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1. Introduction to Marine Mammals

1.1 What is a Mammal?

The scientific word for mammal is Mammalia, a word coined by Carl Linnaeus (the father of taxonomy) in 1758 from the word 'mamma', meaning breast or teat (Wikipedia). There are certain characteristics that all mammals share: a mother nourishes her young with breast milk (Cambridge Dictionary); most give birth to live young; all are vertebrates; all have a 4 chambered heart; all breathe oxygen with lungs; the lower jaw is made of a single bone; they are endothermic (or homeothermic, to keep body temperatures above the ocean temperature) and at some stage in life they have hair (NOAA).

Other animals that are considered mammals are *monotremes* that lay eggs (eg: spiny anteater and platypus) through a cloaca, which they also to urinate and defecate (Parsons et al, 2013); *marsupials* are mammals that are nourished by a yolk sac while in the uterus. They give birth to an immature embryo that climbs up to external body pouch on the mothers abdomen (Libretext: Marsupials) and continues to develop, clinging to a nipple in the pouch (koala bears and kangaroos) (Biology Online: Mammal). Marsupials and monotremes are considered eutherian mammals (aplacental mammals) (Biology Online: Theria).

1.2 Characteristics of Marine Mammals

Marine Mammals are no different in general, even whales have hair at some point during their lives and some even have hair for their entire lives. When whales are born they have sensory hairs along their jaw and head, these hairs are usually shed, but not always. On the head and jaw of humpback whales are enlarged hair follicles called tubercles, each tubercle has one sensory hair

(IFAW). All marine mammals are placental animals (therians), this means that they have a uterus and a vagina. The embryo develops in the placenta in the uterus and is born through the vaginal canal when fully developed (Libretext: Placental Mammals). Fewer mammals born than other animals but survival rate is higher due to great parental care.

2. Marine Mammal Adaptations

There are several adaptations such as that marine mammals need to survive in their watery environment:

- Maintaining body temperatures by reducing heat loss includes a small surface-to-volume area, an increased internal layer of blubber directly under their very thick skin and a reduced number of blood in areas that are in contact with the cold water (Marine Bio, 2019).
- Marine mammals have smaller lungs, proportionately, to humans (Sea Grant Alaska) and are able to deep dive without getting the bends (a rapid decrease in surrounding pressure, in both air or water) because the deeper they dive they exhale instead of inhale and their heart rate is reduced (Marine Bio, 2019). They tolerate tremendous atmospheric pressure at great depths, with collapsible lungs and ribs, air spaces are minimized (Sea Grant Alaska). Air is expelled from their lungs avoiding excess nitrogen from being absorbed (Marine Bio, 2019) (excess nitrogen impairs vision, breathing and can harm the health of forests, soils and waterways) (EPA). Oxygen is used more efficiently when deep diving: filling their lungs, exchanging 90% of air in each breath, the high blood volume and blood chemistry allows for greater oxygen retention. They also have a high lactic acid and carbon dioxide tolerance and their muscles work anaerobically while holding their breath (Sea Grant Alaska).
- Other adaptations include reduction in blood flow to non-vital organs (Marine Bio, 2019).

- A fundamental difference between fish and cetaceans' tails, cetaceans have horizontal tails allowing, whereas most fish have vertical tails used in side to side undulation. A rounded head and tapering body allows for smooth gliding through water using as little energy to resistance (Marine Bio, 2019) as well as appendages modified for maximal propulsion and minimal drag (Sea Grant Alaska). The tail generates most of the swimming power for marine animals (Marine Bio, 2019).
- Marine mammals hardly drink fresh water but they obtain water from their food, inspired air and their blubber and their specialised kidneys produce urine saltier than seawater (Sea Grant Alaska).
- Communicating underwater by using echolocation to locate prey and acute tactile senses. Pinnipeds and fissipeds have well-developed facial whiskers (Sea Grant Alaska).

While there are only a few taxonomic groups of marine mammals it is a very diverse group of animals, found in all marine ecosystems around the world, equipped with physical adaptations for their specific environments from extreme temperatures to the extreme depths, pressure and darkness. There are 4 taxonomic types of marine mammals: cetaceans (whales, dolphins and porpoises), pinnipeds (sea lions, seals, walruses), sirenians (dugongs, manatees) and fissipeds, which include two groups: ursids (polar bears) and mustelids (sea otters) (NOAA). Mammals expend approximately 10 times more energy than fish of comparable size so more food is required to support their high metabolic rate. Marine mammals are able to actively feed both at night and day due to their endothermic nature, which also allows them to adapt to a variety of habitats (Karleskint, 2020).

3. Cetaceans

Of all marine mammals, cetaceans are most well adapted for marine life being entirely aquatic, this group includes whales, dolphins and porpoises (Britannica), all breathe through nasal blowholes on the dorsal side of their heads. After a dive, when whales surface they forcefully expel the previous lungful of air and breathe in new air. Characteristics of the blow can be used to identify a species of whale (University of Alaska). As with other mammals, all whales produce sound (Smithsonian).

There are over 80 species of cetaceans, ranging in size from small 1½ metre porpoises and dolphins to the largest whale on earth, the 25 to 30 metre blue whale! Life spans of these animals differ greatly: humpbacks live at least 50-60 years and bowhead whales live at least 120 years, possibly even 200 years (Whale Trust).

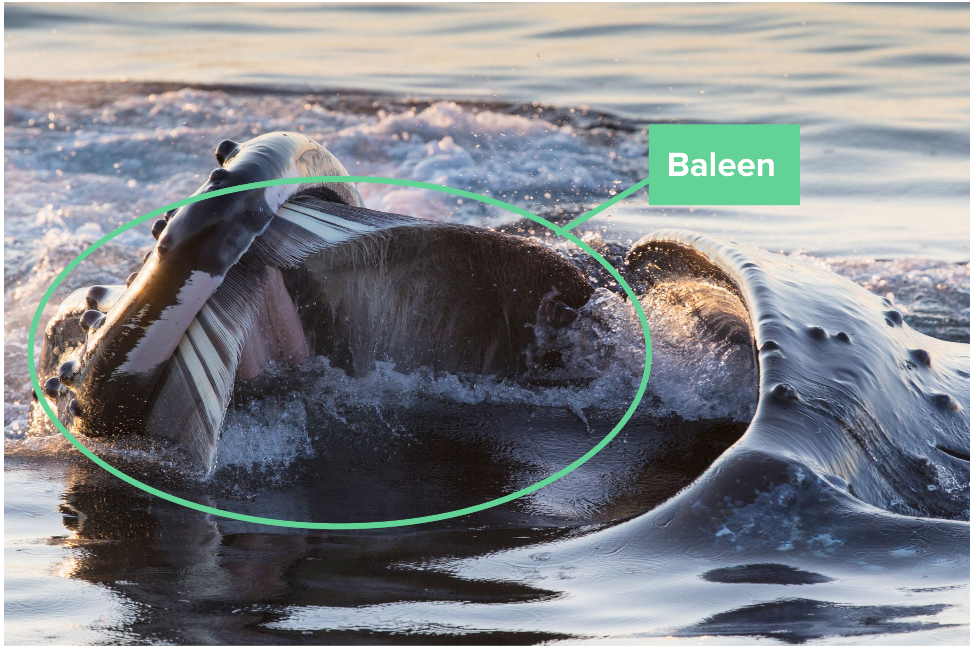
Cetaceans can be found in most oceans of the world and some are known to travel thousands of kilometres annually between high and low latitudes to feed, breed and to birthing regions. On the other hand, others live all year in more restricted areas and some can even be found in the world's largest rivers (Whale Trust).

