PART 1

How did blue whales get so big?

By Polly Shulman

"We live in the age of giants," says Jeremy Goldbogen, a marine biologist at Stanford University's Hopkins Marine Station in Pacific Grove, California. Blue whales are the largest animal that ever lived: more massive than any dinosaur, and probably longer. An adult can weigh over 180,000 kg (400,000 lb), as much as 28 male African elephants. "For scientists and nonscientists alike, they're incredible to see, just based on their sheer size," says Goldbogen. "Just watching them breathe and swim and dive underwater is absolutely awe inspiring." The largest land animals we know of—titanosaurs, which may have been half the mass of blue whales—have been extinct for more than 66 million years, but the giants of the ocean are alive right now.

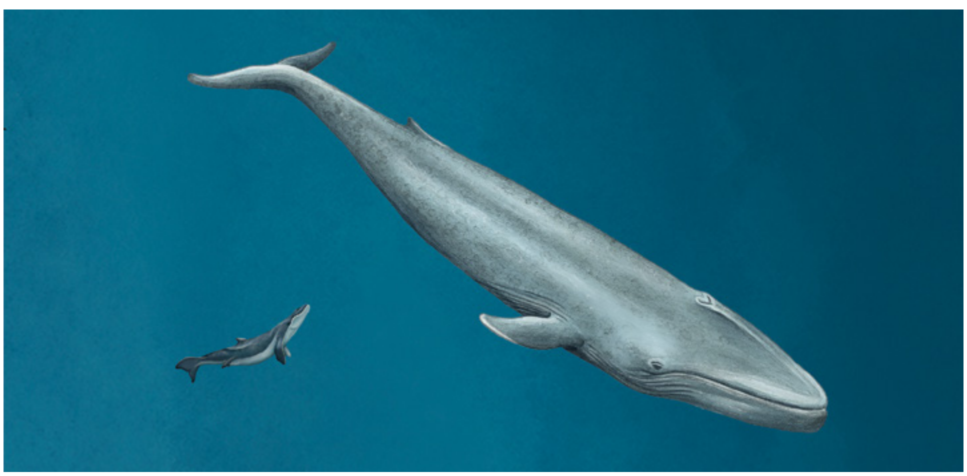

Figure 1. Small ancestor. Today's blue whale (right) evolved from ancestors like the extinct *Maiabalaena nesbittae* (left), a relatively petite species just 5 m (16 ft) long. Illustration by Alex Boersma

The ancestors of blue whales weren't always so big. Pakicetus, a genus of "basically dog-size" four-legged animals, lived on land about 50 million years ago, says Goldbogen, and by about 3 to 5 million years ago their descendants were baleen whales living in the ocean. That's when they grew from a relatively small 5 m (16 ft) to the giants we see today (**Fig. 1**). Around that time, the ocean went through a series of rapid changes: Glaciation increased quickly, leading to shifts in climate and ocean circulation, including **upwelling**, which brings nutrient-rich water up toward the ocean's surface where it nourishes tiny photosynthetic organisms called phytoplankton (**Fig. 2**).

