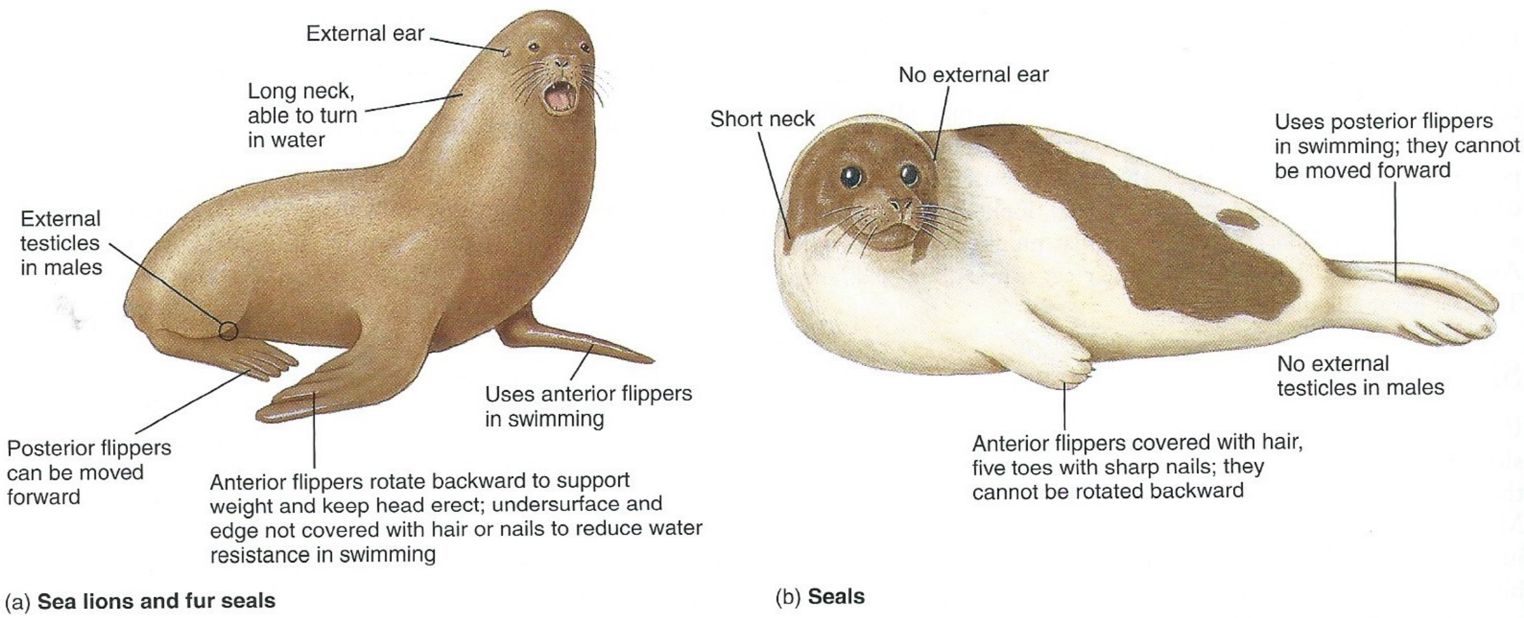


FIGURE 9.9 Though they differ in some structural features and the ways in which they swim and move on land, (*a*) sea lions and fur seals and (*b*) seals are now thought to have evolved from the same group of land carnivores.

Pelicans nest in large colonies along the coast, where space, as in gannets (*Marus*; see Fig. 9.6*c*), may become limited. As in many other seabirds, they typically lay fewer eggs than land birds do, and their broods are reduced when less food is available. The messy nests are made of twigs and anything else they can find. The excrement of millions of pelicans, boobies (see Fig. 9.6*b*), cormorants, and other seabirds accumulates as **guano.** Guano deposits are particularly thick in dry coastal regions and islands near very productive waters such as the coasts of Perú and southwest Africa. These deposits are mined for fertilizer (see "Of Fish and Seabirds, Fishers and Chickens," p. 393).

MARINE MAMMALS

About 200 million years ago another major group of air-breathing vertebrates, the mammals (class Mammalia), evolved from now-extinct reptiles. For a long time the mammals were overshadowed by the dinosaurs, which were reptiles. About 65 million years ago, however, the dinosaurs disappeared. It was then that mammals thrived, taking the place of the dinosaurs. There are now roughly 4,600 species of mammals, including humans. Fishes, reptiles, and birds each outnumber mammals in number of species.

Like birds, mammals have the advantage of being endotherms and homeotherms. The skin of mammals, however, has hair instead of feathers to retain body heat. With few exceptions, mammals are **viviparous.** The embryo receives nutrients and oxygen through the **placenta,** or afterbirth, a membrane that connects it to the womb, thus an instance of **placental viviparicity.** The newborn is fed by milk secreted by the mother's **mammary glands.** Instead of releasing millions of eggs, mammals produce few—but well-cared-for—young.

And then there is the brain. It is larger in relation to body size and far more complex than that of other vertebrates, allowing the storage and processing of more information. This accounts in part for the amazing adaptability of mammals. They live anywhere there is air to breathe and food to eat. This, of course, includes the ocean.

At least five different groups of land mammals succeeded in invading the oceans. They have followed different paths in adapting to the marine environment. Some are so fish-like that we have to remind ourselves that they have hair and bear live young nourished by their mother's milk.

Seals, Sea Lions, and the Walrus

Seals and related forms are marine mammals that have paddle-shaped flippers for swimming but still need to rest and breed on land. They make up one of the 19 or 20 major groups, or orders, of mammals, the **pinnipeds** (order **Pinnipedia;** see Fig. 9.1). Pinnipeds evolved from an early form of terrestrial carnivore (order Carnivora), which includes cats, dogs, bears, and their kin. The similarities are so close that many biologists classify them with the carnivores. Pinnipeds are predators, feeding mostly on fish and squid. Their streamlined bodies are adapted for swimming (Fig. 9.9).

Most pinnipeds live in cold water. To keep warm they have a thick layer of fat, called **blubber,** under their skin. Besides acting as insulation, it serves as a food reserve and helps provide buoyancy. Some pinnipeds also have bristly hair for added protection against the cold. Many of them are quite large, which also helps conserve body heat because large animals have less surface area for their size than small animals and therefore lose less body heat (see Fig. 4.17).

Viviparous Animals Live-bearing animals whose embryos develop within their mothers' bodies and are nourished by the maternal bloodstream.

• Chapter 8, p. 174

(a)

(c)

(b)

FIGURE 9.10 Seals. (*a*) The northern elephant seal (*Mirounga angustirostris*), so called because of the huge proboscis of the male, was almost exterminated for its blubber. By 1890 only about 100 remained, but because of protection and a drop in the use of its blubber it rapidly recovered, and there are now around 150,000 of them along the Pacific coast of North America. (*b*) The New Zealand fur seal (*Arctocephalus forsteri*), like the other fur seals, has a thick underfur. (*c*) Female harp seals (*Phoca groenlandica*), one seen here peeking through the ice, give birth to white, furry pups on the floating Arctic ice. Pups must grow fast and shed their white coats before the drifting ice melts. The clubbing of young pups for their white fur in eastern Canada provoked worldwide protests, and it was banned in 1987. Unemployment caused by the collapse of fisheries and higher demand for the fur, however, prompted the hunt of older harp seals. Some 335,000 seals were killed in 2006, but the quota was set at 280,000 in 2009. Decreased ice because of global warming is a new threat.

Pinnipeds, which include seals and their relatives, are marine mammals, with flippers and blubber, that need to breed on land.

The largest group of pinnipeds, some 19 species, is the **seals.** Seals are distinguished by having rear flippers that cannot be moved forward (Fig. 9.9*b*). On land they must move by pulling themselves along with their front flippers. They swim with powerful strokes of the rear flippers.

Harbor seals (*Phoca vitulina;* Fig. 9.9*b*) are common in both the North Atlantic and North Pacific. Elephant seals (*Mirounga;* Fig. 9.10*a*) are the largest pinnipeds. Males, or bulls, reach 6 m (20 ft) in length and can weigh as much as 3,600 kg (4 tons). One unusual seal is the crabeater seal (*Lobodon carcinophagus*), which feeds on Antarctic krill. These seals strain krill from the water with their intricately cusped, sieve-like teeth. Unlike most seals, monk seals (*Monachus*) live in warm regions. The Mediterranean (*M. monachus*) and Hawaiian (*M. schauinslandi*) monk seals are now endangered. A third species, the Caribbean monk seal (*M. tropicalis*), was last seen in 1952.

Seals have been hunted for their skin and meat and for the oil extracted from their blubber. The Marine Mammal Protection Act of 1972 extends protection to all marine mammals and restricts the sale of their products in the United States. For some seals, however, this protection has not been enough (see Table 18.1, p. 420).

Sea lions, or eared seals, and the related **fur seals** are similar to the true seals except that they have external ears (Fig. 9.9*a*). They can also move their rear flippers forward, so they can use all four limbs to walk or run on land. The front flippers can be rotated backward to support the body, permitting the animal to sit on land with its neck and head raised. Sea lions are graceful and agile swimmers, relying mostly on their broad front flippers. Adult males are much bigger than females, or cows, and have a massive head with a hairy mane (see Fig. 9.32*a*).

There are six species of sea lions and nine of fur seals. The most familiar of all is the California sea lion (*Zalophus californianus;* see Fig. 9.33) of the Pacific coast of North America. These sea lions are the trained barking circus "seals" that do tricks for a fish or two. Fur seals (Fig. 9.10*b*), like the northern fur seal (*Callorhinus ursinus*), were once almost exterminated for their thick fur. Now most are protected around the world, though some species are still hunted. Sea lions are luckier because they lack the underfur of their cousins. Still, both sea lions and fur seals may run afoul of fishers. They sometimes drown in nets or are shot because of their notorious ability to steal fish. Populations of the Steller sea lion (*Eumetopias jubatus*) in Alaska have decreased by 80% since the 1970s, most probably because of a decline in the fish they eat as a result of an increase in commercial fishing. Some blame diseases.

The **walrus** (*Odobenus rosmarus;* Fig. 9.11) is a large pinniped with a pair of distinctive tusks in both sexes protruding down from the mouth. It feeds mostly on bottom invertebrates, particularly clams. It was once thought that the walrus used its tusks to dig

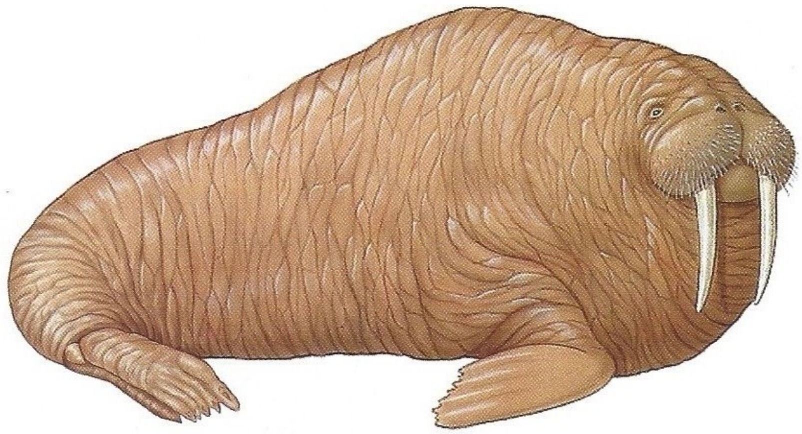


FIGURE 9.11 Walruses (*Odobenus rosmarus*) typically inhabit the edge of pack ice in the Arctic. They migrate as far south as the Aleutian Islands and Hudson Bay, Canada. They also crowd onto beaches on isolated islands that they use as resting places. The walrus is still hunted legally by native Alaskans and Siberians.

FIGURE 9.12 Sea otters (*Enhydra lutris*) are remarkable for their use of a tool—a rock for crushing sea urchins and molluscs. They carry a flat rock in side "pockets" of loose skin and fur. The sea otter floats on its back at the surface, places the rock on its chest, and crushes its toughest prey against it. Some have been observed carrying and using beer bottles as tools!

up food, but there is no evidence for this. Instead, these pinnipeds apparently suck up their food as they move along the bottom. The stiff whiskers of the snout probably act as feelers. The tusks are used for defense and to hold or anchor to ice.

Sea Otter, Marine Otter, and Polar Bear

The **sea otter** (*Enhydra lutris;* Fig. 9.12) is clearly a member of the order **Carnivora.** The sea otter is the smallest truly marine mammal; an average male weighs 25 to 35 kg (60 to 80 lb). It also differs from other marine mammals in lacking a layer of blubber. Insulation from the cold is provided by air trapped in its dense fur. This splendid, dark brown fur, unfortunately, attracted hunters. Sea otters were slaughtered to near extinction until they became protected by an international agreement in 1911. The sea otter was then able to slowly expand from the few individuals that had managed to survive in some remote locations. Their numbers, however, have been declining in recent years, particularly in the Aleutian Islands. In California they have slightly declined since peaking in 2004, mostly as a result of disease. The sea otter is still a threatened species (see Table 18.1, p. 420).

Sea otters are playful and intelligent animals. They spend most or all of their time in the water, including breeding and giving birth. The furry pup is constantly groomed and nursed by its mother. Sea otters need to eat 25 to 30% of their body weight per day, so they spend a lot of time looking for food. They satisfy their ravenous appetites with sea urchins, abalone, mussels, crabs, other invertebrates, and even fishes. They live in or around kelp forests from the Pacific coast of Siberia to central California. Sea otters help protect kelp beds from sea urchins (see "Kelp Communities," p. 300).

The rare marine otter, or sea cat (*Lontra felina*), is a small (up to 6 kg, or 13 lb) otter that inhabits the Pacific coast of temperate South America. It feeds mostly on small invertebrates, but, unlike the sea otter, it spends most of the time on rocky shores. The marine otter is endangered (see Table 18.1, p. 420) because of hunting and habitat loss.

The **polar bear** (*Ursus maritimus*) is the second member of the order Carnivora that inhabits the marine environment. Polar bears are semiaquatic animals that spend a good part of their lives on drifting ice in the Arctic (see "Rolling the Dice: Climate Change," p. 231, Fig. 11). They feed primarily on seals, which they stalk and capture as the seals surface to breathe or rest. Polar bears are threatened by the decrease in Arctic ice.

Manatees and Dugong

It is hard to believe that relatives of the elephant, **manatees** and the **dugong,** live at sea. They are also known as **sea cows,** or **sirenians** (order **Sirenia**). Both have a pair of front flippers but no rear limbs (Fig. 9.13; photo on page 177). They swim with up-and-down strokes of their paddle-shaped, horizontal tail. The round, tapered body is well padded with blubber. They have wrinkled skin with a few scattered hairs. The group is named after the mythical mermaids or sirens whose songs drove sailors crazy!

Sirenians are gentle creatures usually living in groups. They are the only strict vegetarians among marine mammals. Their large lips are used to feed on seagrasses and other aquatic vegetation.