Some cetaceans are capable of high speeds - 40km per hour - and some dive to depths of over 3000km, remaining submerged for up to 2 hours (University of Alaska). The cetacean body is fusiform-shaped (torpedo like) with tapered limbs or none at all, the tail is dorso-ventrally flattened into flukes (University of Maryland) and their smooth, hairless skin reduces drag. Cetaceans are divided into 2 suborders, according to whether or not they have teeth: mysticetes (baleen) and odontocetes (teeth) (University of Alaska).

3.1 Mysticetes

Mysticetes are 'mustached' whales, or baleen whales. There are approximately 14 species of baleen whales grouped into 4 families: the *balaenopteridae* (also called rorqual) have ventral pleats on their throats, which allows for considerable expansion while feeding (example: humpback whales) (Whale Trust); *balaenidae* are recognisable by their large heads (about ⅓ of their total body length), a narrow, arched rostrum, the absence of the dorsal fin and the broad flippers (example: North and southern right whales and bowhead whales (Encyclopedia.com); *eschrichtiidae* have a tapered head, a small dorsal hump, 5 throat grooves and found only in the north Pacific ocean, the only living species in this family is the gray whale (Sea World); and *neobalaenidae* also consisting of one species, the pygmy right whale, the smallest of baleen whales. All mysticetes have a differing amount of ventral pleats depending on species (Whale Trust). Generally, females are larger than males but no other sexual dimorphism is visible (University of Alaska).

Baleen whales have two blowholes on the top of the head, which result in bushier blows than toothed whales that have one blowhole. Several baleen whales (humpback, minke, fin and blue whales) have visible throat grooves that allow their mouths and throats to expand as they take in large mouthfuls of seawater and food (WDC).



Above: A southern right whale off the coast of South Africa. Right whales have as many as 360 plates. **Image Credit:** Holland JS, 2017

3.1.1 What is Baleen?

Generally baleen whales are larger than toothed whales (WDC). Baleen is made of flexible, keratin plates with bristled edges, suspended from the upper jaw and arranged in rows. Different species have different numbers of plates, for example fin whales have 800 to 900 plates but humpbacks only have about 300 plates (Whale Trust). Each curved plate is two flat keratin layers with rows of tubules sandwiched inbetween the plates. The tongue and the prey washing in and out of the whale's mouth abrade the plates and free up a fringe or bristles at the edges of the plates (Holland JS, 2017). The bristles filter, sift, trap and collect shrimp-like krill, plankton and small fish in their mouths during feeding. Bowhead whales have baleen that can reach 4 metres long and each whale species has a unique number, size and colour of the baleen plates (WDC).

A: The baleen of a dwarf minke whale. **Image Credit:** Holland JS, 2017

B: One plate of baleen from a bowhead whale **Image Credit:** National Parks Service, 2020

Different families of baleen whales feed on different prey, relying on different techniques to capture their prey (Whale Trust). Baleen whales either skim, suck or gulp water, expanding their throats to accommodate the water intake and then use their powerful tongue to push the water back out through the baleen, trapping their prey in the baleen bristles (Lucas, Sanibel Sea School). Humpback whales feed mostly on small fish like capelin, herring or krill; gray whales are benthic feeders and prey primarily on amphipods (small crustacean) or mysids (another shrimp-like animal, but not krill) inhabiting a different part of the water column (Whale Trust).

Scientists discovered that baleen provides insight to the life of whales, just like human hair includes data, keratin in baleen gives an indication of a whale's overall health, movement and reproduction information (Lucas, Sanibel Sea School) as the plates grow throughout their lives, so they capture hormonal signals from the adrenal glands, gonads and thyroid. As a plate erodes at one end and grows at the other end, it represents several slices of its life, up to 15 years worth (Holland JS, 2017). This information also sheds light on environmental conditions, diet and migration of whales (Lucas, Sanibel Sea School).

3.2 Odontocetes

Odontocetes are toothed whales with only 1 blowhole, they are predatory animals that hunt cooperatively in packs and have well adapted hearing in air and water (Ocean Conservation Trust). They make up just over 70 species, including dolphins, porpoises and species like killer and pilot whales, as well as beaked whales. The largest of odontocete is the sperm whale (about 18 metres). Whales like the narwhal (*Monodon monoceros*) have no functional teeth at all, but male narwhals have a single tooth that grows outward from the gums up to 3m in length, which is usually referred to as a tusk (Whale Trust). Sexual dimorphism is common in odeotocetes: males are larger than females and secondary sex traits present in some families (differences in dorsal fins and tooth pattern) (University of Alaska).

Toothed whales are divided into 2 groups determined by the shape of their teeth: spade shaped (porpoises) and round, cone shaped teeth (orcas and dolphins) (Ocean Conservation Trust). Odontocetes eat different types of prey, depending on the species but prey ranges from several types of schooling fish and squid to larger predatory fish and mahi-mahi (or dolphin fish), prey is swallowed whole, not chewed. Killer whales have been known to prey on other marine mammals as well as sharks (Whale Trust).

There are 10 families of recognised odontocetes including: *Phocoenidae* (porpoises); *Delphinidae* (true dolphins including the killer whale); *Monodontidae* (belugas, narwhals); Kogiidae (Pygmy and dwarf sperm whales); *Physeteridae* (sperm whales); *Ziphiidae* (beaked whales); *Platanistidae* (Indian River Dolphin); *Iniidae* (Amazon River dolphin); *Pontoporiidae* (Franciscana or la plata dolphin); and *Lipotidae* (Yangtze river dolphin) (Whale Trust).