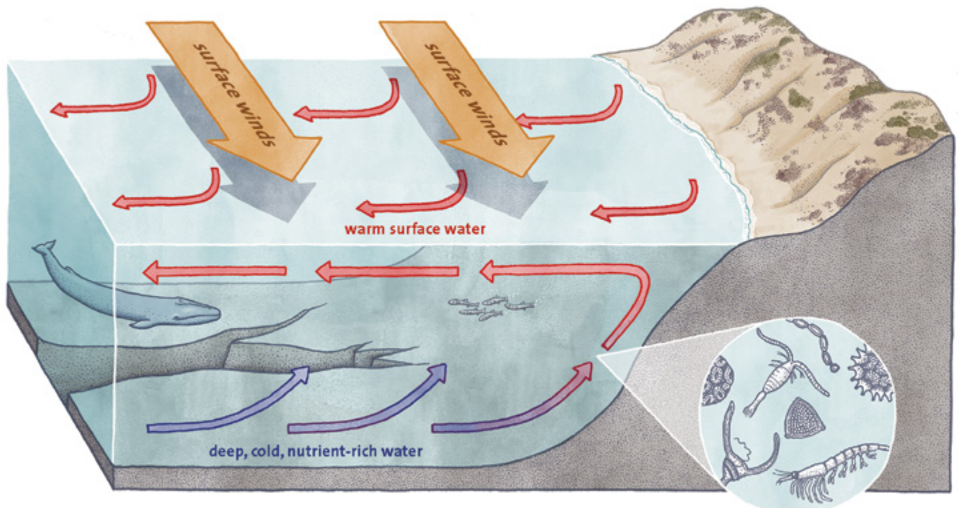

Figure 2. Upwelling. Surface winds blowing parallel to the shore cause the surface water to move at right angles to the wind, pulling the water upward through the process of Ekman transport, a result of the Coriolis effect (see Week 2, Essay 3, "Living in Water: Tides, Currents, and How Organisms Use Water Motion for Advantage"). Deep, cold, nutrient-rich water moves up from the seafloor to replace it. Illustration by Alex Boersma

"The deep water is where things have been dying in the ocean forever," says David Cade, a postdoctoral student in Goldbogen's lab, "and all these dead things are decomposing into nutrients like nitrogen and phosphorus. It's essentially fertilizer that allows these phytoplankton blooms to happen."

The phytoplankton are the base of a vast marine food web, nourishing (among other organisms) the little animals called krill that make up the blue whale's diet. Upwelling is typical of whale foraging spots today; it creates enormous, super-dense patches of food, says Goldbogen. And that dense food, in turn, is what allowed whales to grow so enormous.

What's the Big Deal About Size?

Being big has lots of advantages. It's easier for big animals to avoid predators (if they even have predators). With their large footsteps—or, in the case of whales, fluke strokes—it's easier for them to cover great distances to find food and reach breeding sites. A blue whale's most efficient swimming speed is 2 meters per second (4.5 mph), which allows it to cruise around and migrate long distances with very little effort, and it has burst speeds as fast as 48 kph (30 mph). The larger an animal is, the more efficient its metabolism. Animals lose heat from their surface (their skin), and because larger animals have less surface area per volume than small animals, it takes proportionally less energy for large animals to keep warm than small ones, so they spend less energy on heating. Blue whales, with their efficient metabolisms, can build up fat stores quickly and go without food for long periods. “A healthy whale is a fat whale,” says Cade. During the summer foraging period, some blue whales and related species can put on 50 percent of their body mass in blubber, according to some estimates. That allows them to swim long distances efficiently without pausing to eat, living on the fat they accumulated at their summer feeding grounds as they migrate to their breeding grounds. This lifestyle wouldn’t be possible without their enormous bulk.

And this enormous bulk wouldn’t be possible without their watery home. The ocean provides plenty of space and food, and seawater supports the whales’ weight. Animals on land can’t grow this large because they would have to support their own weight against the force of gravity. The bigger and therefore heavier a land animal gets, the thicker its legs have to be to support it without snapping. But a blue whale is neutrally buoyant—its body has the same density as the water around it, so it floats without the stress of gravity.