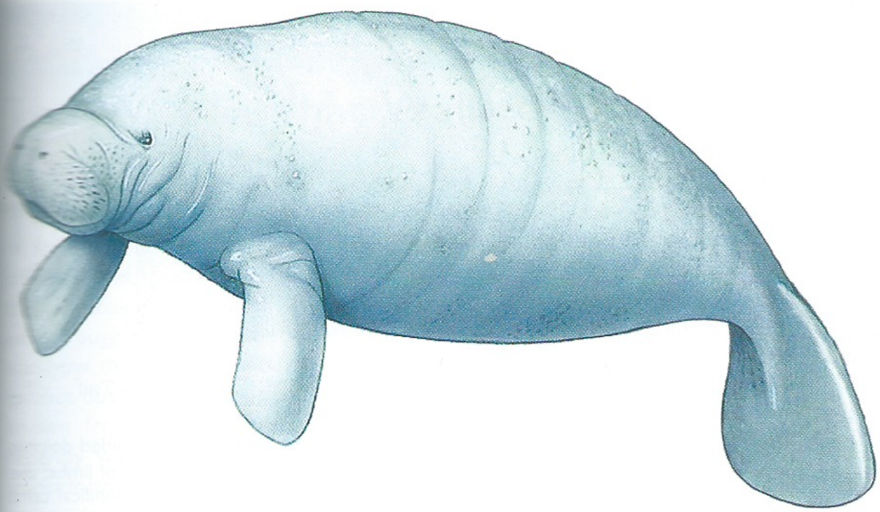


FIGURE 9.13 An estimated 5,000 West Indian manatees (*Trichechus manatus*) remain along the coasts and rivers of Florida. Some concentrate in the warm-water effluents of power plants. They are strictly protected, but collisions with boats take their toll. Manatees have been considered as a possible way to control weeds that sometimes block waterways.

All sirenians are large. Dugongs may reach 3 m (10 ft) and 420 kg (930 lb), manatees 4.5 m (almost 15 ft) and 600 kg (1,320 lb). The largest sirenian of all was the now-extinct Steller's sea cow, which supposedly grew to 7.5 m (25 ft) long (see Fig. 18.13).

Humans have exploited sirenians for their meat (which supposedly tastes like veal), skin, and oil-rich blubber. Like elephants and other large mammals, they reproduce slowly, typically one calf every three years. Seagrass beds, their main source of food, are being destroyed at an alarming rate by anchor and boat damage and by excess silt and nutrients from land, which often results from deforestation and intensive farming. All four species of sirenians are in danger of extinction (see Table 18.1, p. 420). Three species of manatee (*Trichechus*) live in the Atlantic Ocean; one is restricted to the Amazon and the other two inhabit shallow coastal waters and rivers from Florida to West Africa. The dugong (*Dugong dugon*) is strictly marine and survives from East Africa to some of the western Pacific islands. Its numbers are critically low throughout most of its range.

Whales, Dolphins, and Porpoises

The largest group of marine mammals is the **cetaceans** (order **Cetacea**)—the **whales, dolphins,** and **porpoises.** No group of marine animals has captured our imaginations like the dolphins and whales. They have inspired countless legends and works of art and literature (see "Oceans and Cultures," p. 427).

Of all marine mammals, the cetaceans, together with the sirenians, have made the most complete transition to aquatic life. Whereas most other marine mammals return to land at least part of the time, these two groups spend their entire lives in the water. The bodies of cetaceans are streamlined and look remarkably fish-like (Fig. 9.14). This is a dramatic example of **convergent evolution,** in which different species develop similar structures because they have similar lifestyles. Though they superficially resemble fishes, cetaceans breathe air and will drown if trapped below the surface. They are endotherms, have hair (though scanty), and produce milk for their young.

Cetaceans have a pair of front flippers (Fig. 9.15), but the rear pair of limbs has disappeared. Actually, the rear limbs are present in the embryo but fail to develop (Fig. 9.16). In adults they remain only as small, useless bones. Like fishes, many cetaceans have a dorsal fin, another example of convergent evolution. The muscular tail ends in a pair of fin-like, horizontal **flukes.** Blubber (see Fig. 4.2) provides insulation and buoyancy; body hair is practically absent. Cetacean nostrils differ from those of other mammals. Rather than being on the front of the head, they are on top, forming a single or double opening called the **blowhole** (Fig. 9.15).

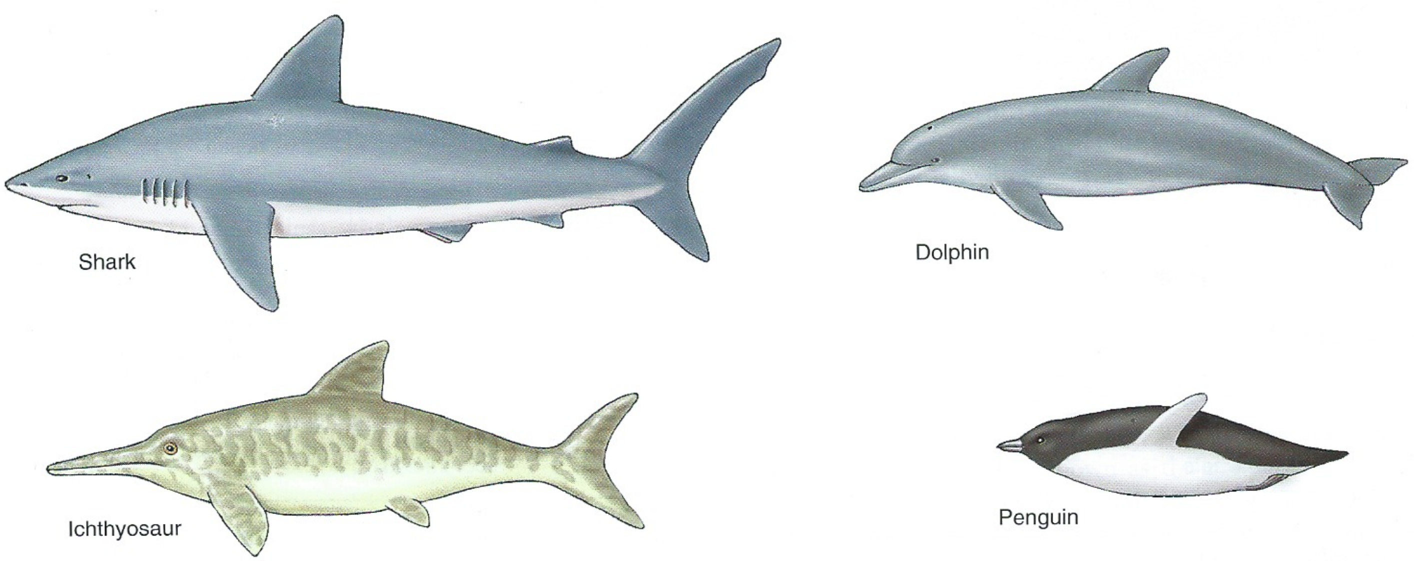


FIGURE 9.14 Streamlining to reduce water resistance evolved independently in different groups of fast-swimming marine animals: sharks, ichthyosaurs (reptiles that became extinct about 65 million years ago), dolphins, and penguins. Notice that dolphins lack posterior fins and that their flukes are horizontal, not vertical like the tail (caudal fin) of fishes (see Fig. 9.24).

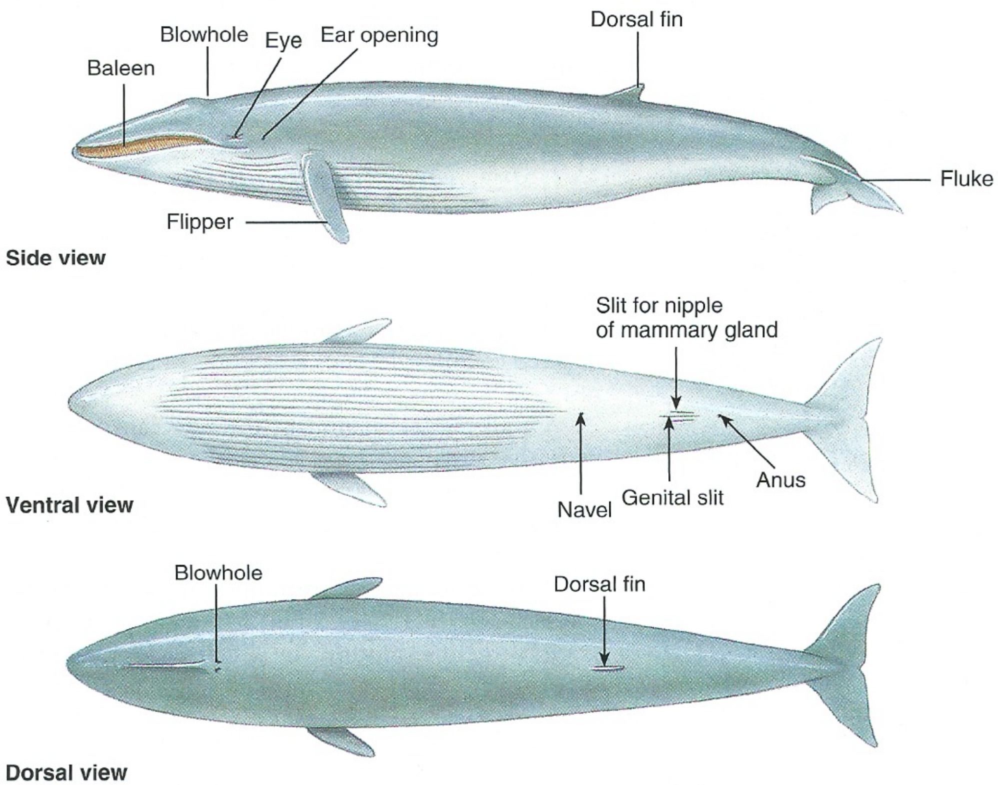


FIGURE 9.15 External morphology of a female blue whale (*Balaenoptera musculus*). Males have a genital slit halfway between the anus and navel, and they lack mammary slits.

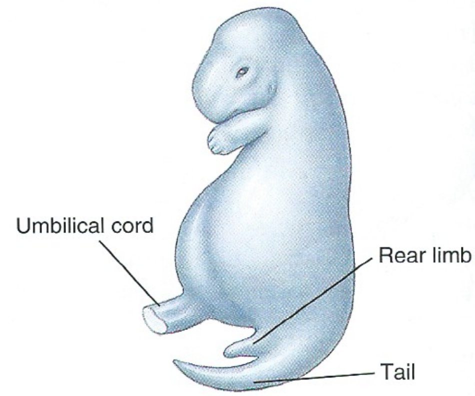


FIGURE 9.16 The fetus of a white-sided dolphin (*Lagenorhynchus*) shows two distinct pairs of limbs; the rear pair will eventually disappear. The umbilical cord connects the fetus with the placenta.

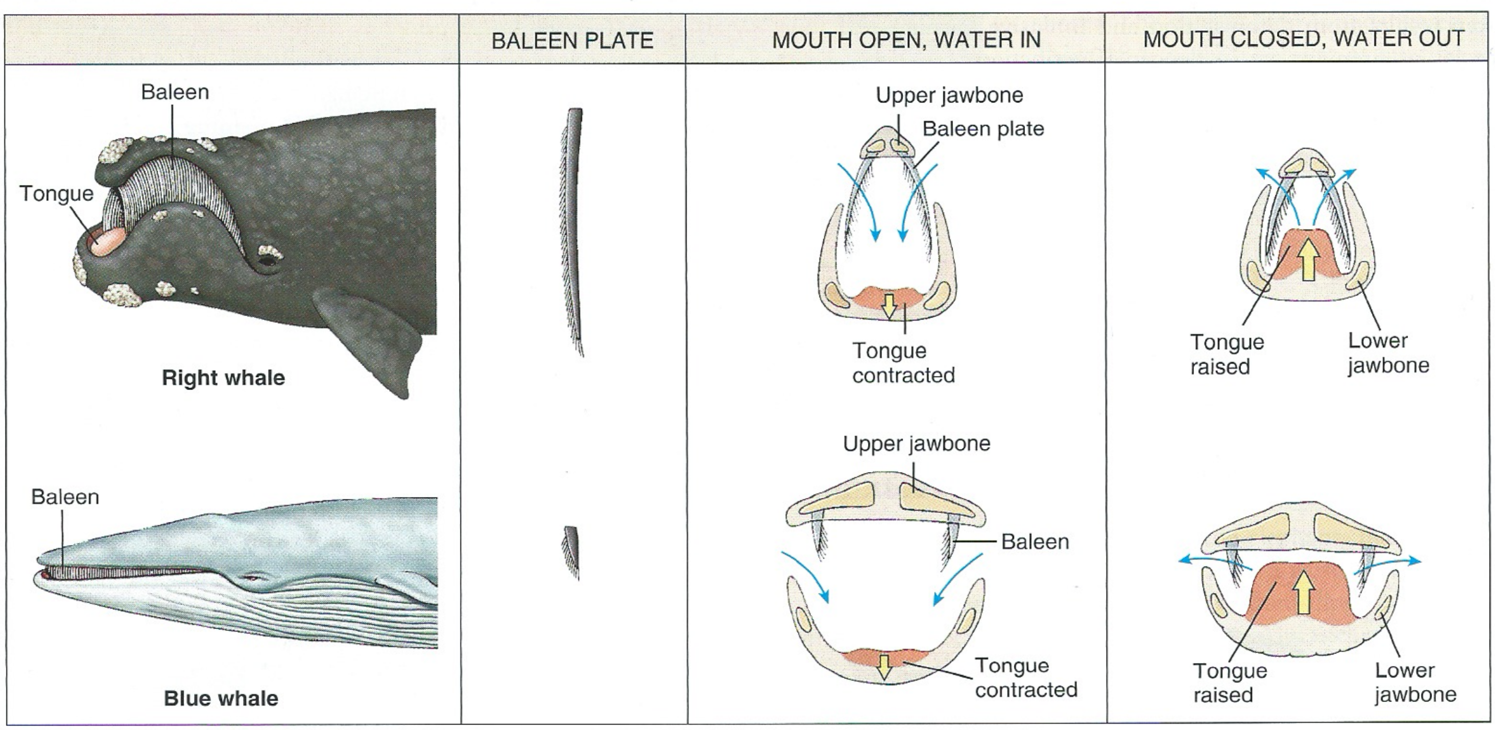


FIGURE 9.17 Filtering in whales involves vertical baleen plates. The number of plates varies with the species, up to an average of 360 on each side in the sei whale (*Balaenoptera borealis*). The plates are up to 3 m (almost 10 ft) in the northern right whale (*Eubalaena glacialis*) but only 1 m (around 3 ft) in the blue whale (*B. musculus*). The baleen, also called whalebone, was once used to make corset stays, backings for billiard tables, and whips. Water is filtered as the mouth closes and the tongue (yellow arrow) pushes up, forcing the water out through the baleen. Cetaceans, however, don't drink water.

