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Tracking whales underwater

Tags not only tell us where a species travels in horizontal space; sometimes they tell us about movements in vertical space. Suction cup tags are short-term tags with no satellite capability, which are deployed on a whale to gain an understanding of its underwater movement patterns. These tags have a timed release or burn wire that releases the tag from the whale's body after a predetermined amount of time, after which it floats to the surface. Once at the surface, this tag must be located, often using VHF, and collected so that the data can be downloaded. Data can relate to how deep the whale went and for how long, how fast it moved over specific segments, whether it turned left or right, the temperature zones it passed through on its journey, and where exactly it lunged for a mouthful of its favorite prey. The data are pieced together to get a sense of a "day in the life" of the tagged whale. These tags have provided fascinating insights, from how deep the deepest diving whale is known to go—a tagged Cuvier's Beaked Whale (*Ziphius cavirostris*) dove to 9,816 ft (2,992 m) over 3 hours and 42 minutes in a single breath!—to the gentle pirouetting that Blue Whales do when they find a patch of food.



WHALE OBSERVATION

Satellite tags enable scientists to observe whales' migratory habits as well as identify parts of the ocean where they may be vulnerable to many anthropogenic threats.

REVEALING THE SECRETS OF BODY PARTS AND BYPRODUCTS

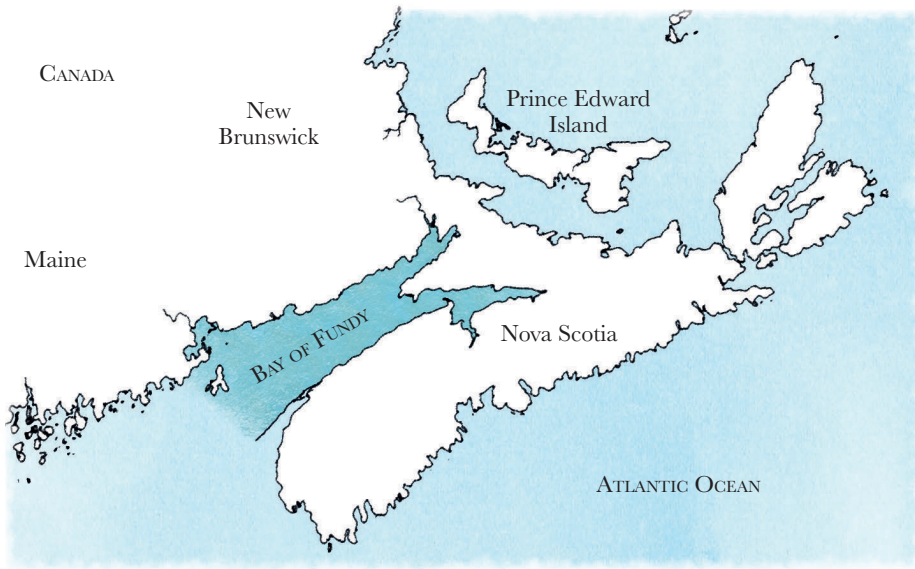
Historically, if boats approached whales, it was bad news. Today, a boat approaching may be carrying scientists seeking to help protect the whales by undertaking research.

Secrets of blubber

Such research may involve attaching a tag or collection of a biopsy sample. For the latter, scientists use specially designed crossbows or pneumatic rifles to shoot small darts at the dorsal flank, right behind the dorsal fin of a whale. The hollow dart then bounces off the whale, holding a small plug of skin and blubber the size of a pencil eraser; these float on the surface until picked up for analysis. This tiny piece of blubber can reveal much about the life of the whale it was collected from. It can be used to identify the species and holds a wealth of genetic information that tells us about the population structure, including the individual's sex and relatedness to others. Hormones in the blubber tell us about the whale's sexual maturity, reproductive cycles, stress levels, and whether or not an animal is pregnant. We can also learn about the diet of the whales and even whether they have ingested chemicals, including persistent organic pollutants (POPs). While biopsies are a good way to collect blubber samples, blubber can also be reliably collected during necropsies and used for hormone analysis postmortem. Importantly, scientists are cautious when taking biopsy samples and do not approach when very young calves are present or if an animal looks visibly distressed.

Dandruff and feces

Whales often dive to the depths to feed, and when they emerge at the surface for a breath of air, they sometimes simultaneously leave behind gifts for the keen observer. Sloughed skin and feces might seem like things to overlook and ignore, but whale dandruff is far more important than that of humans and can



THE BAY OF FUNDY

Whales' stress levels correlate with noise levels in the ocean, as revealed through North Atlantic Right Whale feces collected in the Bay of Fundy.

be used to determine the sex of individuals; whale feces, or poop, reveals secrets about the elusive lives of these beasts. Fundamentally, feces is digested prey matter. By extracting the DNA of the prey that has been consumed and excreted, it is possible to identify what makes up the diet of these whales. It has limitations in that you cannot quantify what has been consumed, but it can provide a sense of the general diet. While Blue Whales across the world are known to feast on krill in vast quantities, in Sri Lankan waters, an analysis of their feces and DNA metabarcoding revealed that these tropical whales predominantly feast on a type of shrimp. Given that this shrimp is more prevalent than krill around Sri Lanka, this makes sense. But it also reminds us not to take everything for granted in a species that, while very large and obvious at the ocean surface, is often unseen and lurks quietly in our global oceans.

Fecal matter is also important for understanding stress in whales, particularly that linked to “invisible” threats like underwater noise. In an elegant study conducted by scientists at the New England Aquarium, North Atlantic Right



DRONE “SNOT BOT”

Drones can be used to collect exhaled air from a whale to help in the study of stress and whale microbiomes.