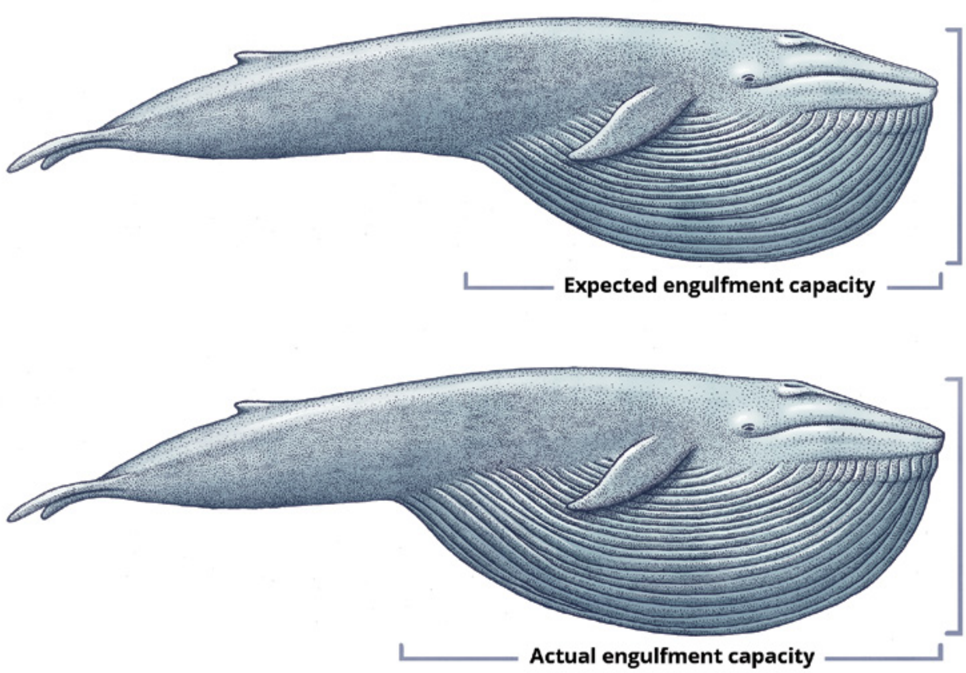

Figure 3. Disproportionate pouch. Blue whales have evolved an astonishingly gigantic gulp. When they feed, their pouches expand to hold a volume of water proportional not just to the cube of the whale’s length (which itself would be impressive) but much more: a volume proportional to the length raised to a power of 3.8. Illustration by Alex Boersma

There's more to the story than just living in water, though. Size may have metabolic advantages, but it comes with a cost. For giants, "survival becomes hard because if you have a large body volume, you need to keep that body fed," explains Shirel Kahane-Rapport, a graduate student in Goldbogen's lab. For that, blue whales need big mouths. "They really put their money where their mouths are," she says. Compared with smaller whales, the front of blue whales' bodies are disproportionately large, with extra-massive skulls, jaws, and ventral pouches: expandable mouths that they use to engulf prey (**Fig. 3**).

What Are Blue Whales, Anyway?

Whales can be divided into two groups: toothed and baleen (**Fig. 4**). Unlike toothed whales—which are hunters, targeting individual prey such as fishes and squids—baleen whales feed in bulk, eating large quantities of small organisms. Baleen is made of keratin, the same protein that makes up our hair and fingernails, as well as many other animals' hoofs, claws, horns, and beaks. In whales it takes the form of a curtain of bristly, comblike plates hanging from the gumline of the whale's upper jaw. The tough, flexible baleen plates serve as a filter, allowing the whale to separate masses of prey from undesirable material such as water or sand.