EVOLUTIONARY PERSPECTIVE

The Whales That Walked to Sea

It should be obvious that cetaceans are mammals. Their streamlined bodies and the absence of hind legs cannot disguise their affinities with land-dwelling mammals. Unlike the sea otter and pinnipeds, however, it is not easy to suggest what the first whales looked like and how they evolved into modern cetaceans. Extinct but already fully marine cetaceans are known from the fossil record. Missing until recently were fossils clearly intermediate, or transitional, filling the gap between walking land mammals and swimming cetaceans.

An exciting discovery was made in Pakistan in 1979 when scientists found what proved to be the oldest known fossil whale. The fossil, officially described as *Pakicetus,* was found embedded in rocks formed from river deposits that were 52 million years old. The river was actually not far from the shores of the former Tethys Sea (see "Continental Drift and the Changing Oceans," p. 29).

The fossil consists of a complete skull of an **archeocyte,** an extinct group of ancestors of modern cetaceans. Though limited to a skull, the *Pakicetus* fossil provides precious details on the origin of cetaceans. The skull is cetacean-like but its jawbones lack the enlarged space that is filled with fat or oil and used for receiving underwater sound in modern whales (see "Echolocation," p. 201). *Pakicetus* probably detected sound through the ear opening as in land mammals. The skull also lacks a blowhole, another adaptation for diving in cetaceans. Other features, however, show experts that *Pakicetus* is a transitional form between a group of extinct flesh-eating mammals, the mesonychids, and cetaceans. It has been suggested that *Pakicetus* fed on fish in shallow water and was not yet adapted for life in the open ocean. It probably bred and gave birth on land.

Several skeletons of another early whale, *Basilosaurus,* were found in 1989 in sediments left by the Tethys Sea and now exposed in the Sahara Desert in Egypt. This whale lived around 40 million years ago, 12 million years after *Pakicetus*. Many incomplete skeletons were found but they included, for the first time in an archeocyte, a complete hind leg that features feet with three tiny toes. The legs are small, far too small to have supported the 50-foot-long *Basilosaurus* on land. *Basilosaurus* was undoubtedly a fully marine whale with possibly nonfunctional, or **vestigial**, hind legs.

Another remarkable find was reported in 1994, also from Pakistan. The now-extinct *Ambulocetus natans* ("the walking whale that swam") lived in the Tethys Sea 49 million years ago, 3 million years after *Pakicetus* but 9 million years before *Basilosaurus*. The fossil includes a good portion of the hind legs. The legs were strong and ended in long feet very much like those of a modern pinniped. The legs were certainly functional both on land and sea. The whale still retained a tail and lacked a fluke. The structure of the backbone shows, however, that *Ambulocetus* swam as modern whales do, by moving the rear portion of its body up and down, even if a fluke was missing. The large hind legs were used for propulsion in water. On land, where it probably bred and gave birth, *Ambulocetus* may have moved as a sea lion does. It was undoubtedly a whale that linked life on land with life at sea.

Ambulocetus natans, the walking whale that swam.

Other fossils found in Pakistan in 2001 link early cetaceans with ungulates, the group that includes cattle, pigs, and hippos. Some of the oldest bones (at least 50 million years old) were from land-living, wolf-like, hoofed animals. Another fossil, found in Australia and described in 2006, clearly belongs to a baleen whale, as evidenced by its skull. The small, big-eyed, 25-million-year-old whale used teeth to capture prey, unlike modern plankton-feeding baleens. It remains unknown if it used echolocation.

There are approximately 90 species of cetaceans. They are all marine except for 5 species of freshwater dolphins. Cetaceans are divided into two groups: the toothless, filter-feeding whales and the toothed, carnivorous whales, a group that includes the dolphins and porpoises.

Baleen Whales The toothless whales are better known as the **baleen whales.** Instead of teeth they have rows of flexible plates, named **baleen,** which hang from the upper jaws (Fig. 9.17). Baleen is made of keratin, the same material as our hair and nails. The inner edge of each plate consists of hair-like bristles that overlap and form a dense mat in the roof of the mouth. The whale filter-feeds by taking a big mouthful of water and squeezing it out through the bristles by pushing up the tongue.

Baleen whales are cetaceans that filter-feed with baleen plates.

Baleen whales are not only the largest whales but also are among the largest animals that have ever lived on Earth. There are 13 species of these majestic creatures. They were once common in all the oceans, but overhunting has brought many species to the brink of extinction. The blue whale (*Balaenoptera musculus*), which is actually blue-gray, is the largest of all (Fig. 9.18*g*). Males average 25 m (80 ft), and there is a record of a female 33.5 m (110 ft) long. How do you weigh a blue whale? Very carefully—they average 80,000 to 130,000 kg (90 to 140 tons), but the record is an estimated 178,000 kg (200 tons).

The blue whale, the fin whale (*Balaenoptera physalus;* Fig. 9.18*f*), and the minke whale (now recognized as two different species, the common minke, *Balaenoptera acutorostrata,* and the Antarctic minke, *B. bonarensis;* Fig. 9.18*b*)—together with four other related species—are known as the **rorquals.** The rorquals and the humpback whale (*Megaptera novaeangliae;* see Figs. 9.18*c* and 9.29), which is often included among the rorquals, feed by gulping up schools of fish and swarms of krill (see "Feeding in the Blue Whale," p. 200). The lower part of the anterior half of the

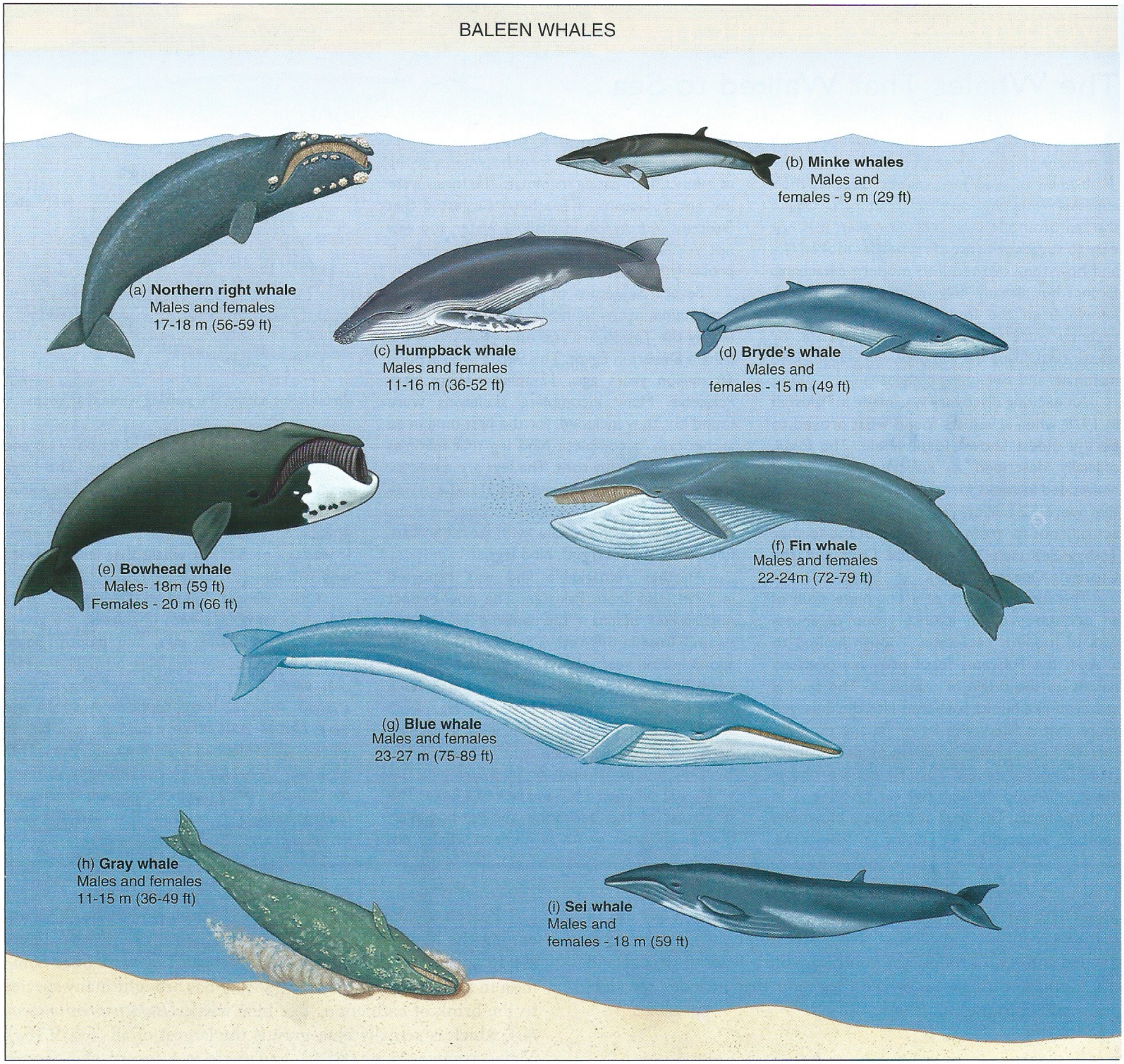
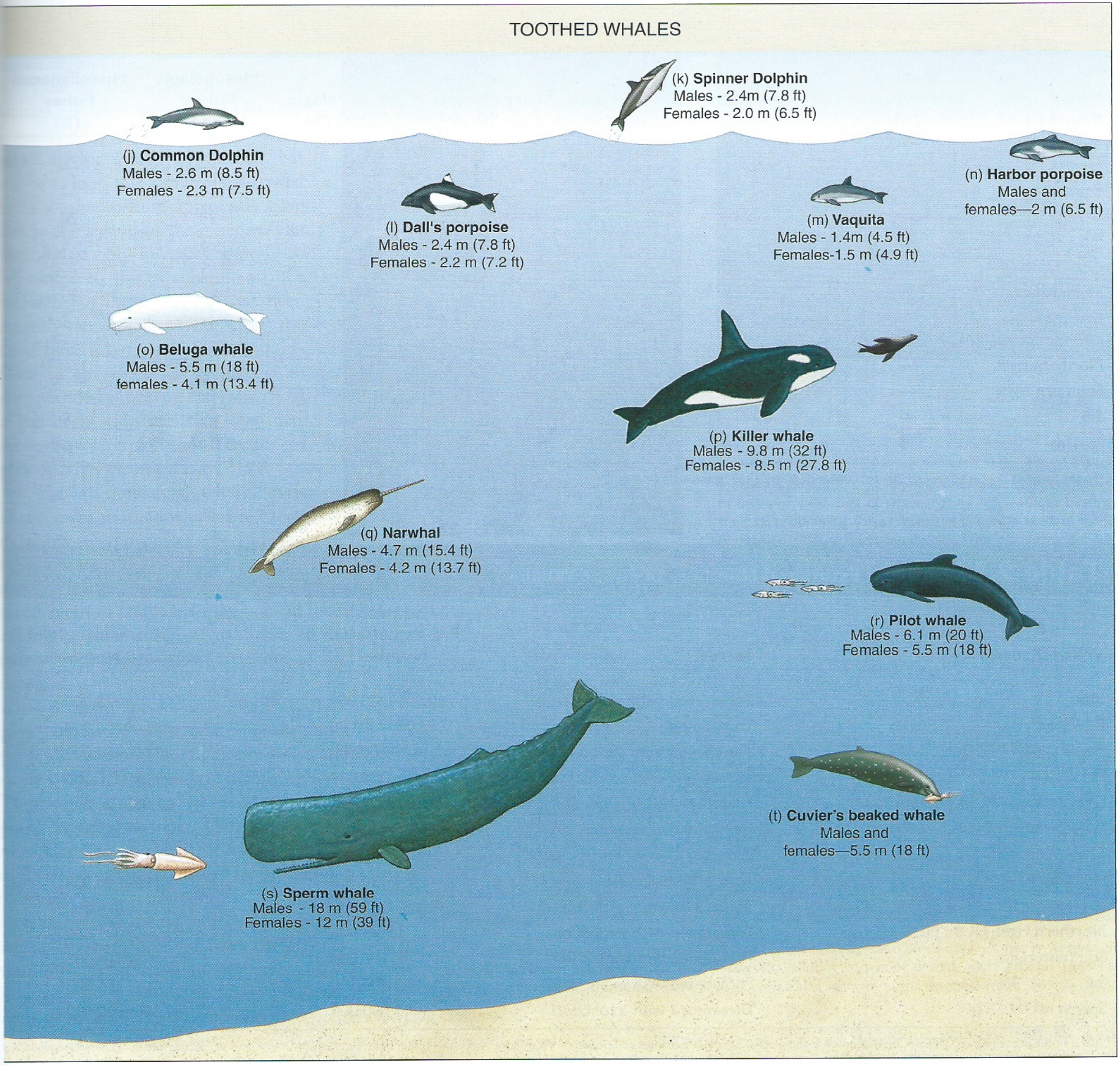


FIGURE 9.18 Representative baleen and toothed whales.

body expands when feeding, hence the distinctive, accordion-like grooves on the underside of these whales (Fig. 9.15). Krill is the most important part of the rorqual diet, especially in the Southern Hemisphere. Humpback whales often herd fishes like herring and mackerel by blowing curtains of bubbles around them.

The right whales (*Eubalaena, Caperaea;* Fig. 9.18*a*) and the bowhead whale (*Balaena mysticetus;* Fig. 9.18*e*) feed by swimming along the surface with their huge mouths open. They have the largest baleen plates of the whales but the finest bristles (Fig. 9.17). This allows them to filter small plankton like copepods and some krill (Table 9.1).

Gray whales (*Eschrichtius robustus*) are primarily bottom feeders. They feed mostly on **amphipods** that inhabit soft bottoms (Table 9.1). Grays stir up the bottom with their pointed snouts and then filter the sediment (Fig. 9.18*h*), leaving characteristic pits on the bottom. Most appear to feed on their right side because the baleen on this side is more worn. Some, however, are "left-handed" and feed on the left side. A 10-week-old female kept in captivity in



San Diego, California, was fed over 815 kg (1,800 lb) of squid every day, gaining weight at the rate of 1 kg (2.2 lb) an hour.

Toothed Whales The roughly 80 remaining species of cetaceans are toothed whales. Their teeth are adapted for a diet of fish, squid, and other prey. They use the teeth only to catch and hold prey, not to chew it, so food is swallowed whole. As in all cetaceans, food is ground up in one of the three compartments of the stomach. The blowhole has one opening, as opposed to two in the baleen whales.

The largest toothed whale is the sperm whale (*Physeter catodon*), the blunt-nosed giant of *Moby Dick* fame (Fig. 9.18*s;* also see Fig. 1.18). Together, the sperm and baleen whales are often called the **great whales.** There is growing evidence that sperm whales, though toothed, are more closely related to baleen whales than to other toothed whales. The sperm whale is now the most numerous of the great whales, even though it was the mainstay of the whaling industry for centuries (Table 9.2). The largest on record weighed 38,000 kg (42 tons).

Amphipods Small crustaceans whose bodies are compressed from side to side.