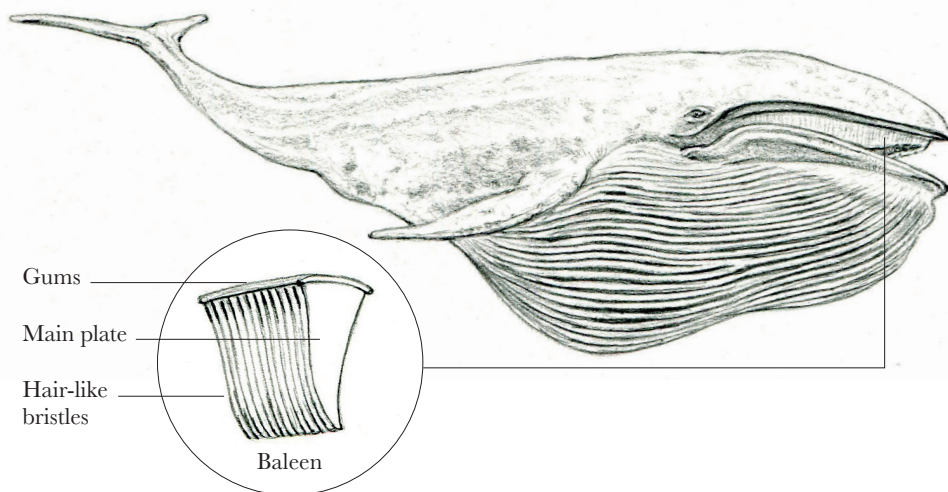
Whale (*Eubalaena glacialis*) fecal samples collected before, soon after, and significantly after the 9/11 terrorist attacks were analyzed for stress hormones. Researchers made a surprising discovery. Ironically, while humans were much more on edge and stressed immediately after the attacks, whales became more relaxed, with decreased baseline levels of stress-related fecal hormone metabolites. This was because the shutdown of shipping in the Bay of Fundy immediately post 9/11 reduced noise levels in the ocean significantly. This reduction in shipping translated into quieter oceans for whales, resulting in reduced stress levels. No sooner had shipping recommenced than their stress levels increased once again. This study encapsulates the power of feces in understanding the private lives of whales—in this case, endangered North Atlantic Right Whales. Stress can also be measured using other tools. The famed “snot bot,” a modified drone that can collect “snot,” “blow,” or exhaled air from a whale’s blowhole—with the aid of a skilled pilot and a petri dish—has opened doors to the study of stress and the analysis of DNA and microbiomes.

Stomach contents

While much messier, stomach analyses can also give us insight into a whale's diet. When a dead whale strands, experts with the right equipment spend hours or even days performing necropsies on the deteriorating carcass. In a race against time, scientists will prioritize identifying the cause of death, but once that has been done, they will use the carcass to reconstruct the life of the whale. Analysis of stomach contents is a common way to investigate the diet of almost any species. However, accessing the stomach of a whale is not quite the same as accessing the stomach of a fish, and once accessed, storing the insides is no mean feat. However, a thorough analysis of what lies within can often provide insights into whales' preferred food and even the parasites they carry.

Baleen

Baleen is another keeper of endocrine secrets. Growing from front to back, where shedding occurs over time, baleen represents a distinct stretch of the whale's life. This structure, made of keratin, much like our hair and nails, is



BALEEN

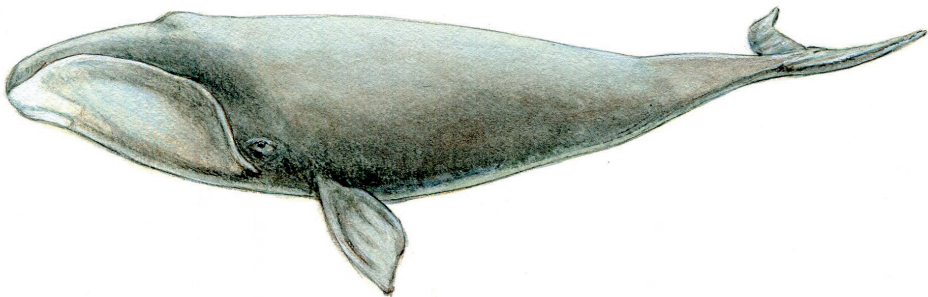
Made from keratin, this filter-feeding system allows scientists to unlock the hormonal histories of individual whales.

more than just a filter-feeding apparatus, as it incorporates hormones as it grows. Each plate is, therefore, a multi-year record of detailed endocrine-related information waiting to be interpreted. Scientists use these plates to study testosterone patterns of male whales in order to understand more about reproductive seasonality, the breeding season, and the individual's life history.

Items left behind

Despite their stressful lives, many whale species have long lives. Blue Whales and Humpback Whales (*Megaptera novaeangliae*) are thought to live for 80–90 years, while Orcas live for 30–46 years, depending on their sex. But the clear winner for the longest lifespan is the Bowhead Whale (*Balaena mysticetus*), which is thought to live for well over a century. This discovery was made in 2007 when Indigenous hunters on Utqiagvik (known to some as Barrow Island), Alaska, hunted (under permit) a Bowhead Whale and found a “bomb lance” inside it. This harpoon, infused with gunpowder that explodes on contact—used to hunt whales in the Arctic in the past—had lodged itself in the blubber of the whale, which had escaped only to be caught once again over a century later.

Fortunately, finding stone harpoon heads lodged in carcasses is not the only way to age whales. Aging of whales can be done using the eye lens protein racemization method. Essentially, the lens of a whale's eye contains crystalline



BOWHEAD WHALE

The protein in the eye lens of a whale can provide the key to unlocking its age.

proteins that are formed before or shortly after birth, and which remain the same throughout the animal's life. The proteins undergo a process known as amino acid racemization, whereby the tiny building blocks of proteins (called amino acids) gradually convert from the L-form (used by living organisms to build proteins) to the D-form (a mirror image of the L-form not used in protein building). In the whale's eye lens, the conversion of the amino acid aspartic acid happens at a slow and predictable pace, so when scientists measure how much of the L-form has turned in to the D-form, they can estimate how long the process has been happening and estimate the whale's age. This technique was used to verify the age of the Bowhead Whale that was hunted in 2007.

Whales' ear wax or ear plugs also offer an opportunity for aging, with alternate light and dark bands representing summer binges and winter migrations. Counting these bands is an alternative means of aging whales.

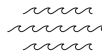
WHALE SONG

Finally, but no less important, is how we have learned about the sounds whales make. Whales have learned to use sound in powerful ways to communicate over vast distances. But human and whale hearing ranges do not overlap for the most part, so we cannot always detect their sounds without the assistance of hydrophones (underwater microphones). These allow us to eavesdrop and record their chatter, and then speed up those sounds to a point where we can hear even those that communicate at the lowest frequencies, like Blue Whales. In some cases, scientists drop recording equipment to the bottom of the ocean for months to capture the comings and goings of all marine mammal species in the area. Ultimately, they are faced with vast quantities of data—recordings of whale songs and ocean noise—not all of which interest them. Listening to it all and picking out the “whale-like” sounds can take a hours, days, months, or more, depending on the size of the dataset; so to speed things up, researchers sometimes extract a

sample and program detectors to trawl through and identify other similar calls automatically. AI is now used to analyze even larger datasets in order to find and unravel more about the language of the whales. Work by Project CETI (Cetacean Translation Initiative) claims to have uncovered a “sperm whale phonetic alphabet,” but there is much speculation about what that means. One thing is certain: We still have a way to go before we can converse with these animals.

* * *

A combination of human ingenuity and technology has allowed us to explore the lives of whales. The understanding we have gained has given us insight into parts of their lives that would otherwise go unseen. While there is beauty in not knowing everything, a basic understanding of other creatures who share our planet allows us to grow in empathy for their needs and provides us with the knowledge necessary to protect them and the habitats within which they live.