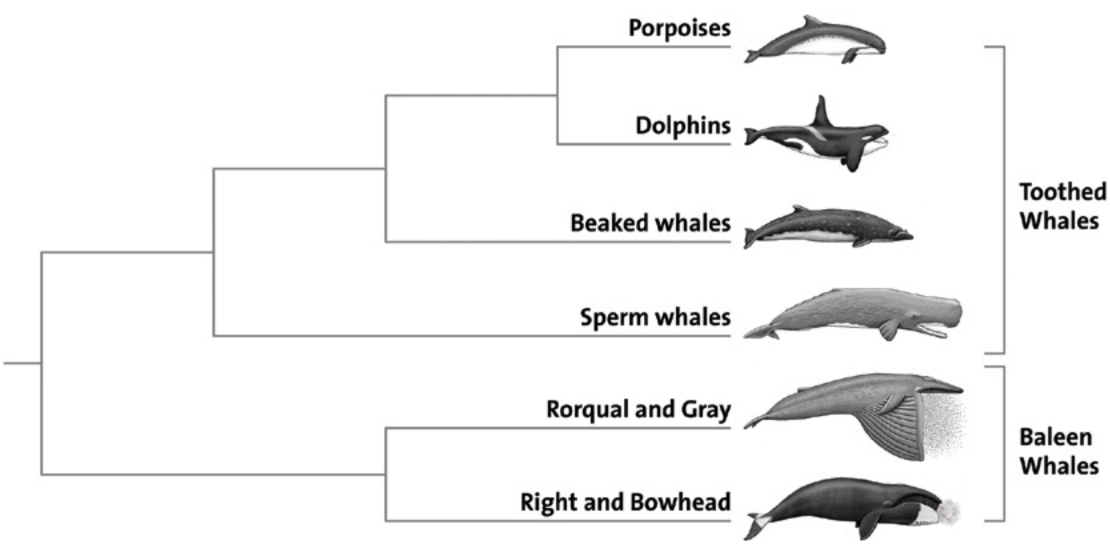

Figure 4. Whale family tree. Illustration by Alex Boersma

All baleen whales use their baleen to help them feed. Right whales, for example, will often swim at or near the surface, continuously filtering water as they swim with their mouths open. Water passes through the back of the mouth and prey is trapped by the baleen. Gray whales, another species of baleen whale, feed by turning on their sides at the seafloor, scooping up sediments, and expelling sand, water, and other small particles through their baleen, leaving them with mouthfuls of crustaceans.

Within the baleen group, blue whales belong to a group called rorquals. The largest group of baleen whales, rorquals include the blue, humpback, and fin whales, and six other extant species (**Fig. 5**). The defining feature of rorquals is their dramatic feeding technique: the big gulp. Longitudinal folds of skin running from below the mouth back to the navel allow the throat to expand immensely when a rorqual feeds. Their throat sacs open up like parachutes, and they engulf enormous volumes of food and water in a single mouthful.

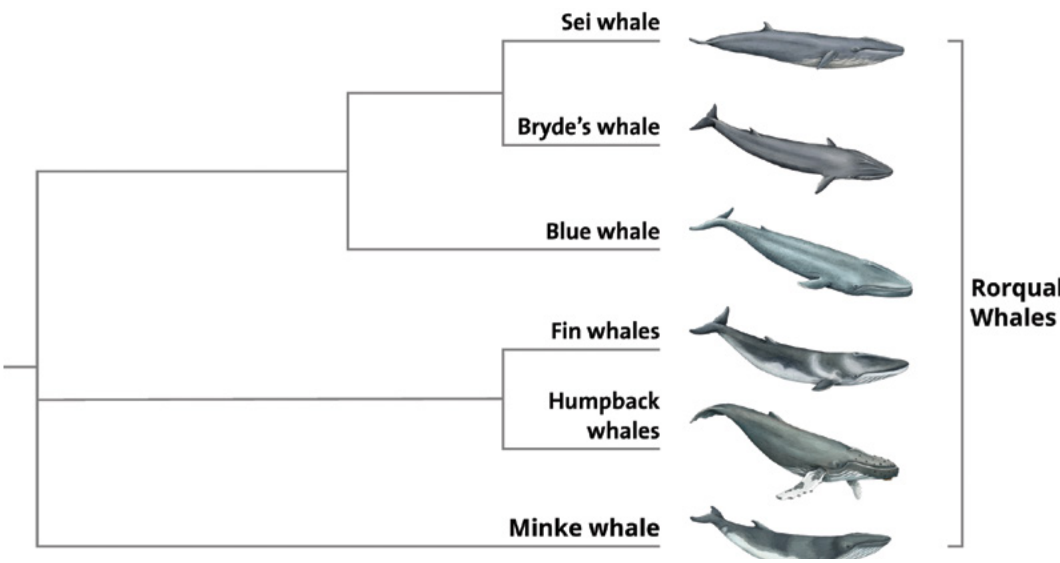

Figure 5. Rorqual family tree. Six of the nine extant rorqual species are represented here. (Not pictured are Ormura's whale and two species of minke whales.) Illustration by Alex Boersma

Expanding its mouth, a blue whale can gulp more than its own body mass of krill-rich water at a time. After rorquals take mouthfuls of prey-rich water, they use the strong muscles, 30-cm (12-in) thick, in the area that stretches about halfway back along the undersides of their bodies to push the water out through their baleen plates as fast as they can—in less than 90 seconds, in the case of blue whales. Expelling the water collapses their throat pouches once more. "The disproportionately large gulp makes it take longer for these whales to filter out the water from their prey, but it also allows them to take huge, very efficient gulps of prey," says Kahane-Rapport. This gives the whales the energy they need to keep their gigantic bodies going.