• Chapter 7, p. 135; Figure 7.32

Table 9.1 Diet of Great Whales

Whale Species	Bottom Invertebrates (%)	Large Zooplankton (%)	Small Squids (%)	Large Squids (%)	Small Pelagic Fishes (%)	Mesopelagic Fishes* (%)	Miscellaneous Fishes (%)
Blue	—	100	—	—	—	—	—
Bowhead	20	80	—	—	—	—	—
Bryde's	—	40	—	—	20	20	20
Fin	—	80	5	—	5	5	5
Gray	90	5	—	—	—	5	—
Humpback	—	55	—	—	15	—	30
Common and Antarctic minkes	—	65	—	—	30	—	5
Northern right	—	100	—	—	—	—	—
Southern right	—	100	—	—	—	—	—
Sei	—	80	5	—	5	5	5
Sperm	5	—	10	60	5	5	15

*Fishes found at depths of around 200 to 1,000 m (660 to 3,300 ft; see Fig. 16.1).

Table 9.2 Status and Estimated Numbers of Great Whales

Whale Species	Status*	Estimated Pre-exploitation Number	Current Estimated Numbers
Blue	Threatened with extinction	160,000–240,000	5,000
Bowhead	Threatened with extinction	52,000–60,000	7,000–8,000
Bryde's **HUNTED**	Threatened with extinction	100,000	40,000–80,000
Fin	Threatened with extinction	300,000	55,000–60,000
Gray (eastern Pacific) **HUNTED**	Threatened with extinction	15,000–22,000	22,000–26,000
Gray (western Pacific)	Threatened with extinction	1,500–10,000	100–200
Gray (Atlantic)	Extinct	Unknown	0
Humpback	Threatened with extinction	150,000	20,000–40,000
Common minke **HUNTED**	Threatened with extinction[1]	130,000–250,000	850,000
Northern right **HUNTED**	Threatened with extinction	Unknown	870–1,000
Southern right	Threatened with extinction	100,000	1,500–4,000
Sei	Threatened with extinction	100,000	55,000
Sperm **HUNTED**	Threatened with extinction	>2,000,000	400,000–500,000

*2011 status according to CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna). The blue, fin, southern right, and sei whales are listed as endangered by the 2011 IUCN (International Union for Conservation of Nature and Natural Resources) Red List of endangered species (see Table 18.1).
[1]Except West Greenland population, which is listed as vulnerable to exploitation.

The toothed whales, which include the dolphins and porpoises, lack baleen and feed mostly on fish and squid.

Sperm whales are fond of squid, including the giant deep-sea ones. Undigested squid beaks and other debris accumulate in the gut as large globs of sticky material known as **ambergris,** an ingredient in fine perfumes. Sperm whales also eat a wide variety of fishes (including sharks), lobsters, and other marine animals (Table 9.1).

The other toothed whales are much smaller than the great whales. One is the killer whale, or orca (*Orcinus orca;* Fig. 9.18*p*), a magnificent black and white predator with a taste for seals, penguins, fishes, sea otters, and even other whales. They use their white bellies to flash and frighten herring schools and their flukes to stun the fish. Killer whales are most common in cold water but are found around the world. Killer whales have a nasty reputation, but there are very few confirmed cases of their attacking humans in the wild. DNA analysis has recently confirmed that there are at least three different species of killer whales, each with a distinct appearance, hunting habit, and diet.

One of the most enigmatic of whales is the narwhal (*Monodon monoceros;* Fig. 9.18*q*), a small Arctic whale having a long, spiral tusk that can be as long as 2.7 m (9 ft). Narwhal tusks washed ashore apparently gave rise to the legend of the unicorn. The tusk, found only in males, appears to be related to the establishment of a hierarchy of dominance. It has been recently shown, however, that the tusks have a network of small, fluid-filled tubes, which are connected to the narwhal's nervous system, and it has been suggested that they may sense the water for the detection of prey or other chemical cues.

Though they are all whales, most of the small toothed whales are called dolphins or porpoises. Technically, the six species of porpoises are blunt-nosed whales (Fig. 9.18*m*, *n*) having flattened teeth in contrast to the conical teeth of dolphins. In some places, however, the name "porpoise" is given to some of the dolphins.

(a)

(b)

FIGURE 9.19 (*a*) Dolphins often ride the bow wave of boats or even that of whales. They ride without beating their tails, obtaining thrust from the pressure wave in front of the ship. (*b*) The Burrunan dolphin (*Tursiops australis*) from southern Australia was recognized as a new species in 2011.

The many species of dolphins typically possess a distinctive snout, or **beak,** and a perpetual "smile." Playful, highly social, and easily trained, dolphins win people's hearts. They often travel in large groups called **pods,** herds, or schools. They like to catch rides along the bows of boats (Fig. 9.19*a*) or around great whales. The bottlenose dolphin (*Tursiops truncatus*) is the dolphin seen in marine theme parks and oceanaria around the world. An Australian population of bottlenose dolphins was recognized in 2011 as a new separate species, *Tursiops australis* (Fig. 9.19*b*). The spinner dolphin (*Stenella longirostris;* Fig. 9.18*k*) is so named because of its spectacular twisting jumps in the air. It is one of the species of dolphins that get caught in the nets of tuna fishers. This happens because the tuna and dolphins eat the same fish and often occur together (see below).

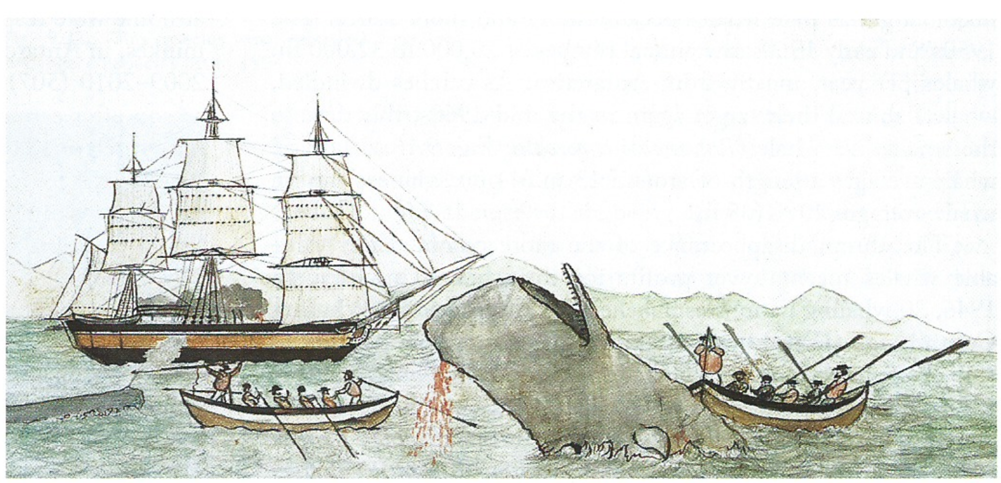


FIGURE 9.20 Sperm whales being harpooned in the South Pacific by the crew of the *Acushnet*, an American whale ship from Fairhaven, Massachusetts. This watercolor painting is part of the sea journal of an 1845 to 1847 voyage. Herman Melville, the author of *Moby Dick*, sailed as a seaman on the *Acushnet* from 1841 to 1842.

Whaling Whale hunting, or **whaling,** is an old tradition with a rich history. Stone Age people hunted whales as early as 6000 B.C. Native Americans hunted gray whales in prehistoric times; the aboriginal peoples of the Arctic still legally hunt them. Basques may have hunted them off Newfoundland before Columbus. It was not until the 1600s, however, that Europeans started to substantially exploit the great whales in the North Atlantic. Americans, who eventually dominated worldwide whaling, began hunting off New England in the late 1600s. Whales were harpooned from small, open boats (Fig. 9.20), a technique whalers learned from the natives. It was a rewarding fishery, though not one exploited primarily for food. Blubber provided "train oil," which was used to make soap and used as lamp oil. Baleen was used to make stays for corsets and other goods. Meat and other valuable products also were obtained. Whaling efforts rapidly increased after fast steamships and the devastating explosive harpoon were introduced in the 1800s. The largest and fastest whales, like the blue and fin whales, were then at the mercy of whalers.

Whales are long-lived mammals with a low reproductive rate. The great whales generally give birth to one well-developed calf that has been carried by the mother for a year or more. Females usually don't become pregnant for one or two years after giving birth. As a result of this low reproductive potential, whale populations could not stand the intense whaling pressure, and many of the fisheries collapsed. Almost all great whales are now classified as endangered (Table 9.2).

The first to be seriously depleted was the slow-swimming North Atlantic right whale (*Eubalaena glacialis;* Fig. 9.18*a*), the "right" species to be killed, according to whalers, because it floated after being harpooned. By the early 1900s whaling had moved to the rich feeding grounds around Antarctica, where other species of whales could be hunted. This location proved to be a bonanza. Whaling nations developed factory ships able to process whole carcasses. The Antarctic fishery reached its peak in the 1930s. The whales received a reprieve during World War II, but it was too late for saving the fisheries. It is estimated that more than a million whales were taken from Antarctica alone.

Blue whales, the largest of them all, were especially sought. A large specimen yielded more than 9,000 gallons of oil. It has been estimated that over 200,000 blue whales were taken worldwide between 1924 and 1971, close to 30,000 during the 1930–1931 whaling season alone. Catches climbed way above the sustainable yield level (see Fig. 17.9). Catch per whaler-day's effort declined every year after 1936. As many as 80% of all blue whales caught by 1963 were sexually immature, so that there were even fewer individuals able to perpetuate the species.

Fin whales, the second largest of all whales, became the next major target as blue whales became more and more scarce. The 1950s and early 1960s saw annual catches of 20,000 to 32,000 fin whales per year, mostly from Antarctica. As catches dwindled, whalers shifted their target again in the mid-1960s, this time to the smaller sei whale (*Balaenoptera borealis;* Fig. 9.18*i*). The sei whale averages a length of around 13 m (44 ft), whereas the fin whale averages 20 m (65 ft).

The abrupt disappearance of the more commercially valuable whales meant lower profits for the whaling industry. In 1946, 20 whaling nations established the **International Whaling Commission (IWC)** in an attempt to regulate whale hunting to stop overfishing. It collected data on the number of whales and set annual quotas for the number of whales to be caught each year, quotas that, unfortunately, were non-binding and could not be enforced. Furthermore, some whaling nations did not belong to the IWC. The blue whale was not completely protected by the IWC until the 1965–1966 season, long after its numbers had been drastically reduced; by then blue whales were so hard to find that the fishery for them was no longer profitable. Even under the protection of the IWC, blue whales were hunted at least until 1971 by countries that did not belong to the IWC.

Intense whaling has led to the near extermination of most species of great whales. Practically all these species are now endangered.

Under mounting pressure from conservationists, the IWC gradually banned the hunting of other whales. Demand for whale products, mostly oil used in the manufacture of margarine and lubricants, was reduced because substitutes had been found for most of them. Whale meat, however, continued to be used as pet food and is still valued as human food, mostly in Japan. The lower quotas of the IWC were, unfortunately, not always accepted by all nations.

The United States Congress passed the **Marine Mammal Protection Act of 1972,** which bans the hunting of all marine mammals in U.S. waters (except in the traditional fisheries of Alaskan natives; see Fig. 4.2) and the importation of marine mammal products. By 1974 the IWC had protected the blue, gray, humpback, and right whales around the world, but only after their catches were no longer economically viable. Sperm, minke, fin, and sei whales were still hunted, but worldwide catches began to dwindle. Catches of these whales fell from 64,418 in 1965 to 38,892 in 1975 and to 6,623 in 1985. A moratorium on all commercial whaling was declared by the IWC in 1985, a move long sought by conservation groups. The former Soviet Union halted all whaling in 1987. Japan, Iceland, and Norway, however, opted in 1988 to continue hunting minke, fin, and sei whales, as allowed by the IWC under the controversial title of "scientific whaling."

In 1994 the IWC created a vast sanctuary for all whales in the waters around Antarctica, the main feeding ground for 80% of the surviving great whales. Japan, however, decided to continue "scientific hunting" of whales in Antarctica. Starting with the 1997–1998 season, Japan took 440 minkes from Antarctica and 100 from the North Pacific each season until 2002, when it expanded its North Pacific catch to include 150 minke, 50 Bryde's (*Balaenoptera edeni;* Fig. 9.18*d*), 10 sperm, and, for the first time since 1987, 50 sei whales. Disruptions from anti-whaling activists and low demand at home were responsible for the low Japanese catches, almost all minkes, in Antarctica in 2007–2008 (550), 2008–2009 (680), and 2009–2010 (507). The hunt was halted during the 2010–2011 season after catching 170 whales. The 2011–2012 season aimed for a catch of 1,000 whales.

Most scientists doubt the scientific value of Japan's whaling program. Only 0.8% of the scientific papers on whales published in 2006 actually used data from Japan's program. The DNA analysis of whale feces provides detailed information on whale diets without the need of cutting open whales.

In 2006 the 70-nation IWC abandoned the conservationist policies of its 2003 Berlin Initiative on the belief that the populations many of the whale species were large enough to support sustainable whaling. Norway had already resumed commercial whaling in 2005 by setting itself an annual quota of 796 North Sea minkes (Fig. 9.21). Iceland, which had not hunted whales since 1989, joined Norway in 2006 to further break the 1985 ban. South Korea announced in 2012 its intention to start scientific hunting of minkes.

Small-scale whaling remains part of the traditional fisheries of the native inhabitants of the Arctic region from Greenland to Siberia and in the Lesser Antilles in the Caribbean. One of the whales hunted in the Arctic, the bowhead, and another in the Lesser Antilles, the humpback, are endangered. Other smaller whales—the killer whale, narwhal, and beluga (*Delphinapterus leucas;* see Figs. 9.18*o* and 9.27)—are also hunted in the Arctic.

Nobody knows when the great whales will again roam the oceans in numbers approaching those before the start of large-scale whaling. Some experts are afraid that a few critically endangered species will never recover completely. Recovery is nevertheless under way in some species. The California gray whale, protected since 1947, has made a comeback (Fig. 9.22). It was removed from the endangered species list in 1994. Recent research, however, estimates that 78,000 to 117,000 grays lived before exploitation, much

FIGURE 9.21 A harpooned common minke whale (*Balaenoptera acutorostrata*) being hauled on board a Norwegian whaling ship in the North Sea.

FIGURE 9.22 California gray whales (*Eschrichtius robustus*) are once again a common sight along their long migration routes from Alaska to Mexico (see Fig. 9.32). This species was removed from the endangered species list in 1994.

higher than most estimates (see Table 9.2). In 1997 the IWC allowed the catching of 600 gray whales by native hunters in Siberia and 20 by the Makah Indian tribe in Washington State. The tribe has, however, only taken a single whale, in 1999. Resumption of the hunt has been stopped awaiting the result of court litigation. Even the blue whale, whose reproduction is severely limited by its restriction to small populations scattered around the world, is making a comeback of sorts. It has returned to the Arctic Ocean north of Norway, a region where they flourished before their near extermination by whalers. Sightings off California have increased sharply. Their numbers in Antarctica, however, are even lower than first estimates: around 500 individuals, or only 0.2% of those feeding there before whaling began.