4. General Cetacean Anatomy

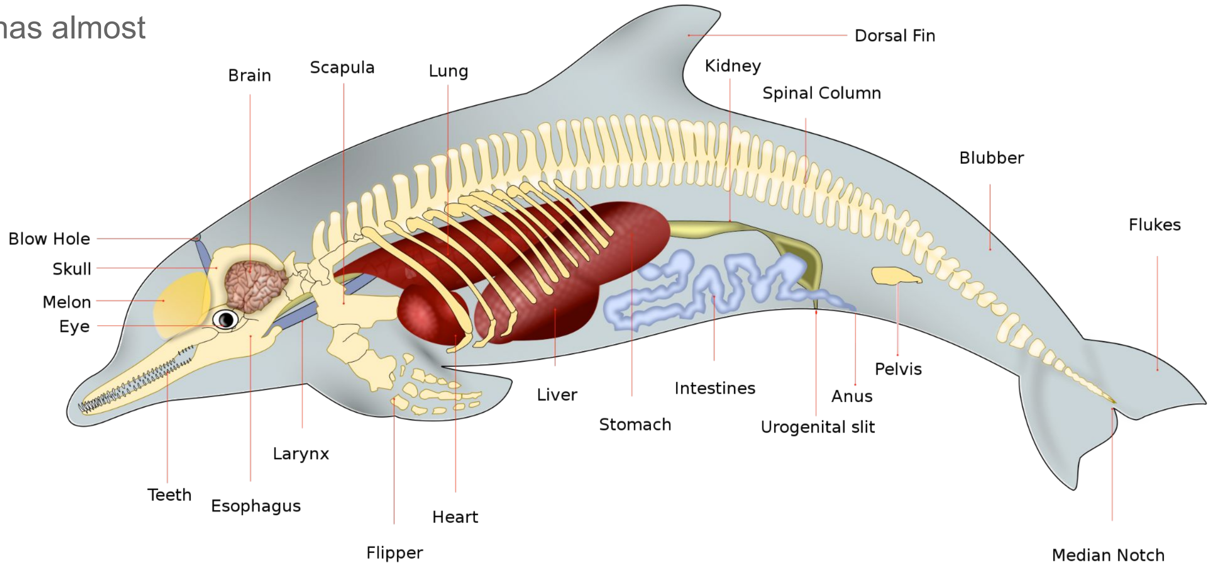
A cetacean fetus is strikingly similar to those of land mammals: they have 4 limbs in early development but the rear appendages disappear before birth, however remain as vestigial pelvis and leg bones in some species. Front appendages develop into pectoral fins with a five-fingered hand bone structure. As a fetus, cetacean nostrils are located on

Top: The spade shaped teeth of a common harbour porpoise. **Image Credit:** A Photo Marine. **Above:** Healthy cone shaped teeth visible in the mouth of a killer whale. **Image Credit:** Otago Daily Times.

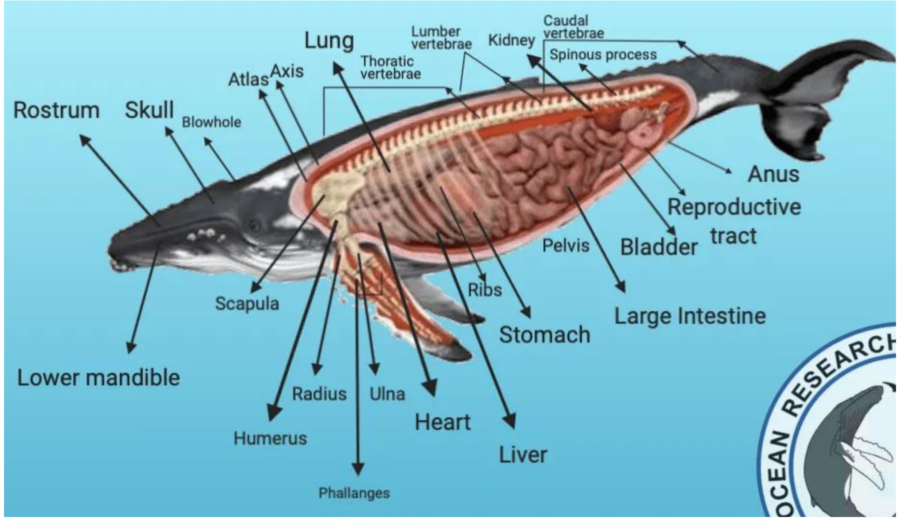
the tip of the snout but migrate to the top of the head before birth, forming either 1 or 2 blowholes with specialised muscles, located so that the animal can effortlessly surface and breathe (Karleskint, 2010).

The blubber prevents loss of body heat: in water body heat is lost at a rate of 50 to 100 times faster than in air and blubber provides insulation for survival in the aquatic environment. Blubber is also an energy reserve and a source of water when metabolised. The thickness of the blubber layer varies from species to species and in individuals as well as one body part to another. The blubber of a bowhead whale (*Balaena mysticetus*) averages 50cm thick, the blubber layer of a sperm whale (*Physeter macrocephalus*) averages about 15cm thick. It also varies in thickness from season to season: whales are thinner after fasting periods, during migration and breeding season. An average bowhead whale has almost 14000kg of blubber, a favourite for whalers. A 1000kg beluga whale (*Delphinapterus leucas*) with its 10cm thick blubber contributes around 360kg of its total body weight in blubber (Karleskint, 2010).

In order to be streamlined, the neck and head is continuous with the rest of the body. The seven cervical vertebrae of cetaceans are very compressed and even fused as a single



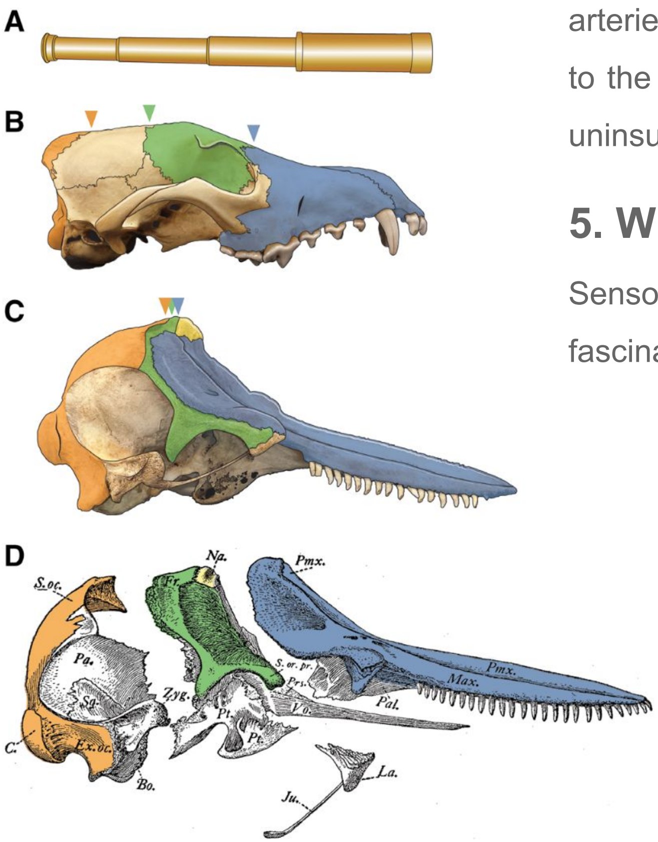
Above: Odontoceti anatomy showing orientation organs and skeletal frame. Image Credit: Wikipedia structure in some species, which limits head movement. Cetaceans have no external pinnae, instead their ears consist of a small opening on the side of the head, leading to an eardrum but the opening is clogged with debris and wax (Karleskint, 2010). Their ear canals are also not attached to the tympanic membrane (or ear drum) (Rhode Island University). The skull of cetaceans includes an unusually long rostrum and telescoped bones (bones almost or completely overlap other bones in the skull). This unusual skull houses a large brain (University of Maryland). The only part of the cetacean body with hair are those found on the head. Their skin is devoid of sebaceous glands, unlike most other mammals, because sweat glands use evaporative cooling, which is not necessary underwater, their absence helps cetaceans to conserve water in their salty environment (Karleskint, 2010).