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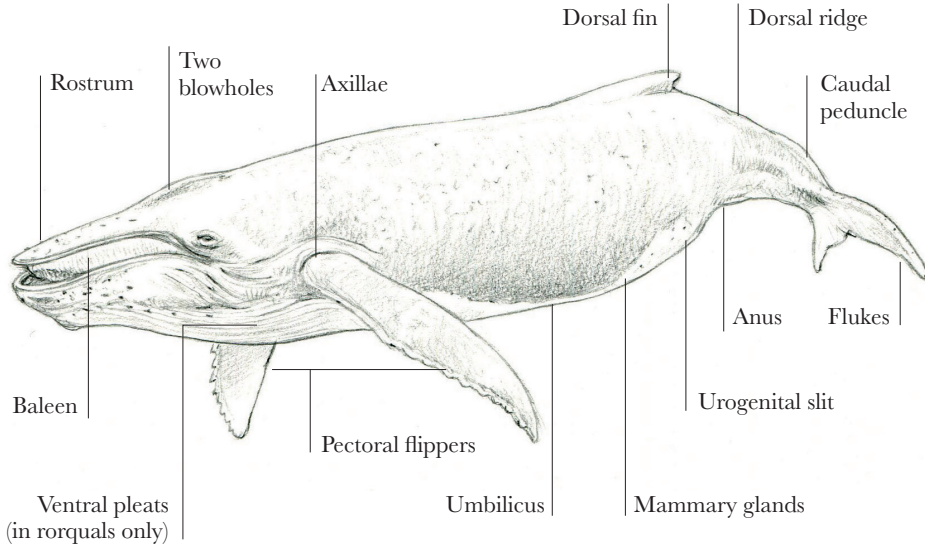
WHAT MAKES
A WHALE
A WHALE?

WHALE DESIGN

Good design is beautiful, efficient, and, most importantly, functional. Well-designed animals are generally more likely to survive and thrive in their environment: Camouflage helps animals avoid predators, vibrant plumage helps them find mates, thicker fur enables them to live in colder climates, and specialized feeding mechanisms enable them to exploit and thrive in different ecological niches. This is where the study of anatomy becomes important. Anatomy is essentially the parts, both internal and external, of an animal's body. Studying anatomy is particularly useful in species like whales that spend most of their lives underwater and out of view. Their anatomy provides clues that allow us to hypothesize about their lives, even the parts we do not see.

For a start, whales generally have streamlined bodies that are propelled by their tail flukes, which are attached to the body by the peduncle. We will discuss these various body parts in more detail shortly but the need for a streamlined body is particularly pertinent as whales spend the majority of their lives moving through water, a medium that is 800 times denser and 55 times more viscous than air, resulting in water having a higher resistance to flow and being more difficult to maneuver through. Despite their large size, being streamlined—and thus well-designed—means that whales can move through the ocean efficiently, expending minimal energy as they do so. This is a crucial factor, particularly for species that travel vast distances during their migrations. The reduced costs of locomotion are important as some whales, such as Humpback Whales (*Megaptera novaeangliae*), embark on migratory journeys during which they do not feed for months.

That said, not all whales are created equal. While some, like Fin Whales (*Balaenoptera physalus*), are long and slender and can reach high speeds, others, like Humpbacks and Right Whales (*Eubalaena glacialis*, *E. japonica*, *E. australis*), are rounder and slower-moving. The speeds at which they travel are likely driven by the food they choose to eat. If you have food that can zip out of the way instantly, your need for speed is higher.



BASIC WHALE ANATOMY

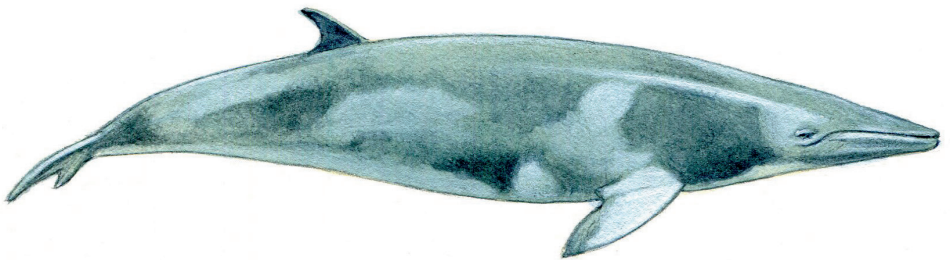
All whales have flippers, flukes, and either teeth or baleen.

WHALE GIGANTISM

Baleen whales are the undisputed champions of being large. As it turns out, whale gigantism is closely tied to two things. The first is lunge feeding, a feeding technique that initially came into being 7–10 MYA and was perfected by the rorquals; it was favored by those with larger mouths (and therefore larger bodies) rather than those with smaller mouths, and lunge feeding is a defining feature of rorquals. The second was the parallel increase, about 5 MYA, of ocean upwelling, where water is rich in nutrients thanks to organisms decomposing, leading to nitrogen and phosphorous release driving increases in phytoplankton blooms. This resulted in an increase in productivity across the board—including an increase in prey availability. The combination of these two phe-

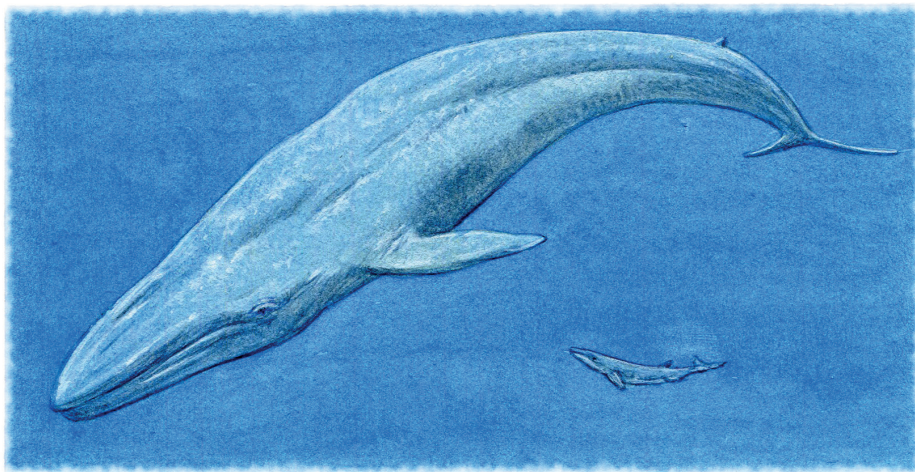
nomena—a new and appropriate feeding strategy and the availability of ample prey—led to the rather recent evolution of Earth’s largest animals.