Dolphins are also at great risk (see Table 18.1, p. 420), having replaced the larger whales as the most threatened of all cetaceans. Small cetaceans are not under IWC regulation, and as many as 28 species are in immediate danger of extinction. Less than 600 *vaquitas,* or "little cows" (*Phocoena sinus;* Fig. 9.18*m*), are left. This shy, shovel-nosed porpoise, known only from the northern Gulf of California, remained unknown to science until 1958. Everywhere, fishers are depleting stocks of fish and squid on which dolphins feed. Dolphins themselves are being hunted for human food. The rarest of all dolphins is the Yangtze River dolphin, or *baiji* (*Lipotes vexillifer*), a freshwater dolphin found only in that Chinese river. It is probably extinct by now.

Tuna fishers using giant purse seine nets (see Fig. 17.6*b*) sometimes trap and drown the many dolphins that often swim above schools of tuna, mostly yellowfin tuna (*Thunnus albacares*) in the eastern Pacific. During the early 1970s an estimated 200,000 dolphins died annually, mostly at the hands of American fishing fleets. The slaughter induced such public outrage that the United States, through the Marine Mammal Protection Act of 1972, called for a reduction in the accidental deaths of dolphins. It imposed a quota of 20,500 for the number of dolphins that could be killed by American fleets. The use of special nets was enforced, and observers were placed on board vessels to verify compliance with the ruling. By 1990 it was estimated that the number of dolphins killed by the American tuna fleet, by then operating in western Pacific waters, had reached zero. The same year the three biggest tuna packers in the United States pledged not to buy or sell fish that was caught using methods that injure or kill dolphins. Tuna cans began to display "dolphin-safe" labels, and imported tuna caught without the use of dolphin-safe methods were banned from sale in the United States.

Dolphins have also been entangled and killed by the thousands in **drift nets** (see Fig. 17.6*a*), which also threaten sharks, sea turtles, seabirds, and other marine life (Fig. 9.23). The nets, some as large as 60 km (37 mi) long and 15 m (50 ft) deep, have been used to catch fish and squid, but they actually catch practically

FIGURE 9.23 This Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) drowned after getting caught in a drift net in the North Pacific.

anything that tries to swim by. Not only do they deplete valuable commercial fisheries like albacore tuna and salmon, but they also trap many noncommercial species. Hundreds of fishing boats outfitted for drift netting were used to catch tuna in the South Pacific. The United Nations called for a moratorium on drift-net fishing in 1992, and Japan and Taiwan, with the largest fleets of drift-net boats in the Pacific, ended the practice in 1993. Still drift-net fishing, some of it illegal, continues in some areas.

Biology of Marine Mammals

It is surprising how little we know about marine mammals. Most are difficult or impossible to keep in captivity or even to observe for long periods at sea. Some whales and dolphins are rarely seen, so what little we know about them comes from captive or stranded individuals and information gathered over the years by whalers.

Swimming Streamlining of the body for swimming is a hallmark of marine mammals. Seals, sea lions, and other pinnipeds swim mostly by moving their flippers. Sirenians and cetaceans, in contrast, move their tails and flukes up and down (Fig. 9.24), whereas fishes move their tails from side to side (see Fig. 8.11). Sea lions have been timed at speeds of 35 kph (22 mph), blue and killer whales at 50 kph (30 mph). A group of common dolphins (*Delphinus delphis*; Fig. 9.18*j*) was recorded bowriding at a speed of 64 kph (40 mph).

Cetaceans have the advantage of having the blowhole on top of the head. This allows them to breathe even though most of the body is under water, although many pinnipeds and dolphins jump clear out of the water to take a breath when they are swimming fast (see Fig. 1.4). It also means that cetaceans can eat and swallow without drowning. To avoid inhaling water, marine mammals take very quick breaths. A fin whale can empty and refill its lungs in less than two seconds, half the time we take, even though the whale breathes in 3,000 times more air!

In the large whales, the moisture in their warm breath condenses when it hits the air. Together with a little mucus and seawater, this water vapor forms the characteristic **spout,** or **blow** (Fig. 9.25). The spout can be seen at great distances, and its

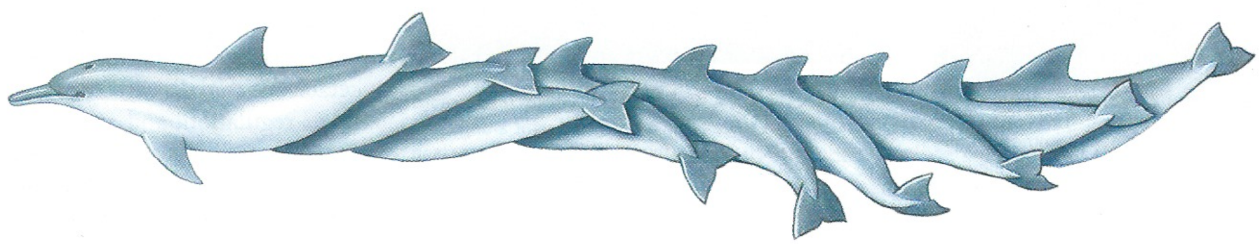


FIGURE 9.24 Cetaceans swim with strong up-and-down movements of the tail and flukes.

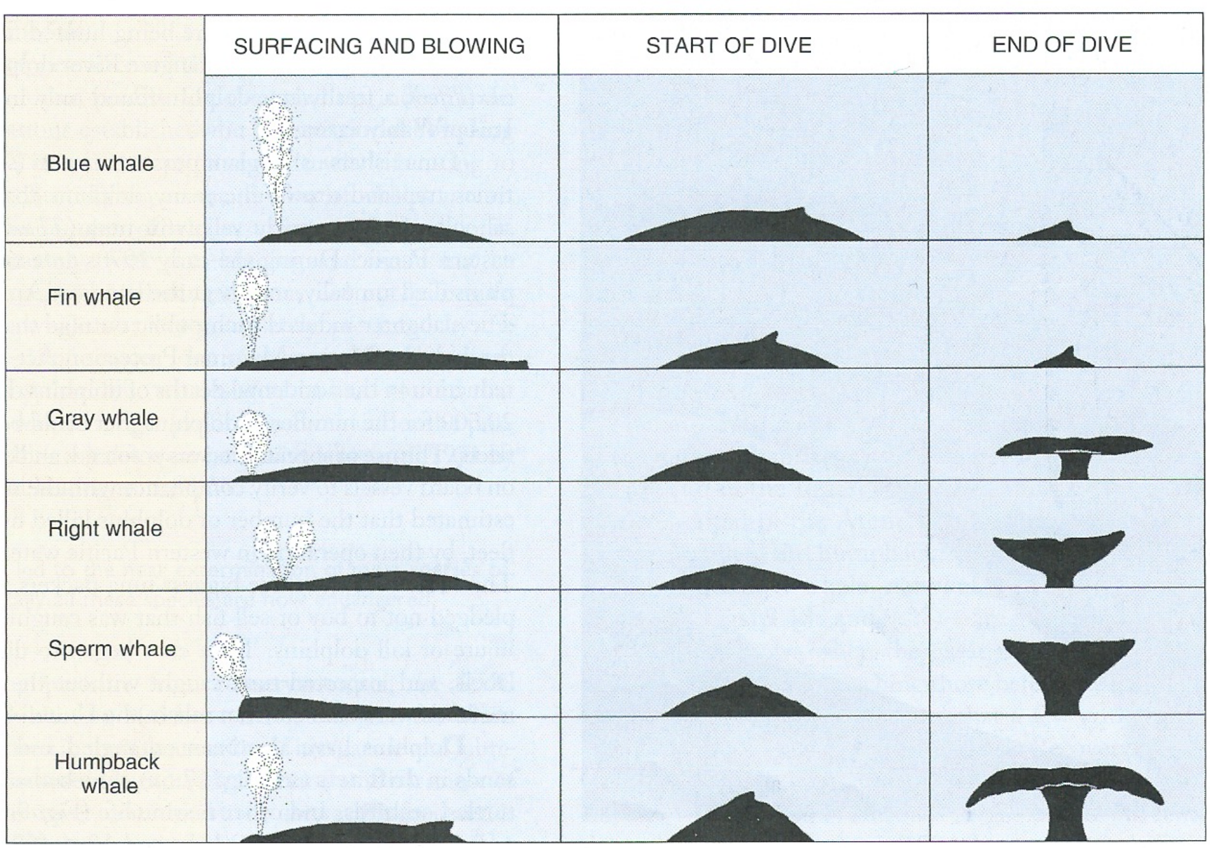


FIGURE 9.25 Great whales can be identified from a distance by their blowing pattern, their outline on the surface, and the way they dive.

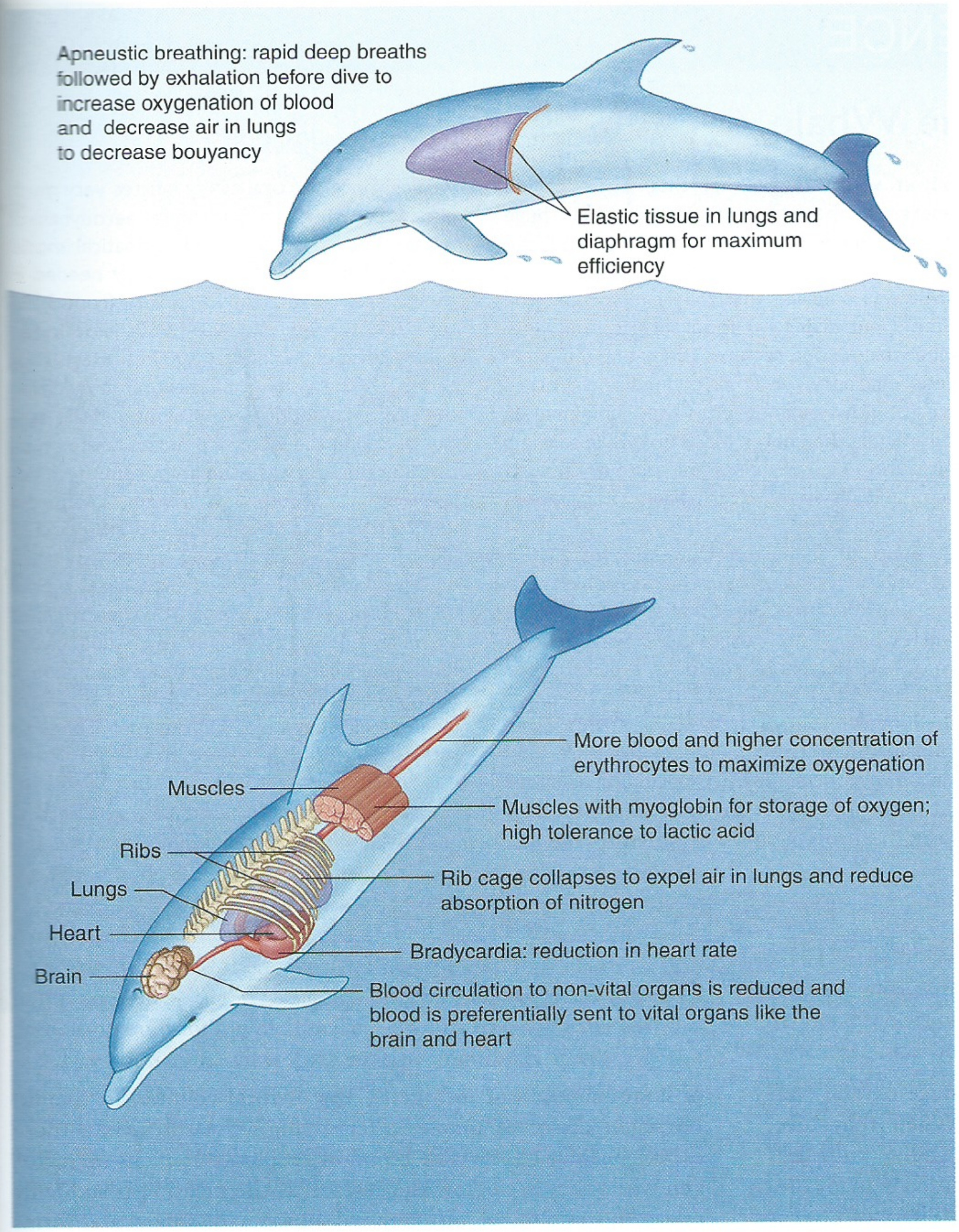


FIGURE 9.26 Marine mammals have evolved a series of adaptations that allow them to undertake long, deep dives.

height and angle can be used to identify the whale (Fig. 9.25). The blue whale, for instance, has a spout some 6 to 12 m (20 to 40 ft) high.

To keep warm in cold water, the great whales depend on a thick layer of blubber (see Fig. 4.2). Feeding, however, leaves their huge mouths exposed to low temperatures, a major problem in the very cold polar waters where they normally feed. A network of blood vessels in their tongues reduces heat loss by transferring heat from warm blood into vessels that carry it back to the body core.

Diving Marine mammals have mastered the art of diving, and most make prolonged dives to considerable depths for food. There is a wide range in diving ability. Sea otters can dive for only 4 or 5 minutes, to depths of perhaps 55 m (180 ft). Pinnipeds normally dive for up to 30 minutes at maximum depths of 150 to 250 m (490 to 820 ft). Female northern elephant seals (*Mirounga angustirostris*), however, are capable of continuous deep dives of up to 400 m (1,300 ft). One individual was recorded diving to a depth of 1,500 m (5,000 ft). The Weddell seal (*Leptonychotes weddelli*) has been recorded diving for as long as 1 hour 13 minutes and as deep as 575 m (1,900 ft).

The plankton-feeding habits of baleen whales do not require them to dive too deeply for their food, and they seldom venture below 100 m (300 ft). Toothed whales, however, are excellent divers. Dolphins are known to dive as deep as 300 m (990 ft). Though sperm whales are known to dive to 2,250 m (7,380 ft) for at least an hour, beaked whales are the champion divers. The Cuvier's beaked whale (*Ziphius cavirostris;* Fig. 9.18*t*) regularly dives to more than 1,000 m (3,300 ft) to catch the deep-water squids that make up most of its diet. The deepest recorded dive of a beaked whale was close to 1,900 m (about 6,230 ft) for up to 85 minutes. Different species of toothed whales have evolved different hunting strategies. Short-finned pilot whales (*Globicephala;* Fig. 9.18*r*), for instance, sprint as fast as 9 m (30 ft) per second after single or several prey as deep as 1,000 m (3,300 ft), very much like large wildcats do.

The long, deep dives of marine mammals require several crucial adaptations. For one thing, they must be able to go a long time without breathing. This involves more than just holding their breath, for they must keep their vital organs supplied with oxygen. Being homeotherms means that marine mammals must use energy to keep their temperature constant—and the release of energy by **aerobic respiration** requires oxygen. To get as much oxygen as possible before dives, most marine mammals and some seabirds take several deep breaths, then rapidly exhale, a behavior known as **apneustic breathing** (Fig. 9.26). As much as 90% of the oxygen contained in the lungs is exchanged during each breath, in contrast to 20% in humans. Many marine mammals have elastic tissues in their lungs and diaphragms, which helps lungs fill and empty rapidly and efficiently.