Above: Internal anatomy showing organs and skeleton of a humpback whale (*Megaptera novaeangliae*). **Image Credit:** Ocean Research and Conservation Ireland (orca Ireland)

The pectoral fins or flippers and dorsal fin (where present) act as stabilisers. Pectoral flippers are used only to move up and down and to twist slightly. The tail consists of 2 flat flukes and are composed of dense connective tissue (Karleskint, 2010). The flukes are the main propulsion organ and regulate vertical movement (Clearwater Marine Aquarium).

To lose heat whales shunt blood to their blubber layer to cool it but the flippers and tail flukes play an important role in retaining body heat (Karleskint, 2010). The flukes lack bone, muscle and cartilage and this tissue is surrounded by arteries and veins that allows cetaceans to regulate blood flow into the appendages (Clearwater Marine Aquarium): arteries carry blood to the flippers, the arteries are surrounded by veins that carry blood back to the heart, this is known as countercurrent flow. The warm blood in the arteries moves to the flipper and transfers heat to the cold venous blood, which is returning to the centre of the body. Heat is returned to the body and the cold blood is carried to the uninsulated flippers and flukes (Karleskint, 2010).



5. Whale Senses

Sensory systems of cetaceans are like those of most mammals however they have other fascinating senses not present in other mammals, but smell in odontocetes is absent.

Left: Telescoping is a metaphor used to describe cetacean skull structure. **(A)**: a collapsible telescope **(B)** A mammal skull (*Canis familiaris*) that conforms to the structure and pattern observed in most mammals. Arrows highlight the distances between the skull bones (sutural boundaries) dividing the maxilla, frontal and interparietal + occipital. **(C)** A dolphin skull (*Tursiops truncatus*) with arrows depicting a shorter distance between the maxilla and occipital on the dorsal surface relative to (B), only a small portion of the frontal is visible externally. **(D)** A disarticulated dolphin skull, with maxilla and premaxilla separated, the full extent of the frontal is revealed: an overlap of the maxilla over the frontal nearly hides the frontal from external view, explaining the shorter distance in (C). Maxilla (blue), premaxilla (blue), frontal (green), interparietal + occipital (orange; fused), nasal (yellow). **Image Credit:** Roston & Roth, 2019

5.1 Hearing

John Hunter's works published in 1787 noted that 'the cetacean ear structure has the same structures as other mammals' ears and include an external opening, a tympanic membrane (ear drum), the eustachian tube, ossicles, cochlea and semicircular canals but no pinna'. The ear canal is a long tube that spirals through the tissues in the head (Mooney et al, 2012). Ear canals of cetaceans are thought to be non-functioning because odontocetes ear canals are narrow and plugged with debris, thick wax and are not attached to the tympanic membrane. The mysticetes narrow ear canal is close by a waxy cap (Smithsonian Ocean). The tympanum (a bony portion of the ear) and the periotic (a single bone that surrounds the inner ear of mammals) are very hard and not as integrated into the skull as other quadrupeds (Mooney et al, 2012). Ongoing debate on how sound is received by mysticetes and transmitted to its cochlea (Kaplan et al, 2016).

Sound is primarily used to acquire information about the cetacean environment and cetaceans have possibly the most sensitive and sophisticated of all mammal ears. Sound travels about 5 times faster in water than it does in air and where visibility is compromised in depth, at night and in murky water, good hearing is important. The hearing sense is required to work in conjunction with other senses, like echolocation (or biosonar) enabling locating prey, detecting predators, identifying conspecifics and navigation, but these senses are affected due to increased noise levels by humans (Mooney et al, 2012).

The lower jaw in odontocetes is surrounded by fats that envelope a very thin, translucent pan bone situated at the back of the lower jaw and is thought to transmit sound to the middle ear (Discovery of Sound in the Sea). The pan bone area is covered in fat called the 'acoustic widow'. When sound enters the odontocete head through this oval fat body it travels through the thinnest part of the mandible to the acoustic fat filled mandibular canal (Mooney et al, 2012).

The middle and inner ears of cetaceans are enclosed in bones located in a cavity outside the skull. In odontocetes, these bones are attached to the skull by ligaments and in mysticetes the middle and inner ear bones are connected to the skull by bones. The exact mechanism used by mysticetes for hearing is still unknown (Rhode Island University) but they do have some of the largest hearing components of all mammals. Odontocetes have a broad hearing range (Mooney et al, 2012).

Above: An earplug displayed at the National Museum of Natural History. The light and dark layers are a build-up of keratin and lipids, which can be used to estimate the age of whales. **Image Credit:** Smithsonian Ocean

The inner ear of cetaceans not only looks but also works much the same way as in terrestrial mammals, the major differences being the number of auditory ganglion cells (nerve cells outside of the CNS); the ratio of number of ganglion cells to the number of hair cells; a much larger auditory nerve; the size of the basilar membrane (the vibrating membrane in the cochlea) and support of the basilar membrane. In addition, odontocetes have more auditory ganglion cells than terrestrial mammals but mysticetes have less auditory nerve cells compared to odontocetes, however more than in terrestrial mammals. Cetaceans are possibly capable of more complex auditory processing (Rhode Island University).

The higher the frequency a cetacean can hear is associated with a thicker and stiffer basilar membrane that extends from the cochlea to the organ of Corti that responds to sound. Odontocetes have additional adaptations that increase the stiffness of the basilar membrane: bony supports in the cochlea that transmit sound waves into nerve impulses. These adaptations allow for an exceptional high hearing range in odontocetes. Mysticetes have very broad, thin, elastic basilar membranes, which contribute to their low frequency hearing range (Rhode Island University).

5.2 Communication

Mysticetes and odontocetes communicate by making sounds like whistles, clicks and 'songs' but also by slapping parts their flukes and fins against the water surface (Sranko). Mysticetes use their larynx and odontocetes use several structures in their head for echolocation in conjunction with their ears (Wikipedia: Whale Vocalization).