Within this overall increase in rorqual size, one species, the Blue Whale (*Balaenoptera musculus*), stands out as the largest by far. While Blue Whales are only about 20 ft (6 m) longer than their cousins the Fin Whales, they weigh about twice as much (with females being about 5 percent larger than males, perhaps due to increased blubber content that provides energy necessary to nurture their calves). In a world filled with competitors, Blue Whales are picky eaters and became fiercely specialized at hunting and feeding on one thing and one thing alone: krill. Krill are a swarming species of marine crustacean that are superabundant but patchy, found in upwelling areas and polar seas. Blue Whales’ dependence on this specific prey has resulted in a large-bodied animal with the ability to travel efficiently through water and maintain large energy reserves for times when their favorite food is less abundant. Their need to travel vast distances between prey patches and access food prioritized a need for speed, trumping a need for extreme maneuverability, resulting in them growing bigger and developing a larger mouth that can take in more krill with each bite (lunge). Maintaining this size requires more food, which in turn requires a larger body and mouth to access, and so on, leading to Blue Whales becoming the largest whales on Earth. Weaned Minke Whales (*Balaenoptera acutorostrata*, *B. bonaerensis*), at a mere 15 ft (4.5 m) in length, are the absolute minimum size that a rorqual can be while still eating enough food to survive.



A MINKE WHALE

Minke Whales are small and elusive. They can be difficult to track, even for researchers.



BLUE WHALES

*These giants of the ocean evolved from ancestors such as the extinct *Maiabalaena nesbittae*.*

To exemplify just how large Blue Whales are, let me tell you a quick story. I was once out on a boat in Monterey Bay, California, watching a large pod of dolphins pass by. Soon, a number of Humpback Whales appeared and began to put on an incredible display of lunge feeding. If you have never seen a whale lunge feed, I would recommend it as one of the most awe-inspiring sights ever. The tourists onboard were awed by the whales' size, particularly in relation to the dolphins that had just whizzed by. After a while, the Humpbacks dived and vanished from view. A few moments of quiet and then "Whoosh!!"—the powerful blow of what could only be a Blue Whale grabbed the attention of everyone on board. People could not believe it as I told them it was a Blue Whale. It was my first Pacific blue sighting and I was as ecstatic as everyone else. Moments later, a Humpback Whale popped back up to the surface, in front of the Blue Whale. Someone exclaimed "Oh! The dolphins are back!" The immense size of the Blue Whale dwarfed the Humpback sufficiently to make people believe it was just a dolphin!

Returning to the topic of feeding, I should point out that in Sri Lankan waters, Pygmy Blue Whales (*Balaenoptera musculus indica*)—the Blue Whale subspecies that lives in the northern Indian Ocean—do not specialize in eating krill but sergestid

shrimp. This is simply because the sergestid shrimp is the dominant swarming species in these waters. While we know little about their feeding behaviors in this part of the world, research indicates that these whales are feeding deeper in the water column than any other Blue Whale population, and this could be because sergestid shrimp are found deeper than krill. This serves to remind us that no two whales are the same, and we cannot take it for granted that whales of the same species living in different ocean basins will act the same way.

It is clear that being big has its advantages, including being able to avoid predation by being too quick to hunt down or simply too large to attack, traveling effortlessly and with energetic efficiency between prey patches, using less energy to keep warm, building fat stores quickly, and being able to go long periods without feeding. But there are disadvantages to weighing so much. While the issue of a heavier skeleton is circumvented through having mostly light and spongy bones, this species is still bulky (a Blue Whale's heart weighs about 400 lb, or 180 kg, and is around 5 ft tall). In the ocean there is plenty of space and food, and the weight of the whale's body is supported by seawater, unlike on land, where animals have to support their own weight against the force of gravity, making it impossible to achieve such enormity. Blue Whales are, in fact, neutrally buoyant: Their density matches their surroundings, so they float.

LOCOMOTION AND MANEUVERABILITY

Flukes and flippers

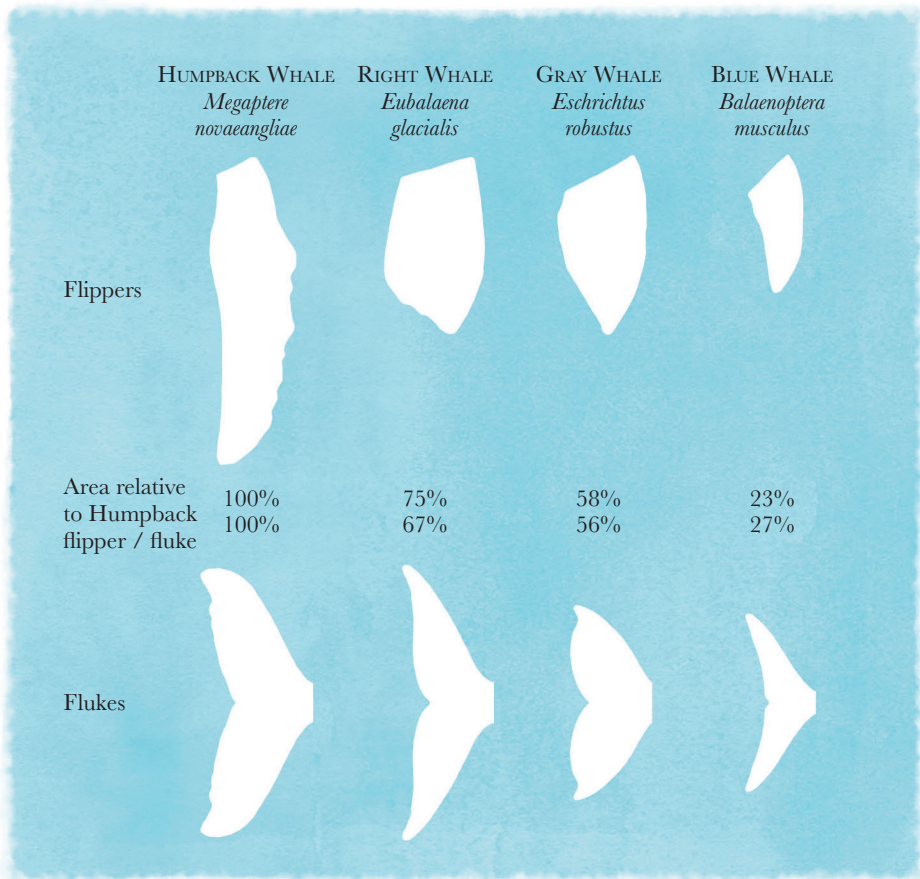
The power whales need to achieve the speeds they do comes from their tails, or flukes. This fluke structure is flexible and strong, extends beyond the bony vertebral column, and provides a clue to their evolutionary past (See Chapter 1). Unlike fish, whose tails move from side to side, whales undulate in an upward–

downward motion with the help of longitudinal muscles in the back and caudal peduncle (where the flukes meet the body). This is because cetaceans have horizontal tail flukes, which evolved from their land-dwelling, four-legged ancestors, whose backbones bent up and down to extend their spine and stride while running. In whales, the aspect ratio of flukes (the ratio of fluke width to height), can indicate whether they are fast or slow movers. Similar height-to-width proportions of their flippers can indicate their maneuverability. Together, they tell us a bit about the whale's life and feeding behaviors.