Marine mammals are also better than other mammals at absorbing the oxygen from the air and storing it in their blood. To start with, they have relatively more blood than non-diving mammals. As in seabirds (see "Biology of Seabirds," p. 185), their blood also contains a higher concentration of erythrocytes, and these cells carry more hemoglobin. Furthermore, their muscles are extra-rich in myoglobin, which means that the muscles themselves can store a lot of oxygen.

EYE ON SCIENCE

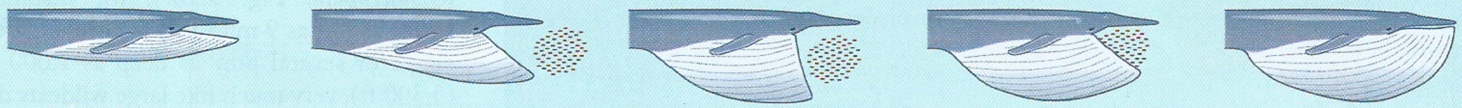
Feeding in the Blue Whale

How blue whales (*Balaenoptera musculus*), the largest animals that have ever lived, maintain such a large size while having to dive for food, migrate long distances, keep body temperature in cold water, and reproduce—all on a diet of krill—is a challenging question. Blue whales and other rorquals feed by lunging at high speeds, huge mouths open, into swarms of krill. They then filter and swallow the krill in the large volumes of water contained in their greatly inflated oral cavities by closing their mouths (see Figs. 9.17 and 9.18*f*) . A unique adaptation in rorquals (from the French *rorqual*, originally from *röyrkval*, Norwegian for "furrow whale") is the presence of longitudinal grooves along a good part of the lower surface of the body (see Fig. 9.15). The blubber along this area consists of tough ridges divided by deep channels of elastic tissue to allow the oral cavity to expand. The volume of the oral cavity is further increased by the retraction of the tongue along the floor of the mouth.

We know that blue whales should get enough energy from plankton (see Fig. 10.16), but it was thought that they burn lots of energy by having to accelerate their huge bodies, lunge, and feed, together with the increased drag of the expanded oral cavity, so it was believed that they had to limit the time spent diving for food. Figuring out how blue whales cope requires estimating the energetic efficiency, or cost, of feeding, in other words, how much energy they obtain after subtracting the energy they burn while feeding. Measuring energy inputs and outputs in such large animals at sea clearly seemed an impossible task.

A team from the University of British Columbia, Canada, nevertheless solved the problem after tracking as many as 265 blue whales along the Pacific coast with several types of electronic sensors. Whales were found to lunge to feed as many as six times during a dive, with each dive lasting from 3.1 to 15.2 minutes. The speed of whales as they lunged was calculated by correlating speed with the noise of water rushing by the animal as measured by hydrophones attached to individual whales. Since the oral cavity inflates very much like a parachute, a parachute aerodynamics expert helped develop a mathematical model that allowed calculating the energy needed in each lunge, a value found to vary from 3,226 to 8,071 kilojoules (770–1,930 kilocalories; 1 kilocalorie equivalent to 1,000 calories). They estimated the volume of the oral cavity from the size of jaw bones in museums and the density of krill in the water from data in the scientific literature. It was estimated from these values that each mouthful of krill contained from 34,726 to 1,912,680 kilojoules (8,310–457,130 kilocalories), which is 240 times as much energy spent in each lunge! Even including the cost of diving, each dive could provide 90 times as much energy as whales use while diving. Blue whales certainly obtain more than enough energy from their food, and such extraordinary feeding efficiency helps explain their ability to survive despite their gigantic size.

For more information, explore the links provided on the Marine Biology *Online Learning Center.*



Marine mammals have adaptations that reduce oxygen consumption in addition to increasing supply. When they dive, the heart rate slows dramatically, an automatic reflex known as **bradychardia.** Diving bradychardia has been recorded in many diving vertebrates, including humans. It is thought to have evolved as an oxygen-conserving mechanism. In the northern elephant seal, for example, the heart rate decreases from about 85 beats per minute to about 12. Blood flow to non-essential parts of the body, like the extremities and the intestine, is reduced, but it is maintained to vital organs like the brain and heart. Thus, oxygen is made available where it is needed most when oxygen supply is cut off during a dive.

The reduction or absence of oxygen triggers the muscle cells of many animals (including humans during exercise) to carry out **anaerobic respiration**, an "emergency" **aerobic respiration** that releases, though inefficiently, some energy without the need of oxygen. A product of anaerobic respiration is **lactic acid**, a chemical that produces cramps and is detrimental to muscular function. The tissues of marine mammals, however, have evolved a high tolerance to the accumulation of lactic acid, another adaptation to increase diving efficiency.

Another potential problem faced by air-breathing, diving animals (including human divers) results from the presence of large amounts of nitrogen (70% of total volume) in the air. Nitrogen dissolves much better at high pressures, like those experienced at depth. The blood of scuba divers picks up nitrogen while they are below the surface. If the pressure is suddenly released, some of the nitrogen will not stay dissolved and forms tiny bubbles in the bloodstream. You can see a similar phenomenon when you open a bottle of soda pop. As long as the top is on, the contents are under pressure. The carbonation, actually carbon dioxide gas (CO_2), remains dissolved. When you open the bottle, the pressure is released and bubbles form. When nitrogen bubbles form in the blood after diving, they can lodge in the joints or block the flow of blood to the brain and other organs. This produces a painful condition known as the **bends,** or decompression sickness. To avoid the bends, human divers must be very careful about how deep they go, how long they stay under water, and how fast they come up.

Marine mammals dive deeper and stay down longer than human divers, so do they get the bends? Marine mammals do have adaptations that prevent nitrogen from dissolving in the blood. Human lungs work pretty much the same while scuba diving under water as on land. When marine mammals dive, on the other hand, their lungs actually collapse. They have a flexible rib cage that

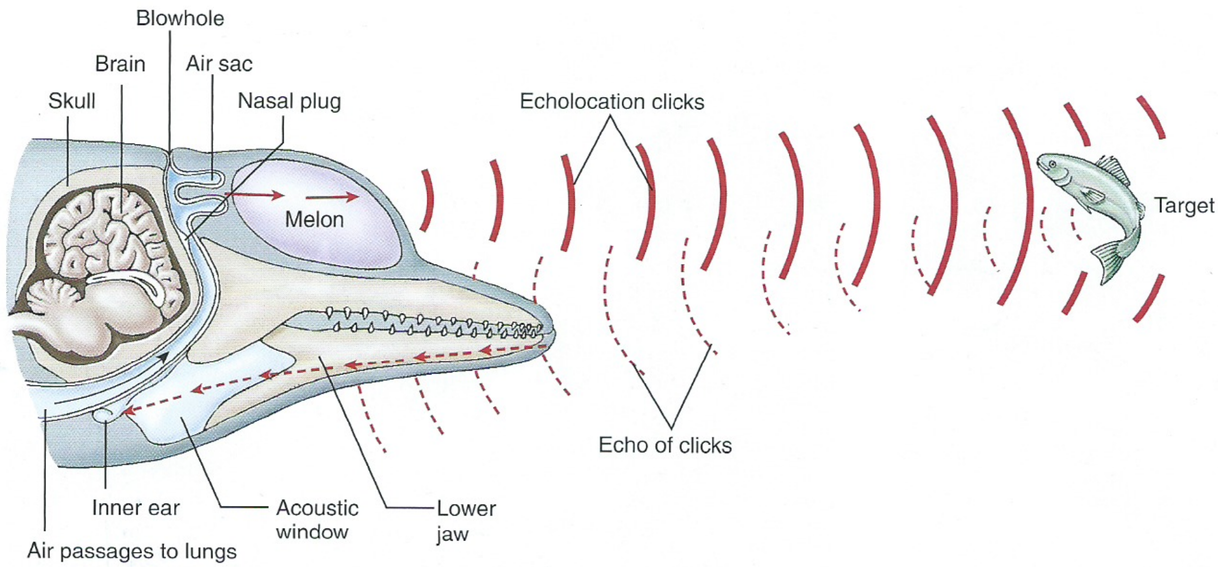


FIGURE 9.27 Dolphins echolocate by emitting bursts of sound waves, or clicks, as air is pushed through internal air passages. Two muscular nasal plugs act as valves, closing and opening the passages. Flaps of tissue on the plugs probably also produce sound by vibrating in the moving air. The clicks are focused into a beam by the melon. To cover a wider area, the dolphin moves its head from side to side. The melon is also known to receive the echoes and transmit them to the ears, but most are received by the lower jaw.

gets pushed in by the pressure of the water (Fig. 9.26). This, and increased water pressure with the increased depth, squeezes the air out of peripheral areas of the lungs where it readily dissolves into the blood. Air is moved instead into the central spaces of the lungs, where little nitrogen is absorbed. High concentrations of hemoglobin and myoglobin store the oxygen that marine mammals need in the blood and muscles during dives. Less air is thus needed in the lungs, which reduces the amount of nitrogen that can be absorbed. Apneustic breathing, exhaling before a dive, further reduces the amount of air—and therefore nitrogen—in the lungs. A reduction in the amount of air in the lungs has the additional advantage of decreasing buoyancy, which makes descents to deep water easier.

The long-held view that marine mammals don't get the bends may not be accurate after all. It has been suggested that deep-diving whales suffer from some of the effects of the bends, as evidenced by the degeneration of bone and cartilage in sperm whales, possibly caused by nitrogen bubbles.

Adaptations for deep, prolonged dives in marine mammals include the efficient exchange of air on the surface, the storage of more oxygen in the blood and muscles, a reduction of the blood supply to the extremities, and collapsible lungs to help prevent the bends.

Echolocation Marine mammals depend little on the sense of smell, which is so important to their terrestrial cousins. Their vision is excellent, but they have developed **echolocation,** another sensory system based on hearing. Echolocation is nature's version of sonar. Most if not all toothed whales, including dolphins and porpoises, and some pinnipeds are known to echolocate. At least some baleen whales may also use echolocation. Echolocation is not exclusive to marine mammals. Bats, for example, use it to find insects and other prey while flying at night.

Marine mammals echolocate by emitting sound waves, which travel about five times faster in water than in air, and listening for the echoes reflected back from surrounding objects (Fig. 9.27). The brain then analyzes the echoes. The time it takes the echoes to return tells the animals how far away the object is.

Many marine mammals echolocate by analyzing the echo of sound waves they emit. Echolocation is used to find prey and orient to the surroundings.

The sounds used in echolocation consist of short bursts of sharp clicks that are repeated at different frequencies. Low-frequency clicks have a high penetrating power and can travel long distances. They reflect from large features and are used to obtain information on the surrounding topography. Low-frequency sound waves may also be used in some toothed whales to stun their prey. It seems that sperm whales catch squids, including giant squids, without using their teeth, even if the teeth are actually of little help because they are present only in the lower jaw. In fact, live squids have been known to come out alive from the stomachs of freshly caught whales! To discriminate more detail and locate nearby prey, high-frequency clicks that are inaudible to humans are used. Experiments have shown that blindfolded bottlenose dolphins can discriminate between objects of slightly different size or made of different types of materials and can even detect wires.

Aerobic Respiration

in all cells

organic matter + O_2 → CO_2 + H_2O + energy
(glucose)

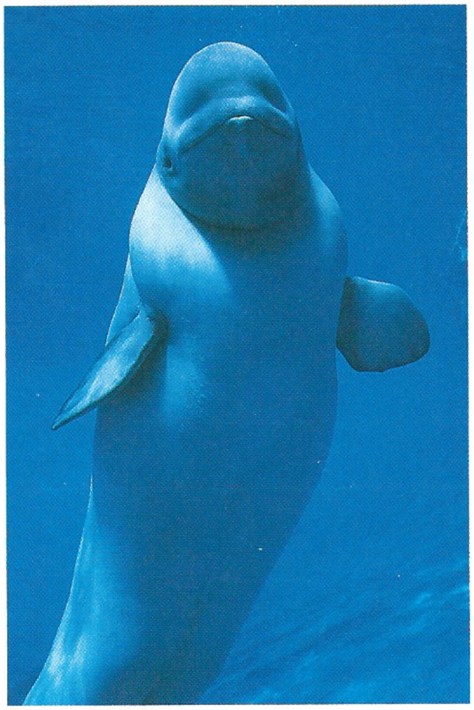
• Chapter 4, p. 67

Anaerobic Respiration

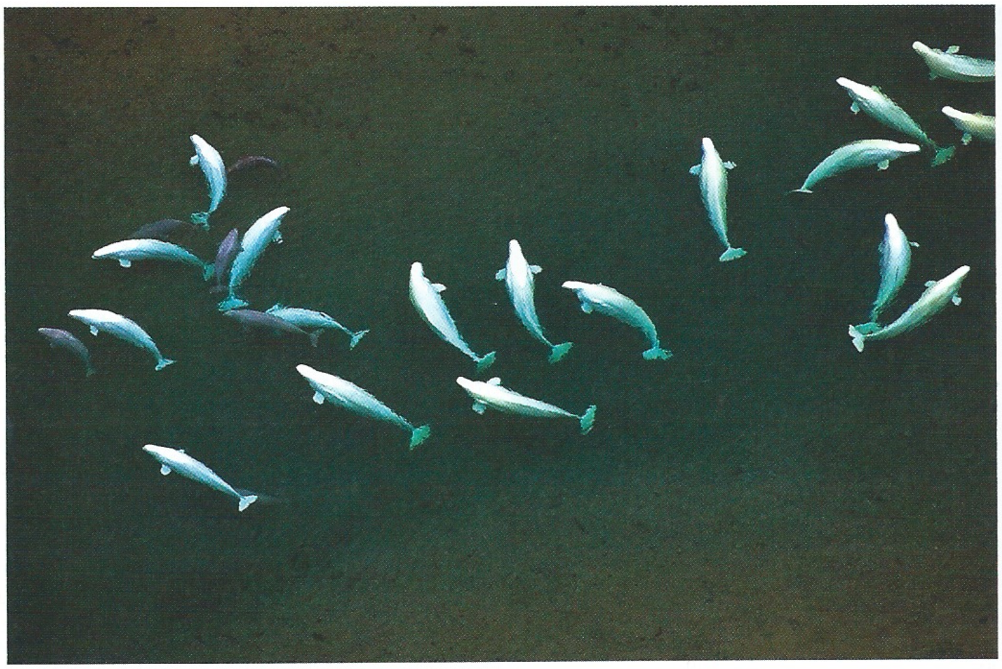
in muscles

organic matter → energy + lactic acid
(glucose)

• Chapter 4, p. 68



(a)



(b)

FIGURE 9.28 (*a*) The beluga (*Delphinapterus leucas*) is a white Arctic whale (*beluga* means "white one" in Russian) with a conspicuous melon. (*b*) In their natural environment belugas live in small groups.