5.2.1 Odontocete Communication (Echolocation):

Only bats and toothed whales use echolocation, emitting a series of sounds called clicks, as a primary sense for navigation purposes and foraging on prey under poor lighting conditions and turbid water. Echolocation is considered a sixth sense and also referred to as *biosonar* (Ladegaard, 2017). Odontocetes use echolocation to assess their surrounding environment by listening to the returning echoes, essentially toothed whales see not only with eyes but with sound also. As sounds bounce off objects in their environment, the returning echo provides information on the objects around them, such as size, shape and distance. Echolocation not only locates prey but also aids in detecting predators (Whale Trust). Echoes are modified incoming pulses of the outgoing pulses from which an image of the surroundings is produced in the brain, giving a 3 dimensional picture, direction and location. Location is determined by the delay between outgoing and incoming pulses (Jones, 2005). All species of odontocetes that produce sound and that have been studied, are found to echolocate, however characteristics of their echolocation signals vary greatly (Sayigh, 2013). It seems that individuals can isolate their own echoes during pod feeding without interference from echolocations of their pod members (Wikipedia: Melon).

Sound travels at 340 metres per second in air; 1480m/s in freshwater and 1500m/s in saltwater. The basic components of sound waves are: frequency; wavelength and amplitude. When objects move underwater sound-pressure waves are created, which cause water molecules to compress and decompress as sound waves travel through the ocean. Sound waves radiate like ripples in all directions from the source. Compressions and decompressions due to sound waves are detected as *changes in pressure* by the aural structures (NOAA).

Frequency is the number of pressure waves that pass by a reference point and measured in Hertz (Hz) or cycles per second. To the human ear, an increased frequency is perceived as a higher pitched sound and a decreased frequency as a lower pitched sound. Most humans hear sound waves of frequencies between 20 and 20 000Hz. Sounds below 20Hz are called *infrasonic* and above 20 000Hz are *ultrasonic* (NOAA). Odontocetes use specialised organs to produce various clicks and buzzes between frequencies of 0.2 to 150kHz, they use lower frequencies for distance echolocation and higher frequencies that are more effective for short distances, to reveal detailed information about a target (Wikipedia: Whale Vocalization).

A *wavelength* is the distance between two peaks of a sound wave, the lower the frequency, the longer the wavelength (NOAA).

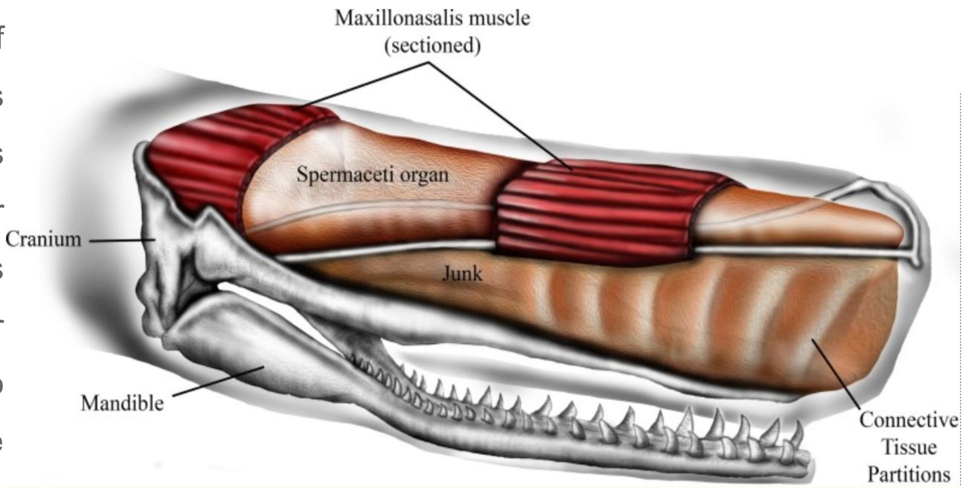
Amplitude is the height of the sound pressure wave (loudness), usually measured on the decibel (dB) scale. Small variations in amplitude (short pressure waves) produce weak or soft sounds, while large variations (tall pressure waves) produce strong or loud sounds (NOAA). Echo amplitudes are lower, the duration may be longer and spectral contents differ slightly from the probe signal depending on the structural features of the echolocation targets (Ladegaard, 2017).

5.2.2 Echolocation Organs in Odontocetes:

The 'melon' is the key organ involved in communication and echolocation (Wikipedia: Melon). The skull and various sinuses also play an important role in a beam of echolocation signals. The nasal complex includes a paired structure called the phonic lips. Produced sound radiates out spherically (not useful for echolocation) but echolocation requires a focussed beam (Witteveen, 2017).

Structurally, the melon is part of the nasal structure, situated between the blowhole and the tip of the snout and comprises a mass of adipose tissue (triglycerides and wax esters) (Wikipedia: Melon). This globular, fatty organ is responsible for the shape of the domed forehead in odontocetes. It is less dense in the centre with the outer layers being more dense, this inhomogeneous density is important for sound refraction. The phonic lips, melon, skull and sinuses are responsible for producing an echolocation beam. Air is pushed through the phonic lips with pressure and produces sound waves, which are reflected by the sinuses into the melon (Witteveen, 2017). The varying composition of the melon creates sound velocity gradients that refract sounds directionally and bounce off the skull and sinuses (Wikipedia: Melon), focussing the beam and reaching the water (Witteveen, 2017). The melon differs in species, some are more specialised than in others, for example the sperm whale (*Physeter macrocephalus*) has the largest nose in the world, the bulk of which is composed of two large, fatty structures, the spermaceti organ (filled with wax esters and triglycerides) and the melon. The melon is *not* homologous to the spermaceti organ (Wikipedia: Melon). Most odontocetes (those documented) use the same mechanism of echolocation for communication (Sayigh, 2013).

Several whistles and pulses have been reported as a means of communication. Scientists say that when dolphins and belugas zero in on their prey they make pulsing or buzzing sounds (sperm whales make a creaking sound) and once they have their fishy 'reward', they squeal with delighted (Lewis, 2014). From as early as 2 months old (others 4 to 6 months) calves develop their own unique whistles that they use most frequently to communicate throughout their lives. These signature whistles are distinctive and may be a form of identification for pod members.



Above: Structural representation of a sperm whale's (*Physeter macrocephalus)* head. **Image Credit:** Panagiotopoulou et al, 2016

Multiple sounds are also produced by passing air through the phonic lips, which act like human vocal cords. As the air passes through the 'nasal' passage, the phonic lip membranes are sucked together, causing surrounding tissue to vibrate (as with the human larynx) and is consciously controlled. These vibrations pass through the melon, shaping and directing the sound like echolocation (Wikipedia: Melon). Rapid auditory temporal processing (perception of sound within a restricted time) facilitates echolocation and sound location and while echolocating some species are known to be able to adjust hearing as well as process the returning echoes and vocalise, all at the same time (Kremers et al, 2016).