Blue Whales are designed for speed, with highly streamlined bodies and small, high aspect ratio flippers and flukes, which increases their propulsive force. While this does have downsides in that it prevents quick starts and reduces maneuverability, given that the whales' preferred prey is nonevasive, these two characteristics are not worth investing in. Instead, the ability to cruise efficiently from one patch of food to the next in the open ocean is a high priority. Right Whales, on the other hand, are rotund, less streamlined, and have flukes with a large surface area and high aspect ratio. These features make them efficient cruisers too, but their preference is for slow movement. This fits well with their feeding requirements, as they are designed optimally for continuous filter feeding as they push through the water column, open mouthed, to feed on zooplankton. This constant open-mouth method of skim feeding, coupled with their large heads, introduces a lot of drag, which a large propulsive tail can overcome.

What some whales lose in speed, they gain in maneuverability. Humpback Whales are a fantastic case in point. With their large, high aspect ratio flippers—notably the largest appendages of any animal on Earth, growing to 20 ft (6 m)—and large, low aspect ratio tail, they can accelerate rapidly and even perform tight 180-degree rolls. This works perfectly for a species that indulges in prey that tend to be evasive, and which therefore depends on techniques like bubble-net feeding. Gray Whales (*Eschrichtius robustus*) are also built to maneuver themselves at odd angles. They use their rostrum to dig for benthic prey, which means food found at the bottom of the ocean, such as amphipods, which they then filter out with their baleen. When digging, they most often roll at an angle greater than 45 degrees, a behavior confirmed by unequal baleen wear in this species.

While both flukes and flippers are designed to assist efficient locomotion and support the feeding needs of the various whale species, they are inherently different in that the fluke is made entirely of a dense, fibrous type of connective tissue while the flipper contains the same bones that we humans have in our hands. This is a reminder that whales' ancestors were land-dwelling animals with paws—just like ours. Paws were inherently unhelpful for swimming, so they evolved into paddles.



FLUKES AND FLIPPERS

The areas of fins and tail flukes vary enormously between species, with Humpbacks having by far the largest.

Dorsal fin

The fin on the back of a whale, known as the dorsal fin, is said to act like a keel and assist with stability while swimming. Whales with bigger dorsal fins are thought to attain higher speeds but possess reduced maneuverability. North Atlantic Right Whales (*E. glacialis*)—named as the “right” whales to kill partly because of their ambling pace—do not possess a dorsal fin, while Orcas (*Orcinus orca*) are the second-fastest marine mammal in our oceans and have incredibly tall dorsal fins—male Orca dorsal fins can reach as high as 6 ft (1.8 m)! That said, in species like Blue and Sperm Whales (*Physeter macrocephalus*), the dorsal fin is so small relative to their body size that it likely does not serve any purpose.

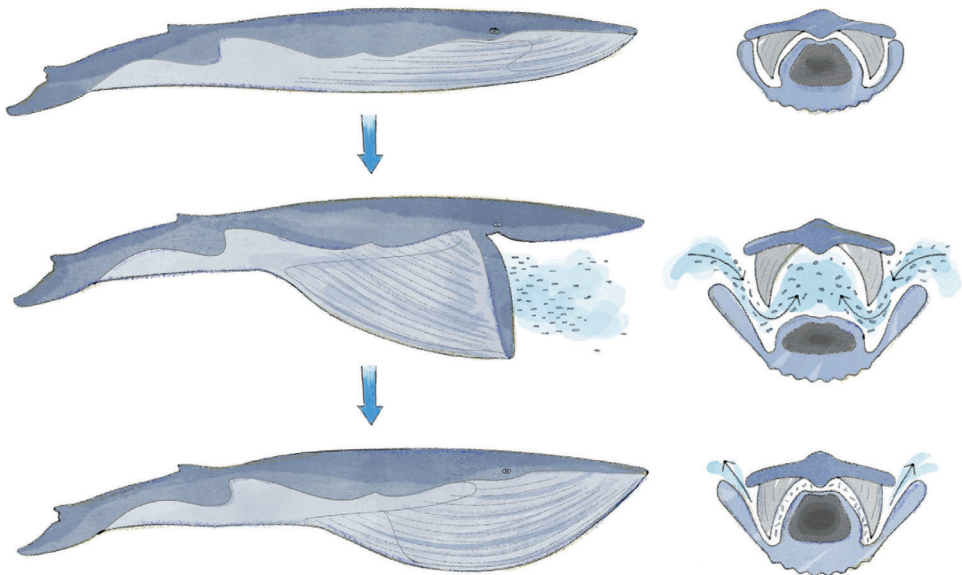
FEEDING: TEETH, BALEEN, AND VENTRAL PLEATS

While we have already divided whales into their respective groups based on their feeding structures (Chapter 1), it is pertinent to revisit these features here briefly. Teeth are typically found in species that need to capture fast-moving prey. They vary in number between species, from a few to over 200. Sperm Whales have 36–50 banana-shaped teeth in their lower jaw, which fit into sockets in their upper jaw, where they do not have any teeth. Spinner Dolphins (*Stenella longirostris*), on the other hand, have more teeth than any other dolphin species, with 45–65 teeth on each side of the upper and lower jaws.

Baleen, a keratinized comb-like structure built into the roof of the mouth of many great whales, is essentially a giant strainer used to access food. Baleen is flexible and tough and is found in the mouths of some of the largest species because it allows them to capture a huge number of small creatures all at once.

The color and length of baleen differ between species, with Blue Whales having short, wide, black baleen and Fin Whales having black baleen on the left jaw and white on the right jaw.

Given the sheer amount of food these whales require to fulfill their energetic requirements, they need large heads to accommodate it all. To deal with this and the issues of drag that would come into play if their heads were bulbous and large, they have developed ventral pleats. Ventral pleats, the stripes extending from under the whale's chin to its belly button, are not just for aesthetics but are functional. When the whale finds a patch of food, its lower jaw opens to 90 degrees and takes in a mouthful of water and prey.



BALEEN WHALE VENTRAL PLEATS

Ventral pleats in baleen whales are accordion-like structures under their chin that they can use to expand their gulf to engulf a mouthful of prey.

Their accordion-like ventral pleats then expand according to the volume of engulfed water—the pouch can expand so much that it exceeds the volume of the whale itself. But this is all temporary, with the whale using its tongue to expel the water through its baleen, and any prey stuck in the baleen is then swallowed. The advantage of these ventral pleats is obvious—while they enable the whales to make the most of large patches of food, they are easily contracted at other times, enabling the whale to remain streamlined as it moves through the ocean.