We are not completely sure how echolocation operates in marine mammals. Cetaceans produce clicks, squeaks, and whistles as air is forced through the air passages and several associated air sacs while the blowhole is closed (Fig. 9.27). The frequency of the clicks is changed, or modulated, by contracting and relaxing muscles along the air passages and sacs. A fatty structure on the forehead of toothed whales, the **melon,** appears to focus and direct the outgoing sound waves.

The melon gives these whales their characteristic rounded foreheads. To accommodate the melon, the skull is modified to form a pointed, dish-shaped face. The skull is also asymmetric, the right side being slightly different from the left side. Belugas (Fig. 9.28) have a bulging forehead, which changes shape as the melon, moved by muscles, focuses the sound. The huge forehead of the sperm whale is filled in part with a massive melon called the **spermaceti organ.** Whalers originally thought this was the sperm sac of the whale, hence the peculiar name. This organ is filled with a waxy oil, **spermaceti,** once much sought after for making candles and still used as a lubricant for precision instruments. The actual function of the spermaceti organ is a controversial issue. It has been suggested that the deep-diving sperm whale might also use the spermaceti organ to regulate buoyancy or to absorb excess nitrogen, keeping it out of the bloodstream.

In toothed whales incoming sound waves are received primarily by the lower jaw (Fig. 9.27). The ear canal that connects the outside with the inner ear is reduced or blocked in most cetaceans. The jawbones, filled with fat or oil, transmit sound to the two, very sensitive inner ears. Each ear receives sound independently. The ears are protected by a bony case and embedded in an oily mixture that insulates the ear but allows sound waves to pass from the jaws. Sound information is sent to the brain, which forms a mental "picture" of the target or surroundings. In fact, sight and sound information seems to be handled similarly by the brain. Captive dolphins can recognize by echolocation objects they have seen and recognize by sight those they have previously echolocated.

Behavior The mammalian brain has evolved as an association center for complex behaviors in which learning, not instinct, dominates. In contrast to fishes, birds, and other vertebrates, mammals rely mostly on past experience, stored and processed by the brain, to respond to changes in the environment (see "How Intelligent *Are* Cetaceans?," p. 203).

Most marine mammals are highly social, living in groups at least part of the time. Many pinnipeds live in huge colonies during the breeding season. Most cetaceans spend their entire lives in highly organized pods of a few (Fig. 9.28*b*) to thousands of individuals. Some pods include smaller subgroups organized by age and sex. To keep in contact, many of their highly complex and sophisticated behaviors are directed toward members of their own species. It can be said that cetaceans, like humans, have complex cultures that vary from group to group.

Sounds, or **vocalizations,** play a prominent role in communication. Sea lions and fur seals communicate by loud barks and whimpers; seals use more sedate grunts, whistles, and chirps. The vocalizations of pinnipeds are especially important in maintaining territories during reproduction (see "Reproduction," p. 206). Females and their pups or calves recognize each other partly by their sounds, partly by smell.

Cetaceans produce a rich variety of vocalizations that are different from the sounds used for echolocation. Both types of sounds can

How Intelligent Are Cetaceans?

We often hear that whales, dolphins, and porpoises are as intelligent as humans, maybe even more so. Are they really that smart? There is no question that cetaceans are among the most intelligent of animals. Dolphins, killer whales, and pilot whales in captivity quickly learn tricks. Bottlenose dolphins have been trained to detect underwater mines in murky water.

This type of learning is called **conditioning.** The animal simply learns that when it performs a particular behavior it gets a reward, usually a fish. Many animals, including rats, birds, and even invertebrates, can be conditioned to perform tricks. We certainly don't think of these animals as our mental rivals.

Unlike most other animals, however, dolphins quickly learn by observation and may spontaneously imitate human activities. One tame dolphin watched a diver cleaning an underwater viewing window, seized a feather in its beak, and began imitating the diver—complete with sound effects! Dolphins have also been seen imitating seals, turtles, and even water-skiers.

Given the seeming intelligence of cetaceans, people are always tempted to compare them with humans and other animals. Studies on discrimination and problem-solving skills in the bottlenose dolphin, for instance, have concluded that its intelligence lies "somewhere between that of a dog and a chimpanzee."

Such comparisons are unfair. It is important to realize that intelligence is a very human concept and that we evaluate it in human terms. After all, not many people would consider themselves stupid because they couldn't locate and identify a fish by its echo. Why should we judge cetaceans by their ability to solve human problems?

Both humans and cetaceans have large brains with an expanded and distinctively folded surface, the **cortex.** The cortex is the dominant association center of the brain, where abilities such as memory and sensory perception are centered. Cetaceans have larger brains than ours, but the ratio of brain to body weight is higher in humans. Again, direct comparisons are misleading. In cetaceans it is mainly the portions of the brain associated with hearing and the processing of sound information that are expanded. The enlarged portions of our brain deal largely with vision and hand-eye coordination. Cetaceans and humans almost certainly perceive the world in very different ways. Their world is largely one of sounds, ours one of sights.

Contrary to what is depicted in movies and on television, the notion of "talking" to dolphins is also misleading. Though they produce a rich repertoire of complex sounds, they lack vocal cords and their brains probably process sound differently than ours do. Bottlenose dolphins have been trained to make sounds through the blowhole that sound something like human sounds, but this is a far cry from human speech. By the same token, humans cannot make whale sounds. We will probably never be able to carry on an unaided conversation with cetaceans.

As in chimps, captive bottlenose dolphins have been taught American Sign Language. These dolphins have learned to communicate with trainers who use sign language to ask simple questions. Dolphins answer back by pushing a "yes" or "no" paddle. They have even been known to give spontaneous responses not taught by the trainers. Evidence also indicates that these dolphins can distinguish between commands that differ from each other only by their word order, a truly remarkable achievement. Nevertheless, dolphins do not have a real language like ours. Unlike humans, dolphins probably cannot convey very complex messages.

Bottlenose dolphins (*Tursiops truncatus*) participating in research to test acoustic communication. The devices on their heads, which are held in place by suction cups, light up every time a dolphin whistles.

Observations of cetaceans in the wild have provided some insights into their learning abilities. Several bottlenose dolphins off Western Australia, for instance, have been observed carrying large, cone-shaped sponges over their beaks. They supposedly use the sponges for protection against stingrays and other hazards on the bottom as they search for fish to eat. The use of sponges as tools is shown mostly by females, and it appears that this behavior is passed on by mothers to offspring. This is the first record of tool use and of its cultural transmission in a marine mammal in the wild.

Instead of "intelligence," some people prefer to speak of "awareness." In any case, cetaceans probably have a very different awareness and perception of their environment than do humans. Maybe one day we will come to understand cetaceans on their terms instead of ours, and perhaps we will discover a mental sophistication rivaling our own.

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be produced simultaneously, providing further evidence of the complexity of sound production in marine mammals. Social vocalizations are low-frequency sounds that humans can hear. The variety of sounds is amazing and includes grunts, barks, squeaks, chirps, and even "moos." Different sounds are associated with various moods and are used in social and sexual signaling. Whistles, emitted in many variations and tones, are characteristic of each species. Some of these sounds serve as a "signature," allowing individuals of the same species to recognize one another. Male fin whales use high-intensity songs to attract females. Among the more than 70 calls that have been identified among killer whales, some are present in all individuals, whereas others are "dialects" that identify certain pods.

Sounds are also used to maintain the distance between individuals and have an important role in the structure of the pod. Particular sounds are emitted during breeding, feeding, alarms, and birth. Mother gray whales grunt to stay in contact with their calves. Fin whales make a low-pitched sound thought to be involved in long-distance communication. Right whales have at least six distinct calls, each related to a specific function, and they can even call louder as background noise gets louder.

The humpback whale is renowned for its soulful songs. They are sung by breeding males to attract females by advertising their readiness to mate. The songs consist of phrases and themes repeated in a regular pattern for a half hour or longer. They may be repeated over and over for days. The songs change over time. Males also start each breeding season with the song they were singing at the end of the previous breeding season. New songs learned from immigrants have been shown to gain instant popularity among native whales. Researchers record and catalog songs to help track whales in their annual migrations. It has been found, for instance, that blue whales are enigmatically singing in a key that is lower than in previous records.

Communication among cetaceans is not restricted to vocalizations. Researchers have described a variety of postures and movements that may indicate the animal's mood. Dolphins clap their jaws or turn around with their mouths open as a threat. The loud cracking sound made when some marine mammals slap their flukes or flippers on the surface is thought to be a warning signal.

Cetaceans are noted for their **play behavior,** seemingly pleasurable activities with no serious goal. Many species, including the great whales and killer whales, play with food or floating objects like logs, kelp, and feathers, throwing them up in the air or holding and pushing them with their snouts. Individuals may swim head down or on their backs apparently just for the fun of it. Dolphins play with rings of air bubbles they create. Dolphins also like to surf, and pilot and right whales go sailing with their flukes out of the water to catch the wind. Sex play, the rubbing and touching of the genital opening, is also common.

The sight of a great whale **breaching,** leaping up in the air and loudly crashing on the surface, is awesome (Fig. 9.29). Breaching has been variously interpreted as a warning signal, as a way of scanning the surface or the shoreline, as a means of getting rid of external parasites or an ardent lover, and simply as fun. After a deep dive, sperm whales may breach, fall on their backs, and make a splash that can be heard 4 km (2.5 mi) and seen 28 km (17.4 mi) away! Many whales stick their heads out of the water to spy on their surroundings (Fig. 9.30*b*).

The complex behavior of cetaceans is evident in other ways. When one individual is in trouble, others may come to assist (Fig. 9.30*a*). Members of a pod refuse to leave a wounded or dying comrade. Whalers knew that a harpooned whale was a lure for others, which are drawn from miles around. Dolphins will carry injured individuals to the surface to breathe (Fig. 9.30*c*), and there are records of females carrying the body of a stillborn calf until it rots.

Many toothed whales work together when they hunt, some in coordinated pairs. Sometimes whales take turns feeding while their partners herd a school of fish. An individual may investigate something strange lying ahead while the rest of the group waits for the "report" of the scout. Studies of animals in the wild show that dolphins belong to a complex society, one in which long-term partnerships of members of the same sex play an important role in sexual behavior, parental care, and other aspects of daily life. Social behavior in cetaceans may ultimately show many parallels with social behavior in large-brained mammals such as apes and humans.

One of the mysteries of the behavior of whales and dolphins is the **stranding,** or **beaching,** of individuals, sometimes dozens, on beaches (Fig. 9.31). The animals refuse to move, and efforts to move them into deeper water usually fail. Even if they are pulled out to sea, they often beach themselves again. The whales die because their internal organs collapse without the support of the water. Stranding has been described in many species, but some, such as pilot and sperm whales, strand themselves more often than others. It appears that whales become stranded when they follow one or more members of their group that have become disoriented by a storm, illness, or injury. This indicates the strong cohesiveness and herd instinct of the group.

Marine mammals, particularly cetaceans, use a rich variety of vocalizations and tactile and visual signals to communicate with each other. Play behavior and mutual assistance are additional evidence of the complexity of their behavior.

Stranding of whales has recently been linked to high-intensity sonar that uses bursts of intense sound waves. The navies of the United States and other nations have used the sonar to detect enemy submarines. Whales stranding after naval exercises where the sonar was used showed hemorrhages in the brain and inner ears, which cause disorientation and death. Tissue injury may also be caused by the formation of nitrogen bubbles or the bends. As a result, a 2002 court decision temporarily banned the United States

FIGURE 9.29 A humpback whale (*Megaptera novaeangliae*) performing a full spinning breach.

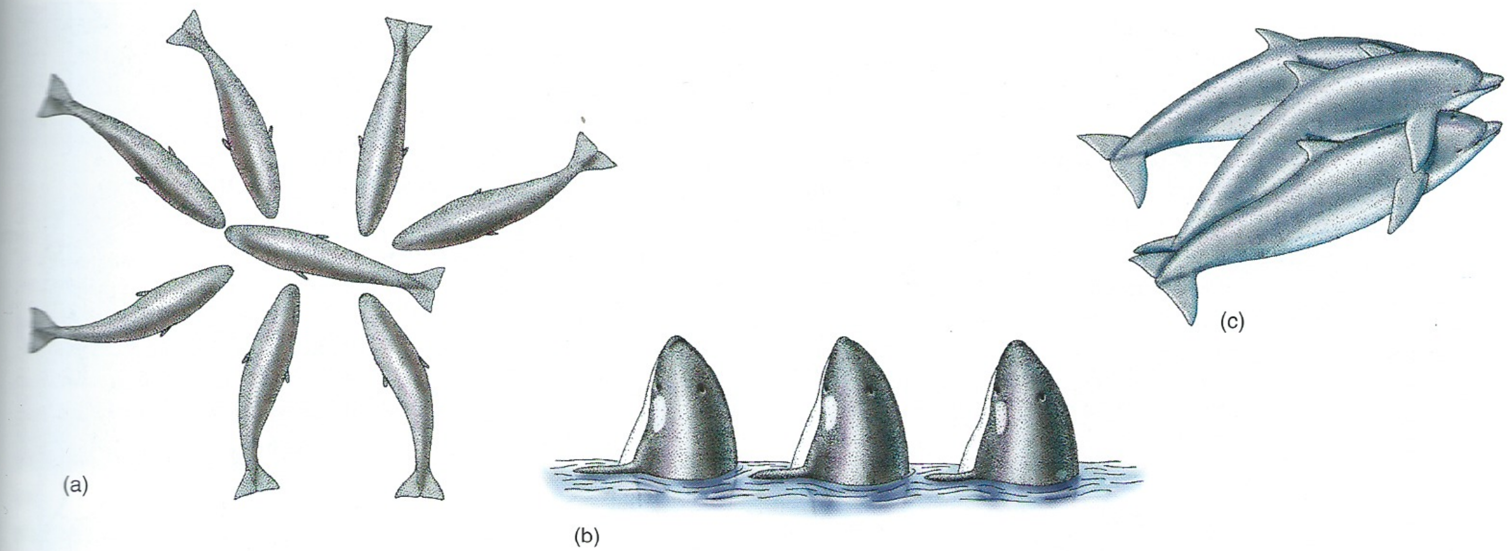


FIGURE 9.30 Whale watchers may be rewarded with examples of the complex behavior of whales: (*a*) sperm whales (*Physeter macrocephalus*) surrounding an injured member of a pod, (*b*) "spying" behavior in killer whales (*Orcinus orca*) in the wild, (*c*) two bottlenose dolphins (*Tursiops truncatus*) carrying a stunned companion to the surface to breathe.

Navy from the worldwide use of the high-intensity sonar. Noise from ship propellers, depth sounders, and sonar used for scientific purposes has also been suggested as disturbing to whales. Dolphins spend more time on the surface and rest less, and killer whale calls last longer, when whale-watching boats are close by.

The relationship between dolphins and humans is a controversial one. Though exaggerations abound, there are authenticated cases of dolphins approaching human swimmers who appeared to be in trouble. For more than a century, fishers in southern Brazil have established a unique partnership with dolphins. The dolphins detect fish and deliver them to fishers waiting with nets. Fishers have learned to interpret cues given by the dolphins about the location and abundance of fish. Generations of dolphins have learned that a row of fishers holding a net in shallow water means an easy catch for themselves, even if it has to be shared with funny-looking, two-legged mammals.