All odontocetes, besides the sperm whale, have two sets of phonic lips, enabling them to make 2 sounds independently (Wikipedia: Melon). Most delphinids communicate by whistling, while others use pulses, like the commerson's dolphin (*Cephalorhynchus* *commersonii)*. It is thought that some delphinid and other odontocete species, like Phocoenidae (porpoises), the pygmy sperm whale (*Kogia breviceps)* and the genus of *Pontoporia*, produce pulse sounds only due to orca predation risk and so it is hypothesised that species with high orca predation risk favour vocalisations that orcas hear poorly or not at all, below 2 and above 100kHz. On the other hand, transient orcas (feed on marine mammals) adapt vocal behaviour according to the prey being hunted: orcas hunting on marine mammals (that have sensitive hearing), vocalise less and reduce vocal activity before and during hunting compared to when feeding on fish, that have poor hearing ability (Kremers et al, 2016).

5.2.3 Mysticete Sounds:

Whales are social animals that recognise each other, coordinate activities and stay connected over long distances. In order to do this they have a complex communication system (Smithsonian). There is no confirmation around the precise manner in which mysticetes produce sound and what the different sounds or calls mean, as observations are hindered due to the spatial scale between senders and receivers (Sayigh, 2013).

Between the blowhole and the lungs is the larynx, which includes a membrane called the U-fold, directly connected to an expandable sac (laryngeal sac) within the whale's chest (ventral to the larynx) and sometimes found in pairs (DOSITS: How do marine mammals produce sounds? and Smithsonian). When the whale produces sound the muscles in the throat and chest are contracted so that air flows from the lungs, through the U-fold and fills the laryngeal sac. By alternating expansion and contraction, the lungs and air sac pushes air across the U-fold, which vibrates and produces sound. The vibrations from the laryngeal sac cause sound waves to travel through the ventral throat pleats into the surrounding water and changes in the shape of the laryngeal sac in turn changing frequency and amplitude of sounds. Unlike toothed whales, they do not have phonic lips (DOSITS: How do marine mammals produce sounds?). Sounds produced by mysticetes are loud enough to travel thousands of kilometers (Smithsonian).

While mysticetes have a larynx they do not have vocal cords like humans so their sound production is not analogous with human sound production as they do not have to exhale in order to produce sound (Wikipedia: Whale Vocalization). After a respiratory cycle, a portion of inhaled air remains in the nasal passage and thought to move back and forth in the respiratory cavity, it is recycled, allowing sound production to continue (Whales Online: Do whales use vocal cords to produce sound?).

The balaenopteridae family are sleek whales that includes the humpback whale, the only chunkier, large flippered species in this family and also the most researched for its 'songs' and sounds. Humpbacks have the most intricate 'songs' of all whales with sounds produced at frequencies within human hearing range. Along with this, humpback whales breed in areas accessible to researchers (Sayigh, 2013). Early research on humpback sounds focused on song structure, which consists of units combined to form phrases and themes, repetitive songs that can last up to 30 minutes. Focus then turned to deciphering the function of the sounds by observing behaviour, however there is still no consensus and still largely not understood other than being breeding calls (Sayigh, 2013).

Humpback sounds consist of moans, grunts, blasts and shrieks at high and low frequency sound waves, which travel very far without losing energy through the water (Journey North: Humpback Whales). Humpback males in the same area sing the same song and small changes take place over time, a song can take up to 15 years to completely change. Humpback social sounds are not structured but vary in frequency sweeps with temporal characteristics. Blue and fin whales produce sounds low enough in frequency to be heard across ocean basins, assisted by frequency sweeps and repetition at 20Hz or lower. Estimates that basin calls can reach up to 90km, sometimes for hours at a time (Sayigh, 2013).

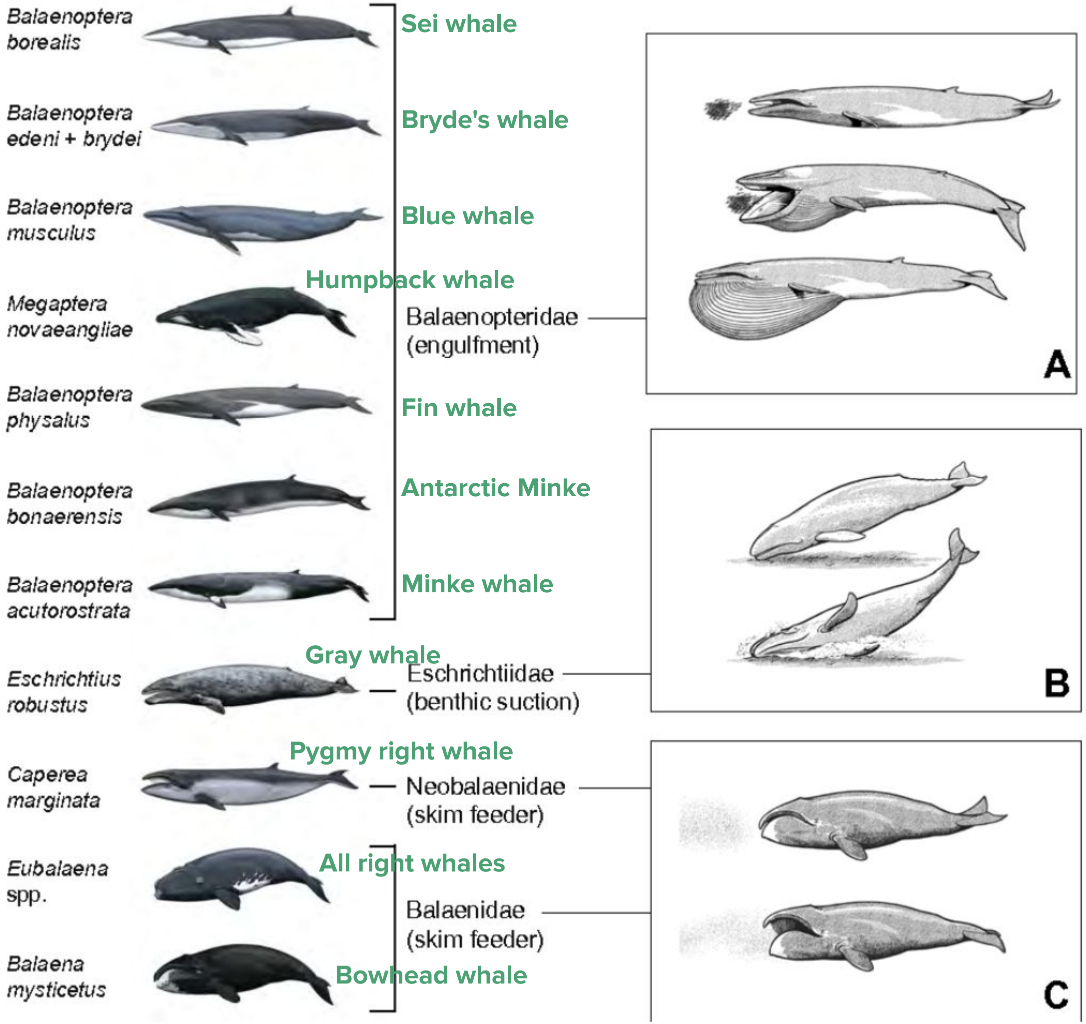
Fin whale calls are associated with feeding or agonistic interactions. The blue whale song is more complex with more than one call type that is about a minute long, remaining stable for years; feeding calls have also been recorded. Minke whales produce simpler bouts of repetitive calls. During interaction with predators, minke whales produce a 'boing' sound that has been called 'Star Wars' due to its synthetic sound. Little communication has been observed in Brydes and sei whales except between mother and child when separated, as with several other species, and once reunited the communication stops. Adults have been recorded producing frequency modulated, tonal moans and pulses but the purpose of these is unknown (Sayigh, 2013).