Interestingly, the length and number of ventral pleats are important features in distinguishing different species of baleen whales. In some, like Blue Whales and Humpbacks, they end at the belly button, while in Sei (*Balaenoptera borealis*) and Minke Whales, they do not extend so far. Bryde's Whales (*Balaenoptera edeni*) have fewer ventral pleats (42–54) than Blue Whales (90–95). While it is rare to see a whale belly up, this little-known fact is beneficial when investigating a stranded specimen.

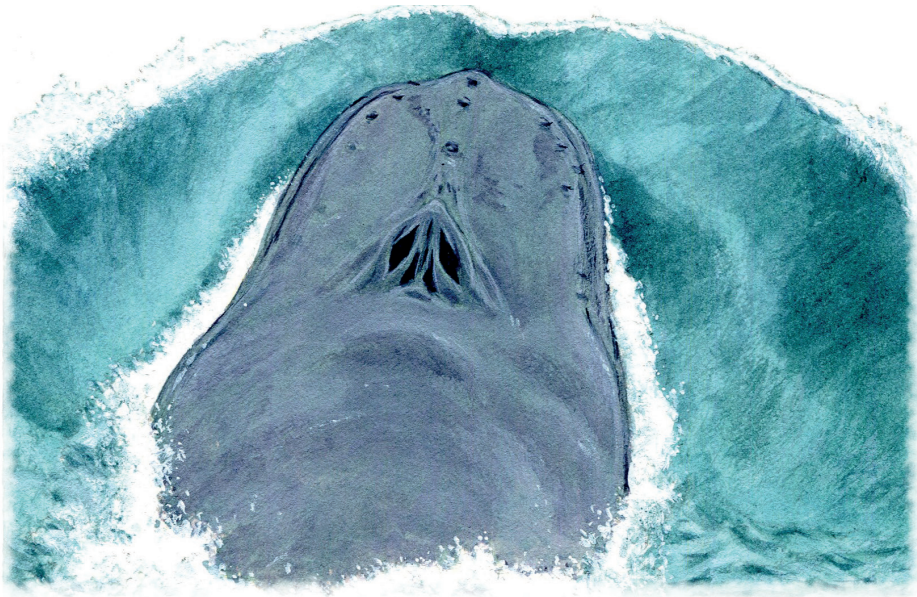
While most baleen whales depend on the combination of baleen and ventral pleats to feed, some, like the Right Whales, do not have any pleats, despite possessing baleen. This is because, unlike many of the whales that lunge at their prey swarms, Right Whales swim with their mouths open at all times and filter feed continuously, negating the need for increased space. Bowhead Whales (*Balaena mysticetus*), with their record-breaking 13-ft-long (4-m) baleen plates, have the largest mouth in relation to their body length. They, too, are continuous ram feeders who swim slowly through prey concentrations for long periods with their jaws wide open. The central gap between the two baleen plates in the front allows prey-laden water to flow continuously through their mouths, negating the need for ventral plates.

While most toothed whales have skipped the need for ventral pleats because they catch what they want and chow it down, beaked whales like Cuvier's Beaked Whales (*Ziphius cavirostris*) bend the rule by having a pair of ventral throat grooves that help to create a vacuum within their mouths, allowing them to suck in their targeted prey very efficiently.

BREATHING: BLOWHOLES AND LUNGS

As mammals, whales must breathe air and thus come up to the surface to do so. Their nostrils, or blowholes, are located at the top of the head as that is the first part of their body to reach the surface when they emerge after a big dive. This means they do not have to bring their whole head out of the water to take a breath, making the process faster and also energetically more efficient.

While it may seem that these blowholes are designed to keep seawater out, recent work suggests the opposite. Whales, including Humpback Whales, have been documented routinely inhaling seawater, which likely means that water enters their upper respiratory tract. This is largely unproblematic except when whales swim through toxic pollutants, such as oil.



BLOWHOLES

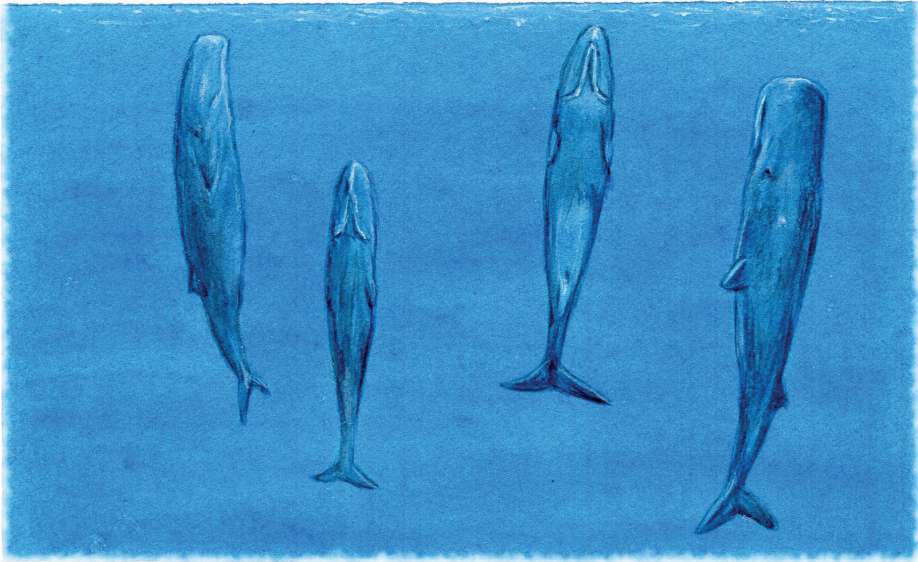
A whale's blowholes, the equivalent of our nostrils, are under voluntary control.

A whale's blowholes are directly connected to its lungs. Every time they breathe, Blue Whales purportedly exchange 80–90 percent of the oxygen in their lungs, compared with the 10–15 percent in humans. This is despite the fact that their lungs constitute 3 percent of their body cavity while human lungs make up 7 percent of ours. This efficiency is vital, given that whales have limited time at the surface and must restock on sufficient air for the long dives ahead.

RESTING

Contrary to how humans breathe, the blowhole in cetaceans is under voluntary control, and they must be “awake” to breathe. This means that, unlike humans, they must think about each breath they take, 24 hours a day. Complete shut-down of the system during sleep is therefore dangerous, and whales have developed a means of shutting down just half their brain at a time as they float at the surface resting. As they rest, they switch which hemisphere of the brain is awake. This unihemispheric sleep enables swimming, voluntary breathing, predator avoidance, and social contact. During unihemispheric sleep, the eye opposite to the waking hemisphere is fully or partially open, while the eye opposite to the sleeping hemisphere is fully or partially closed. When a whale transitions from being awake to unihemispheric sleep, the temperature in the sleeping hemisphere decreases while the temperature in the waking hemisphere remains unchanged. After a period of rest, awakening is accompanied by a gradual increase in temperature in the sleeping hemisphere.

