as a result of the substance being absorbed faster than eliminated by the organism through catabolism and excretion.

Bioindicator *Sentinel* species, which reveals the qualitative status of the environment and indicates a problem within the ecosystem when monitored for changes in, for example, biochemistry, physiology or behaviour.

Biomagnification Also known as *bio-amplification*. Biomagnification is the increased concentration of contaminants in organisms higher up the food chain. The contaminants are accumulated by foraging on smaller animals having assimilated contaminants at lower concentrations.

Blubber A layer of fat under the skin of marine mammals, serving as energy and water reservoir as well as thermal insulator, and also important for buoyancy control and streamlining the body.

Bycatch Incidental non-targeted catch of marine animals in fishing gear. By-caught species can be non-target fish species as well as marine mammals, birds, turtles and invertebrates.

Clade A taxonomic group consisting of all organisms belonging to the evolutionary descendants of a common ancestor.

Class A high-level taxonomic group of organisms with a common evolutionary origin. All mammals (including whales, seals and humans) belong to the class Mammalia, and birds belong to Aves.

DDT An insecticide, which is not only toxic but possibly also carcinogenic to humans and animals. Abbreviation of *dichlorodiphenyltrichloroethane*.

Drag The resistance exerted by the water to the movement of a body.

Echolocation Sensing the environment by receiving returning echoes of sound pulses produced by the animal. Echolocation, also known as *biosonar*, is found in toothed whales, bats and a few species of birds.

Environmental contaminant Harmful chemical, biological or radiological substance that has an adverse effect on living organisms and their environment. Contaminants can be derived from human (e.g. industries, wastewater, agriculture) or natural (e.g. algae and bacteria) activities.

Epoch Geological time period that can be observed as a layer in rocks, caused by sediments that have turned into stone. Some scientists argue that we currently live in a newly formed epoch, called the *Anthropocene*, as traces of modern human activities, such as microplastics and pollutants, can be found in newly formed sediments.

Family A low taxonomic rank, right above *genus*. All dolphins (including orcas) belong to the family Delphinidae, whereas humans and great apes (e.g. chimpanzees and gorillas) belong to the family Hominidae.

Fishing gear Gear used to catch, for example, fish, crustaceans and squid. Fishing gear design is adapted to the behaviour and depth of targeted species. Fishing gear can be active (e.g. trawl) or passive (e.g. trap). Some widely used types of fishing gear are traps, pots, trawls, longlines, as well as fyke, seine and gill nets.

Fluviatile Found in, or produced by, a river.

Fyke net A static fishing gear consisting of a long cylindrical or cone-shaped netting bag that is fastened to rigid rings. Fish is guided towards the entrance of a trap by *wings* or *leader nets* and have a problem finding their way out again. Fyke nets are anchored or attached with poles to the bottom.

Genus Taxonomic rank right above species. The harbour seal (*Phoca vitulina*) belongs to the same genus, *Phoca*, as the spotted seal (*Phoca largha*). The only species in the human genus *Homo* is humans, *Homo sapiens*.

Gill net Nylon nets attached to the bottom with anchors and held up by floating lines and corks. The mesh size determines which size of fish is most effectively caught. The fish pass through the net with its head, but not its body, and get entangled when it tries to back off. Some gill nets stand at the bottom, whereas others are floating at the surface.

Gyres Enormous circular surface water currents in the ocean.

Immunotoxicology The study of toxicity of foreign substances and their effects on the immune system.

Invasive species Non-native species introduced by, for example, aquaculture or ballast water of ships.

Macroplastics Plastic fragments larger than 2.5 cm.

Mesoplastics Plastic fragments with a size of 2.5–5 cm.

Microplastics Plastic fragments smaller than 5 mm.

Mitigation methods Methods used to decrease anthropogenic stressors in the environment, usually based on the concept ‘avoid, accept, reduce, control’.

Myopia Near-sightedness.

Necropsy Post-mortem examination of a dead animal; corresponding to autopsy of a human.

Noise pollution Adding man-made sound to the environment that may harm animals.

Order A grouping of organisms at a taxonomic rank lower than *class* but higher than *family*. Whales and dolphins belong to the order Cetacea, whereas seals belong to the order Carnivora. Humans, and apes and monkeys, belong to Primates.

Otolith Ear stone in bony fish that functions as a sensory organ detecting gravity, balance, movement and direction to sound sources. Because otolith shape is species-specific, it is used in dietary studies of marine piscivores.

PCB Toxic and carcinogenic organic chlorine compounds that were previously used as plasticizers and flame retardants for plastics. Globally banned since 2001 due to toxic properties. Abbreviation for *polychlorinated biphenyls*.

Phylogenetic tree Illustrating the relationships between organism as a tree, where clades are found on branches stemming from the same base.

Pinger Acoustic deterrent device attached to gill nets and emitting ultrasonic sounds aversive to, for example, harbour porpoises. Pingers are used to mitigate bycatch problems and are mandatory in some European gill net fisheries.

Pollutant A substance with harmful or toxic effects on organisms and the environment.

POPs Long-lasting toxic organic substances that degrade extremely slowly. Two famous examples of POPs (*Persistent Organic Pollutants*) are DDT and PCB.

Predators Animals killing and eating other animals.

Recycling The process of enabling waste products to be reused.

Refractive index A medium-specific measure of the amount of bending of light rays experience when going from one medium to another. Proportional to the speed of light.

Rete mirabile A complex network of veins and arteries found in some marine mammals. The function is unknown but is believed to be involved in the diving response.

Rods Anatomical structure in the eye containing pigments that are light sensitive but cannot discriminate between colours (for colour visions, the eye uses pigments found in cones).

Seafood certification schemes Official certificate organizations with the main objective to ensure that labelled fish was caught using techniques that minimize bycatch of marine mammals or other marine organisms.

Seal culling Seal hunting. Seals have been harvested through thousands of years for their fur, blubber, liver and meat, as well as a pest control to reduce their competition with fisheries.

Soundscape The entire amount of sound in a certain location, usually added together by many different sound sources (both natural and man-made). The term is the acoustic analogue to the visual *landscape*.

Steroid hormones The term 'steroid' indicates certain hormones synthesized in the gonads (sex steroids) and adrenal glands (corticosteroids). Steroid hormones control metabolism, immune functions, inflammation and development of sexual characteristics.

Taxonomy The science of classification of animals and plants according to how closely they are related. The corresponding adjective is *taxonomic*.

Toxins Poisonous substances (molecules, peptides or proteins) produced within living cells or organisms. Toxins can cause disease on contact with or absorption by body tissues.

Trace elements Previously called *heavy metals*, trace elements are trace dietary components essential in minute quantities for the proper function of the organism. Examples are cobalt, copper, fluorine, iodine, iron, manganese and zinc. Trace elements may be toxic at high concentrations, and some are toxic even at lower concentrations.

Trawling Fishing by towing a trawl (a cone-shaped net ending in a bag) with one or more boats. Some trawls are made to be towed long the sea floor (bottom trawl) and others at mid-depth (pelagic trawl).

Viviparity Live birth (as opposed to, for example, birds laying eggs).

Wave propagation The physical description of how a wave (e.g. an acoustic signal) travels from one location to the other. The wave changes while traveling with respect to its amplitude, duration and frequency content.

Whaling Hunting whales, dolphins or porpoises. Whaling has been going on for thousands of years. In the nineteenth century, whales were mostly hunted for their blubber and baleen. Industrial whaling of the twentieth century, mainly for meat, brought many large whale species to near extinction.