Bowhead songs change radically, often with no resemblance to the previous song. Right whales do not 'sing', vocalisation is purely for contact purposes using frequency upsweeps (upcalls) but stops once together. A tagging exercise revealed that balaenidae, of all ages and sexes, produce upcalls and a variety of tonal calls, with rates affected by behaviour: lower calls during foraging, traveling or logging (hanging upside down so the fluke is exposed) and higher calls at the surface. Male southern right and northern Atlantic right whales produce broadband and gunshot sounds, possibly to attract females (Sayigh, 2013).

The eschrichtiidae family (gray whales) also produce sounds but the purpose is unknown, however recordings reveal a centre frequency under 200Hz, in repetitive patterns followed by long periods of silence between calls. There is also very limited information about sounds of the neobalaenidae family (pygmy right whales, the smallest of all whales). One juvenile was recorded producing one type of sound: a short thump-like pulse or tone with a downsweep in frequency (between 60 and 120Hz) in pairs (Sayigh, 2013).

Non-vocal communication in mysticetes includes body language that conveys different emotions, sounds produced using flukes or flippers, or pec slapping on the water surface, jaw clapping or blowing bubbles.

Tail slapping indicates distress or ward off predation. Slapping of flippers, usually by females in winter breeding season, is a flirtatious behaviour, sometimes they roll on their backs and use both fins to slap the water while releasing a scent, which combined attracts males. Pec slaps are also used to teach calves and to hit each other (Whale Watch Western Australia, 2016).



Right: Extant mysticetes showing their filter-feeding mode (A to C - far right). **Image Credit:** Gatesy et al, 2013

Breaching is typical cetacean behaviour in which they leap out of the water into the air, producing a sound that may travel several kilometres. Breaching is not fully understood but is thought to be a spacing mechanism, keeping contact or to inform about sexual status, food location or response to an injury, perhaps even to remove parasites and dead skin. Breaching requires more research attention (Camps, 2018).

6. Conclusion

Ocean noise pollution is of growing concern particularly on cetaceans as they are highly dependent on sound - their principal sense - and since noise travels so rapidly in water, noise pollution has the potential to also impact water for thousands of kilometres. All kinds of animals transfer information efficiently using sound by producing and perceiving periodic pressure fluctuations, however there are growing concerns around the effects that anthropogenic ocean noises and what this continuous increase in noise has on marine mammals' hearing. The main producers of anthropogenic noise are explosions, shipping, seismic exploration (for oil and gas industries) and naval sonar operations. These have been linked to strandings and mortalities, especially of beaked whales (family Ziphiidae). It is still not known what the mechanism is behind these mortalities, but highly likely related to gas and fat emboli mediated by behavioral response, like a change in diving patterns (Weilgart, 2007).

Almost all studies on cetacean acoustic communication focus on sound pressure measurements but the particle motion components of their communication signals are overlooked. This less explored pathway may help to understand whale acoustic communication and the the biological role of acoustic particle motion (particles next to a vibrating source are moved backwards and forwards, these particles then move the particles next to them and so on) (Kaplan et al, 2016).

Results from a study suggest that ambient noise levels possibly have an effect on a whale's ability to isolate a source with particle motion due to masking. Their data suggests that particle motion of anthropogenic noise, increasingly produced mostly at low frequencies, should be considered as a mask to hearing and communication and potentially cause stress, behavioural responses or auditory impacts (Kaplan et al 2016).

Noise has been a substantial concern to conservation and management of endangered sea mammal species. Knowing that particle motion is an available acoustic communication pathway offers an opportunity to research and understand the signal's biological function, transmission distances and its impact on whales (Kaplan et al 2016).

Bibliography:

A Photo Marine, Harbour or Common Porpoise, (online: https://www.aphotomarine.com/mammal_phocoena_phocoena_harbour_porpoise.html)

Aragones LV, Laule GE, Alesna EB, Encomienda RP, Flores MB, Follosco NG, Laule GE, Ledesma MC, Maniago FE, Phillips WF, Roque MAA, Torno CS, Torres AT, (2008), Marine mammal stranding response manual, Researchgate (online: https://www.researchgate.net/publication/262911989_Aragones_LV_and_G_E_Laule_Eds_2008_Marine_mammal_stranding_response_manual_A_manual_on_the_rescue_rehabilitation_and_release_of_stranded_cetaceans_and_dugongs_in_the_Philippines_A_Wildlife_In_Need_and)

Biology Online, (2021), Mammal, (online: https://www.biologyonline.com/dictionary/mammal)
Biology Online, (2021), Theria, (online: https://www.biologyonline.com/dictionary/theria)

Britannica, List of Cetaceans, (online: https://www.britannica.com/topic/list-of-cetaceans-2057165)

Camps MA, (2018), How do cetaceans communicate?, (online: https://allyouneedisbiology.wordpress.com/2018/03/18/cetaceans-communication/)

Clearwater Marine Aquarium, (2019), What is a dolphin's dorsal fin used for? (online: https://mission.cmaquarium.org/news/what-dolphin-dorsal-fin/)

Conlin TL, The Humpback Song, Journey North (online: https://journeynorth.org/tm/hwhale/SingingHumpback.html)

Discovery of Sound in the Sea, Hearing in Cetaceans and Sirenians, the Fully Aquatic Ear, (online: https://dosits.org/animals/sound-reception/marine-mammals-hear/hearing-in-cetaceans/)
Discovery of Sound in the Sea, How do marine mammals produce sounds? (online: https://dosits.org/animals/sound-production/how-do-marine-mammals-produce-sounds/)

Encyclopedia.com, Right and Bowhead Whales (online: https://www.encyclopedia.com/environment/encyclopedias-almanacs-transcripts-and-maps/right-whales-and-bowhead-whales-balaenidae)

Environmental Protection Agency, Nutrient Pollution, (online: https://www.epa.gov/nutrientpollution/issue)