Little is known about sleeping in wild cetaceans; however, electrophysiological studies on captive species have revealed how long and how often some species engage in unihemispheric sleeping. Bottlenose Dolphins (*Tursiops* sp.) sleep for an average of 42 minutes 2–12 times per day, Beluga Whales (*Delphinapterus leucas*) sleep for about 44 minutes, and Amazon River Dolphins (*Inia geoffrensis*) and Harbor Porpoises (*Phocoena phocoena*) sleep for longer than two hours at a



WHALES SLEEPING

Sperm Whales doze for bouts of 10–15 minutes in an upright position—head up, tail down.

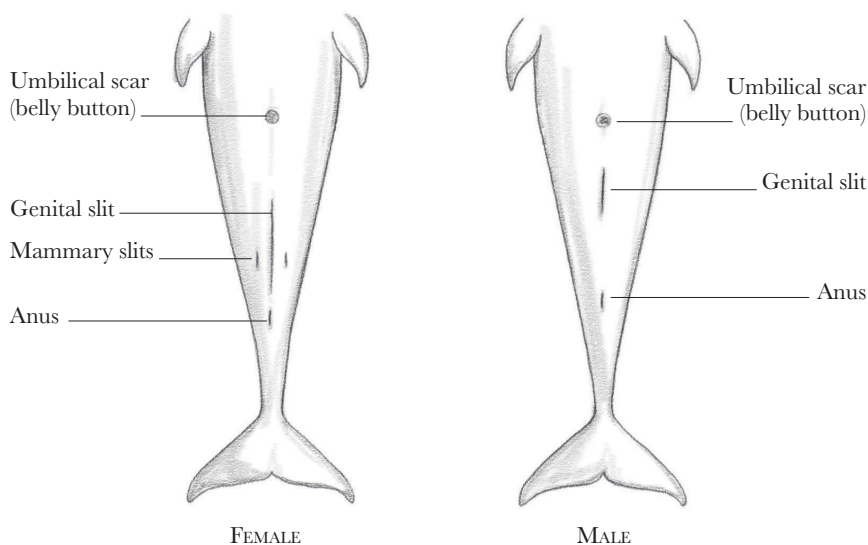
time. However, while REM (rapid eye movement) sleep has been recorded in terrestrial mammals, it appears to be absent in marine mammals, which might be related to their unihemispheric pattern of sleeping.

Typically, wild whales sleep near the surface, a behavior called *logging*, because they resemble logs. Rather unusually, however, Sperm Whales have been documented sleeping vertically with their heads up and tails down. They initiate this vertical sleep by swimming down to depths of one to two times their body length, where they rotate to a head-up posture and passively drift to the surface over time. Researchers have found that Sperm Whales spend a portion of their day sleeping vertically for 10–15 minutes at a time. Hawaiian Spinner Dolphins and Dusky Dolphins (*Lagenorhynchus obscurus*) are known to rest in shallow lagoons but swim slowly in tight formations as they do so, with limited echolocation activity. Like many others, Beluga Whales lie at the surface or swim slowly in tight groups along coastlines. This continuous motion during sleep is important as swimming is life-sustaining for whales—another advantage of unihemispheric sleep.

REPRODUCING

Genitals and pelvic bones

Unlike their terrestrial counterparts, male whales do not have genitals that hang outside their body, as anything dangling outside their fusiform shape would introduce an element of drag. The penis is therefore contained inside a genital slit on the underside of the whale, emerging only when necessary. Because the penis is not visible, it can be tricky to identify gender. However, the location of this genital slit is one way to differentiate between a male and a female. In males, the genital slit is located closer to the whale's belly. Females, on the other hand, have a genital slit closer to their tail flukes, which is followed by a grapefruit-sized lump known as a hemispherical lobe.



GENITAL AND MAMMARY SLITS

Whale anatomy is adapted perfectly to life on the go in the ocean.

As it turns out, the pelvic bones we used to believe were vestigial in whales are in fact important in reproduction. For a long time, we assumed these bones were redundant (and that evolution would wave its magic wand and do away with them in time). However, it has turned out that the muscles that control a whale's penis attach directly to the pelvic bones, allowing for the well-known dexterity of the whale's penis.

Mammary slits

As marine mammals, whale calves depend on their mother's milk, but outwardly dangling breasts or nipples would once again introduce drag to a streamlined animal. Therefore, female whales tuck their nipples inside the two mammary slits on either side of their genital slit.

NAVIGATING THEIR WORLD

Sound

Early in development, the fetuses of all whales have similar ear structures to fetal land mammals. However, as they develop in the womb, the ears of each species begin to develop differently, indicating that they may have different ways of hearing. The acoustic funnel, a structure found in both toothed and baleen whales, is positioned differently in the two groups, so likely evolved in early whales before the two groups split 34 MYA.

Toothed whales depend on sound to find their food, but, as we know, they don't have external ears like dogs, donkeys, or ourselves. Instead, they have a fat pad embedded in the lower jaw that traps sound, which then travels to the middle ear and onward to the cochlea. Despite them having similar fat pads close to their lower jaws, baleen whale hearing remains unresolved. However, scientists describe their ears as being "as big as a human head and as dense as a bowling bowl."

Sight

The cetacean eye has had to adapt to the varying environmental challenges associated with living in an aquatic environment, which include the mechanical, chemical, osmotic, and optical conditions of living in water. Most mammals have dichromatic vision—they cannot discriminate along the red–green color axis. Overall, mammal vision is not highly developed, because our ancestors were more interested in seeing in the dark than in the light. As a result, whales have limited color vision.

In fact, whales have monochromatic vision and see the world in shades of gray. Through their eyes, the ocean is not blue but likely black. Unlike other mammals, whales appear to have lost their short-wave-sensitive cones (S-cones), which have species-dependent maximal sensitivity in the red–green and blue parts of the color spectrum.

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Research suggests that this loss occurred early in the evolution of marine mammals and that the ancestors of whales probably lost their blue color vision shortly after they returned to sea.

Beyond being unable to see in color, whales also do not appear to have binocular vision, given that they have an eye on either side of their head. How they process visual information and integrate what they see (or don't see) with each eye is still a subject of speculation.