Although baleen whales use vocalizations to communicate, they don't echolocate to find food, as toothed whales famously do. Instead, rorquals use vision. "We think that these whales actually use light to find their food, even in really deep environments," says Cade. "Blue whales have giant eyes, just massive—they have great eyesight." (The big eyes allow them to gather more light in the dark depths.) They may use other modalities as well, say the scientists. They may listen for sounds the plankton make, or for the absence of ambient sound blocked by plankton patches. Or they may use whiskerlike hairs on their chins, called vibrissae, to feel for food in very low light conditions. "The theory here is that you basically swim around until the food hits you in the face, and then you open your mouth and feed on the stuff," says Cade. And memory is important, too. A team of researchers found that rorquals return to spots where they've had success foraging in past years.

Baleen whales migrate vast distances to areas where their prey animals live. They perform among the longest migrations of any mammalian species, traveling across all the major oceans between their tropical breeding grounds and the cooler waters where they forage. The amount of energy they need for these migrations is immense, and they have to get most of it by bulking up at their summer feeding grounds before setting out on their long trip. And as humans increasingly fill the ocean with activities such as shipping and fishing, whales face ever more obstacles in their migrations.

Adapting to Challenges Under the Waves

Blue whales' massive body size and range bring with them a unique set of challenges. First, they feed exclusively on krill, which are among the smallest organisms in the ocean. It takes a whole lot of tiny krill to keep a giant blue whale going. During its feeding season, from around May to November, a blue whale must capture about 500 million krill a day!

Another challenge is breathing. As mammals, whales can't just take in oxygen from the water that surrounds them the way nonmammalian marine animals such as fishes and squids do; they need air. Land animals breathe reflexively, but whales must breathe consciously. They breathe only through nostrils located on the top of the head (**Fig. 6**), can close their respiratory tracts to prevent the pressure from letting water into their lungs, and can go without breathing for more than 15 minutes at a time. When they do breathe, they can get it done quickly, emptying their huge lungs and refilling them in as little as two seconds. Human divers get decompression sickness, also called the bends, when nitrogen dissolved in the blood bubbles out as the diver rises rapidly from the intense pressure of the depths to the lower pressure near the surface. Whales have adaptations that help protect them from this danger. They can collapse their lungs as water pressure increases, decreasing the surface area over which air can enter their lungs and thus decreasing the amount of nitrogen that passes from their lungs into their blood. And unlike human divers, who breathe continuously while underwater, which exposes them to lots of new air, marine mammals have to dive on a single breath. Blue whales typically dive between 180 and 300 m (600 and 1,000 ft) and can reach depths of more than 500 m (1,600 ft)—plenty deep enough to find the dense patches of krill they need to survive.

Figure 6. Blowhole. Like all mammals, blue whales breathe air, not water. This one has breached the ocean's surface to take a breath through its blowholes—its equivalent of human nostrils. The default state of the blowholes is closed; the whales have to apply their muscles actively to open them.
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As much as we know about blue whales, there is much more left to learn. These marine giants are very challenging to study. Spatially they inhabit a completely separate world from ours, but unlike the land giants of yore, temporally they share our world. Because we happen to be living at the same time, says Goldbogen, "we have a unique opportunity to study how these animals function at the upper extreme of body mass. How do they interact with our environment? And how can we protect these species and ensure that they can persist for future generations?"

Stop and Think

1. Why is it important to understand the feeding behavior of blue whales?
2. If you wanted to know what a whale does underwater, what kind of data would you need to collect?
3. How would you collect it?