Gatesy J, Geisler J, Chang J, Buell C, Berta A, Meredith R, Springer M, McGowen M, (2013), A phylogenetic blueprint for a modern whale, Semantic Scholar (online: https://www.semanticscholar.org/paper/A-phylogenetic-blueprint-for-a-modern-whale.-Gatesy-Geisler/d75ca102da15495d2649d346e05787d8a0348841)

Holland JS, (2017), The Oral History of Toothless Whales, Hakai Magazine (online: https://hakaimagazine.com/features/oral-history-toothless-whales/)

IFAW, (2021), FAQ about whales (online: https://www.ifaw.org/uk/journal/faq-about-whales)

Jones G, (2005), Echolocation, Current Biology Magazine, Current Biology Vol 15 No 13, (online: https://www.cell.com/current-biology/pdf/S0960-9822(05)00686-X.pdf)

Kaplan MV, Lammers MO, Mooney TA, (2016), How sound is received within a mysticete's head and transmitted to its cochlea has been a subject of historical debate (online: https://royalsocietypublishing.org/doi/full/10.1098/rsbl.2016.0381)

Karleskint G Jr, Turner R, Small JW, (2010), Introduction to Marine Biology, Brookes/Cole, CA, USA

Bibliography continued:

Kremers D, Célérier A, Schaal B, Campagna S, Trabalon M, Böye M, Hausberger M, Lemasson A, (2016), Sensory Perception in Cetaceans: Part I—Current Knowledge about Dolphin Senses as a Representative Species, Frontiers in in Ecology and Evolution (online: https://www.frontiersin.org/articles/10.3389/fevo.2016.00049/full)

Ladegaard M, (2017), Echolocation in small cetaceans, Researchgate (online: https://www.researchgate.net/publication/318921778_Echolocation_in_small_cetaceans_PhD_dissertation)

Lewis T, (2014), Whee! Whales and Dolphins Squeal with Delight, (online: https://www.livescience.com/47345-dolphins-squeal-with-delight.html)

Libretext, (2021), Marsupials, (online: https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_(CK-12)/12%3A_Vertebrates/12.30%3A_Marsupials)
Libretext, (2021), Placental Mammals (online: https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_(CK-12)/12%3A_Vertebrates/12.02%3A_Placental_Mammals)

Lucas S, What is Baleen? Sanibel Sea School, (online: https://www.sanibelseaschool.org/experience-blog/2020/7/7/what-is-baleen)

Marine Life, (2019), Structure and Adaptations to Marine LIfe, (online: https://www.marinebio.org/conservation/marine-ecology/structures-adaptations/)

Mooney TA, Yamato M, Branstetter BK, (2012), Hearing in Cetaceans: From Natural History to Experimental Biology, PubMed.gov (online: https://pubmed.ncbi.nlm.nih.gov/22877613/)

National Oceanic and Atmospheric Administration, (2019), Marine Mammals, NOAA (online: https://www.noaa.gov/education/resource-collections/marine-life/marine-mammals)
National Oceanic and Atmospheric Administration, Understanding Ocean Acoustics, (online: https://oceanexplorer.noaa.gov/explorations/sound01/background/acoustics/acoustics.html)

National Parks Service, (2020), #sciencedeskdeiga: Baleen, (onlinehttps://www.nps.gov/articles/deskdigs_brandt.htm)

Ocean Conservation Research, Odontocetes & Mysticetes (online: https://ocr.org/sounds/intro-to-odontocetes-mysticetes/)

Orca Ireland, Humpback whale internal anatomy, (online: https://www.orcaireland.org/how-humpback-whales-survive-in-the-marine-environment-part-ii)

Otago Daily Times, (2017), Kiwi scientists alarmed at orcas' teeth, (online: https://www.odt.co.nz/news/national/kiwi-scientists-alarmed-orcas-teeth)

Panagiotopoulou O, Spyridis P, Abraha HM, Carrier DR, Pataky TC, (2016), Architecture of the sperm whale forehead facilitates ramming combat, NCBI (online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4824896/)

Parsons ECM, Bauer A, Simmonds MP, Wright AJ, McCafferty D, (2013), An Introduction to Marine Mammal Biology and Conservation, Jones & Bartlett Learning, massachusetts, USA

Bibliography continued:

Rhode Island University, Hearing in Cetaceans and Sirenians, the Fully Aquatic Ear (online: https://dosits.org/animals/sound-reception/marine-mammals-hear/hearing-in-cetaceans/)

Roston RA, Roth VL, (2019),Cetacean Skull Telescoping Brings Evolution of Cranial Sutures into Focus, Duke University, NC (online: https://anatomypubs.onlinelibrary.wiley.com/doi/pdf/10.1002/ar.24079)

Sayigh LS, (2013), Chapter 6: Cetacean Acoustic Communication, Researchgate (online: https://www.researchgate.net/publication/285211065_Cetacean_Acoustic_Communication)

Sea Grant Alaska, Marine Mammal Adaptations, (online: https://seagrant.uaf.edu/marine-ed/mm/fieldguide/adaptations.html)

Sea World, More about baleen whales, (online: https://seaworld.org/animals/all-about/baleen-whales/classification/)

Smithsonian, Whales: Cetacea, (online: https://ocean.si.edu/ocean-life/marine-mammals/whales)

Sranko G, How Do Whales Communicate and Make Sounds Under Water?, BioGeo Planet (online: https://biogeoplanet.com/whale-communication/)

University of Alaska, Whales, Dolphins, and Porpoises: Cetaceans, (online: https://seagrant.uaf.edu/marine-ed/mm/fieldguide/cetaceans.html)

University of Maryland, Order Cetacea (online: https://science.umd.edu/classroom/bsci338m/Lectures/Whales.html)

Weilgart LS, (2007), The impacts of anthropogenic ocean noise on cetaceans and implications for management (online: https://cdnsciencepub.com/doi/10.1139/Z07-101)

Whale and Dolphin Conservation (WDC), What is Baleen?, (online https://uk.whales.org/whales-dolphins/what-is-baleen/)

Whales Online, Do whales use vocal cords to produce sound? (online: https://baleinesendirect.org/en/do-whales-use-vocal-cords-to-produce-sound/)

Whale Trust, (2016), What are Cetaceans?, (online https://whaletrust.org/what-are-cetaceans/)

Whale Watch Western Australia, (2016), Pectoral Slapping (online: https://whalewatchwesternaustralia.com/single-post/2016/08/26/pectoral-slapping/)

Wikipedia, Mammal, (online: https://en.wikipedia.org/wiki/Mammal)
Wikipedia, Melon (cetacean), (online: https://en.wikipedia.org/wiki/Melon_(cetacean))
Wikipedia, Dolphin, (online: https://en.wikipedia.org/wiki/Dolphin)
Wikipedia, Whale Vocalization, (online: https://en.wikipedia.org/wiki/Whale_vocalization)

Witteveen M, (2017), Melon, but not the one you're thinking of, (online: https://oceanadventures.co.za/melon-not-kind-youre-thinking/)