Smell

Not much is known about whales' ability to smell. But the lack of nerves required for smelling in toothed whales led people to believe that baleen whales, with whom they share a common ancestor, would also have a lousy sense of smell. However, the well-developed olfactory system in a dissected Bowhead Whale brain was perhaps the first indication that we may have underestimated the use of this sense in this species group. Bowheads may use smell to sniff the air in search of krill. Experiments with Humpback Whales at sea off Iceland

have indicated that the scent of their favorite dinner might result in surface behaviors indicative of sensory exploration, such as diving under the scent and putting the brakes on. It has been suggested that those species that feed closer to the bottom of the food chain likely rely more on smell than those that feed higher up. It also turns out that the closer a baleen whale's typical prey item is to the bottom of the food chain, the wider the distance is between the two blowholes of the whale relative to its body width, suggesting that baleen whales smell in stereo. Stereo-olfaction is the ability to perceive odors or smells with both nostrils independently of one another, sending different signals to the brain that are then used to identify the direction of an odor. This ability helps them to sniff out dimethyl sulfide (DMS), a gas released by phytoplankton when it is being preyed on by zooplankton such as those that whales enjoy feeding on—ultimately leading the whales to a good meal. This hypothesis still needs testing, but it is clear that prey-derived chemical cues are important to baleen whales when hunting for prey in the vast ocean.

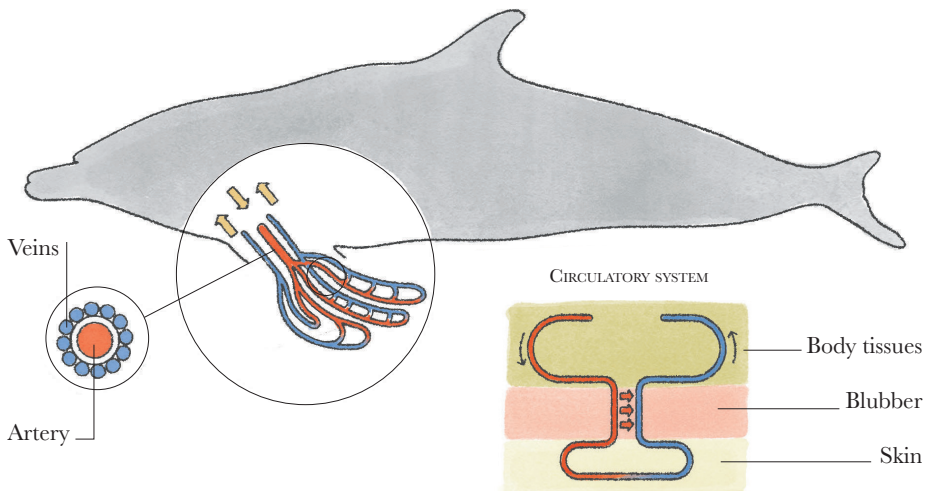
THERMOREGULATION

You may wonder how these warm-blooded animals stay warm while living in cold polar waters. While they have a steady core body temperature, heat loss is a continuous issue, regardless of temperature, as water conducts heat away from the body 25 times faster than air. To reduce heat loss, whales have three main adaptations that are important to explore when understanding the anatomy of this species.

The first is their surface area to volume ratio. In short, smaller mammals like shrews have greater surface area to volume ratios than larger animals like elephants, or indeed whales. This lower volume to surface area ratio means that heat loss is slower, because a smaller percentage of the total body volume is exposed to the surface—an advantage of being huge in the ocean.

The second adaptation for keeping warm is their layer of blubber. Blubber thickness can vary in whales, with Bowhead Whales having the thickest of all, and can vary with the time of year; for example, Humpback Whales have blubber layers that are around 6 in (15 cm) thick, which can increase to 20 in by the end of the feeding season. Blubber is an efficient way to keep warm, even at depths where compression occurs, as it smooths out the whale's shape, reducing hydrodynamic drag and acting as an energy store.

Reduced surface area to volume ratios and thick blubber are great evolutionary adaptations for living in water; however, what happens when whales swim fast or are in warmer water than they are used to? How do they dump the excess heat that blubber prevents them losing? The answer is that they have certain sneaky spots that lack blubber and are not well insulated,

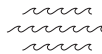


COUNTER-CURRENT HEAT EXCHANGE

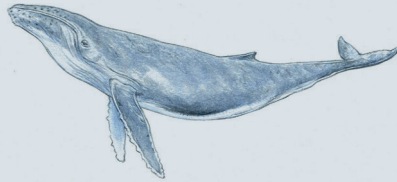
This ingenious system means warm-blooded whales can easily manage their core body temperatures at all times. The magnified area on the left shows blood vessels arranged closely together, specifically arteries (red) and veins (blue) running in opposite directions. This arrangement allows warm arterial blood from the body core to transfer heat to the cooler venous blood returning from the extremities. The schematic on the right shows heat moving from the red vessel to the blue one as blood flows in opposite directions. This counter-current flow conserves body heat by preventing it from being lost to the environment at the surface of the skin.

termed *thermal windows*, such as their flippers, dorsal fins, and flukes. Relative to the blubber, these areas are thin and highly vascularized. Having arteries and veins that run close to each other means that blood of different temperatures flowing in different directions transfers heat across the membranes in an efficient system called the *counter-current heat exchanger*. Warm blood leaving the heart passes heat to the cooler returning blood from the extremities—like the fluke—conserving heat and minimizing loss to the surrounding cold water.

Since species like Bowhead Whales spend long periods at the surface with their mouths open when feeding, they have an organ called the *corpus cavernosum maxillaris*, a bulbous ridge of highly vascularized tissue in the soft palette of their mouth. This organ acts as a counter-current heat exchange system and prevents the excessive loss of heat from their bodies, perhaps even protecting the brain from hypothermia.



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STARTING
FROM THE VERY
BEGINNING

CONCEPTION, GESTATION, AND PREGNANCY

Whale reproduction is a costly exercise. The energy it requires diverts from other crucial activities like growth, immune function, and self-maintenance, and can have huge impacts on a female whale's overall health and survival.

Both toothed and baleen whales invest heavily in the gestation and growth of their offspring. This means that environmental shifts and the varied availability of prey in the ocean require whales to weigh up the commitment of rearing a calf with that of their own survival. In long-lived animals such as whales, this trade-off, combined with their dedicated parental investment in offspring, can even result in a miscarriage or abandonment of a calf. Blue Whale (*Balaenoptera musculus*) and Southern Right Whale (*Eubalaena australis*) females follow this reproductive strategy whereby they prioritize their own body condition and reserves over carrying a pregnancy to term or raising a calf in poor conditions. If the female is weakened due to a lack of food or environmental stress, she may miscarry or abandon a calf to ensure she can recover and increase her chances of successfully reproducing in the next season. This means that she maintains shorter calving intervals and ensures she has the necessary fat stores and energy to provide her next born with sufficient milk for survival. While this strategy results in occasional losses, elephants and primates also use it to maximize reproductive success over time.

Reproductive rates

In many species of baleen whales, their reproductive cycle is closely tied to their migratory cycle, which requires them to undertake annual long-range migrations between feeding and calving grounds. The reproductive cycle, which is a minimum of two years, starts with mating, followed by calving in the wintering grounds, and ends with the weaning of calves before they arrive at the feeding grounds during their first summer.