Some people swear of experiencing "spiritual inspiration" while swimming among dolphins during the "dolphin encounters" offered by some resorts. Dolphins trained for military purposes by the former Soviet navy are being used to treat children suffering from behavioral disorders. Other people see this as outright exploitation of the captive animals, and interactions with humans may after all be harmful to dolphins. It has been suggested that stress among captive dolphins reduces their life span.

FIGURE 9.31 These pilot whales (*Globicephala melas*) stranded themselves on a beach in Cape Cod, Massachusetts. Only two of the 55 stranded whales survived.

Migrations Many pinnipeds and cetaceans make seasonal migrations, often traveling thousands of miles from feeding grounds to breeding areas. Male southern elephant seals (*Mirounga leonine*) are known to travel as far as 8,000 km (almost 5,000 mi) to mate. Most toothed whales, on the other hand, do not migrate at all, though they may move about in search of food.

The migrations of the great whales are by far the most remarkable. Many baleen whales congregate to feed during the summer in the productive waters of the polar regions of both hemispheres, where huge concentrations of diatoms and krill thrive in the long days. During the winter they migrate to warmer waters to breed. The seasons are reversed in the Northern and Southern Hemispheres, so, when some humpback whales are wintering in the Hawaiian Islands or the West Indies, other humpbacks living in the Southern Hemisphere are feeding around Antarctica during the southern summer (Fig. 9.32).

Most great whales migrate from winter breeding areas in the tropics to summer feeding areas in colder waters.

The migratory route of the gray whale is the best known of any of the great whales (see Fig. 9.32). From the end of May to late September, the whales feed in shallow water in the northern Bering, Beaufort, and East Siberian seas. They begin moving south in late September when ice begins to form. In November they begin crossing through the eastern Aleutian Islands. They eat less while on the move, burning off close to a quarter of their body weight. The whales cover about 185 km (115 mi) per day. They travel alone or in small groups along the coast of the Gulf of Alaska and down the western coast of North America en route to the Baja California Peninsula in Mexico (see Fig. 9.22). Migrating individuals often show spying behavior, pushing their heads out of the water. This raises the possibility that they navigate by using memorized landmarks. They reach Oregon around late November or early December and San Francisco by mid-December. Females

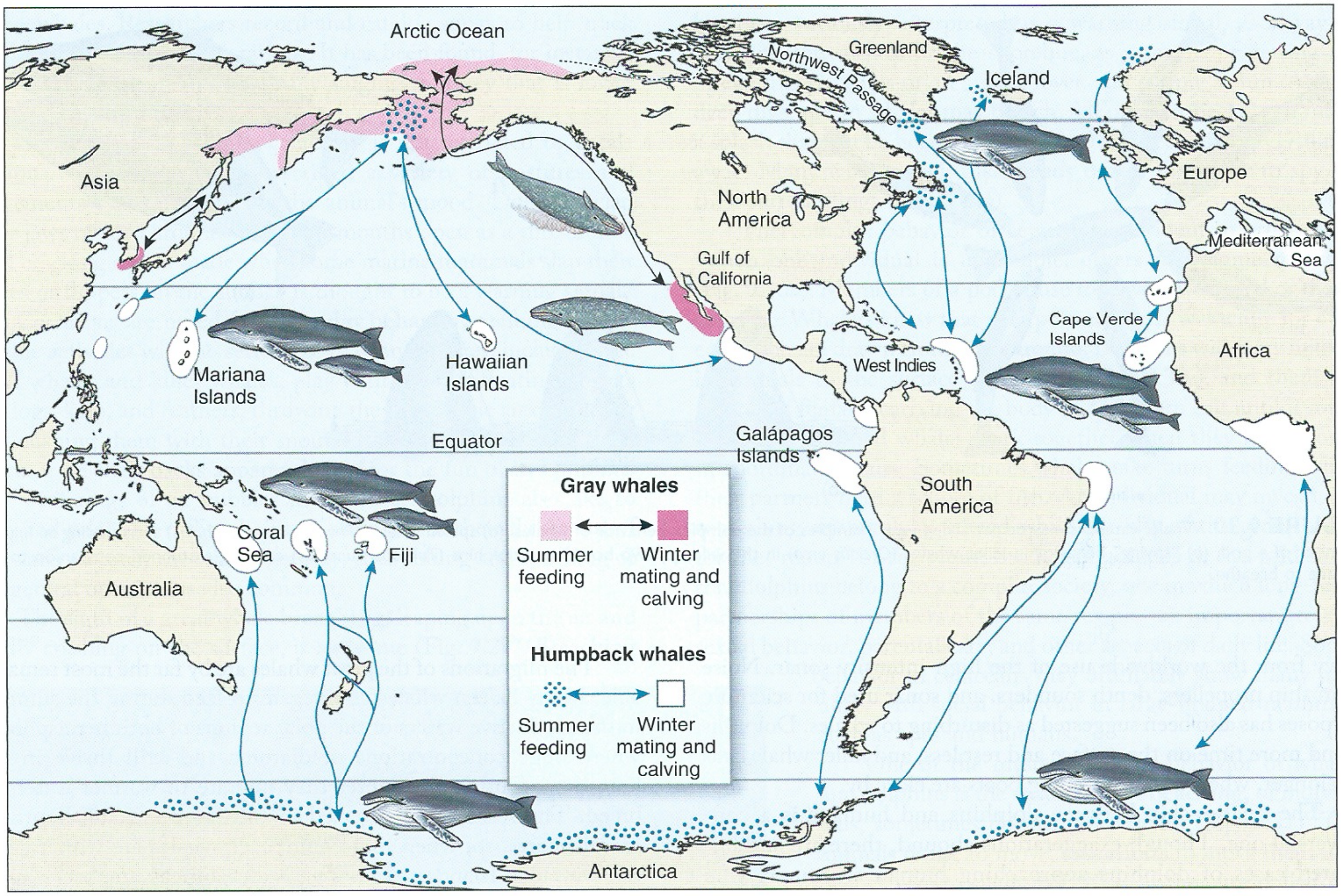


FIGURE 9.32 Migration routes of humpback (*Megaptera novaeangliae*) and gray whales (*Eschrichtius robustus*). Both species tend to migrate and breed close to shore, where they were easily hunted. Both species are on the comeback, and the gray whale is no longer considered endangered. The western Pacific population of grays that may still breed south of Korea also appears to be making a comeback. Gray whales used to live in the North Atlantic until exterminated in the nineteenth century. A gray whale was spotted in the Mediterranean Sea in 2010, apparently swimming there along the ice-free Northwest Passage in northern Canada.

generally migrate earlier. In late February pregnant females are the first to appear in shallow, quiet lagoons in southern Baja California and the southern mainland coast of the Gulf of California. It is here that females give birth and males mate with non-pregnant females.

The northbound migration begins by March, after the birth of the 700- to 1,400-kg (1,500- to 3,000-lb) calves. Females mate every two years, and the first to migrate north are the newly pregnant females that did not give birth. They will return 12 months later to give birth. Mothers with calves leave last. On the way north the whales tend to stay farther from the coast and move slower than on their southward migration, an average of 80 km (50 mi) per day because of the unfavorable currents (see Fig. 3.20) and the newborn calves. The last whales leave the coast off Washington State by early May. They start reaching their feeding areas by late May, completing an amazing eight-month trip of up to 18,000 km (11,200 mi), the longest migration of any mammal.

There is still much to be learned about the migrations of the gray and other whales. One vexing question is how whales navigate. It has been suggested that they use the earth's magnetic field, a possibility that implies that they carry some type of internal compass to orient themselves.

Scientists are using novel ways to investigate the migration of whales. Attaching small radio transmitters to whales and tracking their movements by satellite promises to uncover intriguing details. It has been found, for instance, that some isolated groups of gray whales along the migratory route do not migrate at all. One group resides in the Queen Charlotte Islands off the coast of British Columbia. Gray whales are also known to avoid cities by moving away from the coast. Females and young may slow down their migration back to the Arctic by taking shelter in kelp forests to avoid killer whales. Analysis of the DNA of humpback whale populations in the Hawaiian Islands suggests that, as in the green turtle, individuals always return to the feeding grounds of their mothers.

Reproduction The reproductive system of marine mammals is similar to that of land mammals. They have some unique adaptations to life in the water, however. To keep the body streamlined, male cetaceans and most other marine mammals have an internal penis and testes. The penis, which in blue whales is over 3 m (10 ft) long, is kept rigid by a bone. It is extruded just before copulation through the **genital slit,** an opening anterior to the anus (see Fig. 9.15).

Pinnipeds breed on land or ice, some migrating long distances to isolated islands to do so. In most species of seals each adult male breeds with only one female. Camcorders attached to animals in the wild (see "Observing the Ocean," p. 6) have shown that male harbor seals make rumbling noises, quiver their necks, and release a stream

(a)

(b)

FIGURE 9.33 (*a*) A male Steller sea lion (*Eumetopias jubatus*) guarding his harem on a rocky island off the coast of Alaska. Steller sea lions are the largest of the eared seals; males may weigh nearly 900 kg (1 ton). (*b*) A harem of female California sea lions (*Zalophus californianus*) on Santa Barbara Island, Southern California. The harem (center) is being guarded by a large, darker bull (top left). Large female elephant seals (*Mirounga angustirostris*) rest near the harem, oblivious to the occasional fights between the bull and rival males around the harem.

of air bubbles, perhaps a display to attract females. In sea lions, fur seals, and elephant seals, however, a male breeds with many females. During the breeding season the males of these species, which are much bigger and heavier than females, come ashore and establish breeding territories. They stop eating and defend their territories by constant, violent fighting. They herd **harems** of as many as 50 females onto their territories and keep other males away (Fig. 9.33). Only the strongest males can hold territories and breed. The others gather into **bachelor groups** and spend much of their time trying to sneak into harems for a quick copulation. Defending the harem is exhausting work, and dominant males "burn out" after a year or two, making way for newcomers. It nevertheless pays off in the huge number of offspring they leave, compared with the males that never reach dominance, even though the subordinate males live longer.

Female pinnipeds give birth to their pups on shore. They seem to be indifferent to the birth process but soon establish a close relationship with the pup (Fig. 9.34). Because females continue to go to sea to feed, they must learn to recognize their own pups out of all the others by sound and smell. The pups generally cannot swim at birth. They are nursed for periods of four days to two years, depending on the species. Most pinnipeds have two pairs of mammary glands that produce a fat-rich milk ideal for the rapid development of the pup's blubber.

A female pinniped can become pregnant only during a brief period after **ovulation,** the release of an egg by her ovaries. This occurs just days or weeks after the birth of her pup. Females of most species return to the breeding grounds only once a year. By contrast, **gestation,** the length of time it takes the embryo to develop, is less than a year. This difference would cause the pup to be born too early, before the mother returns to the breeding ground. To prevent this, the newly formed embryo stops developing and remains dormant in the female's womb, the **uterus.** After a delay of as long as four months, the embryo finally attaches to the inner wall of the uterus and continues its normal development. This phenomenon, known as **delayed implantation,** allows pinnipeds to prolong the embryo's development so that the timing of birth coincides with the female's arrival at the safety of shore.

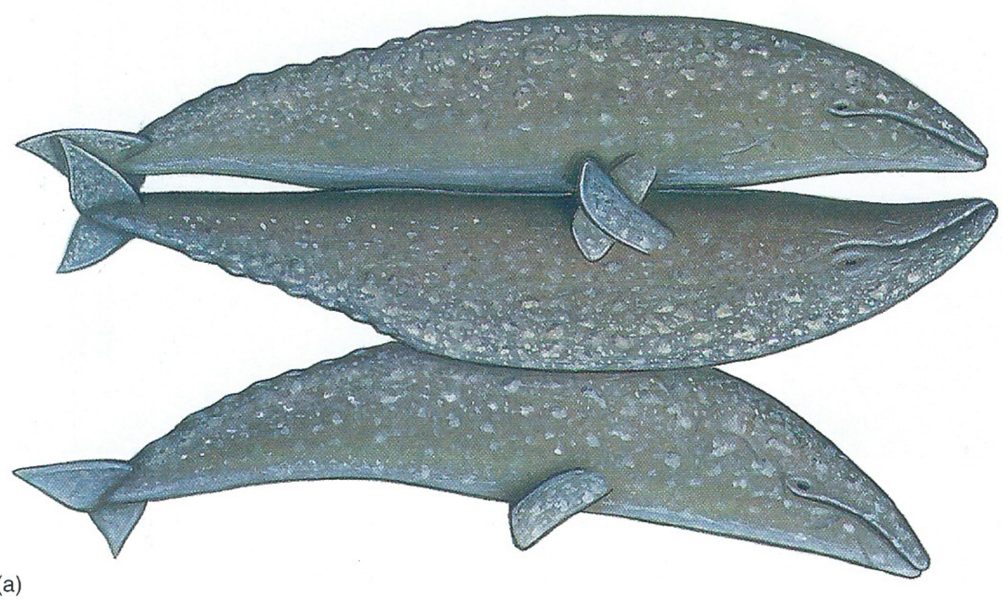
FIGURE 9.34 A California sea lion (*Zalophus californianus*) with a nursing pup.

Delayed implantation allows pinnipeds to time the birth of pups with the arrival of pregnant females in breeding areas.

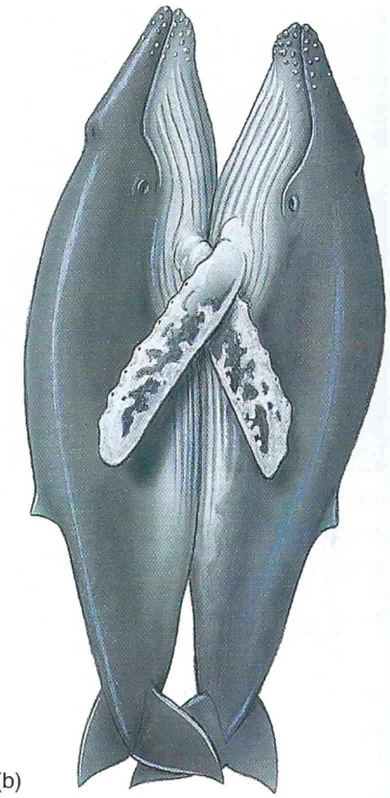
We know relatively little about cetacean reproductive behavior. We do know that cetaceans are intensely sexual animals. Sex play is an important component of the behavior of captive dolphins. Like humans, they appear to use sex not only for procreation but for pleasure as well. Cetaceans reach sexual maturity relatively early, at age 5 to 10 in great whales. Sexual behavior appears to have a role in the establishment and maintenance of bonds among all individuals, not just potential mates. The sexes are typically segregated within the pod, and males perform elaborate courtship displays to catch the attention of potentially receptive females. Fights among rival males are common, but cooperation also occurs sometimes. Gray whales are known to copulate with the help of a third party, another male that helps support the female (Fig. 9.35*a*). Group matings have been observed in humpback and beluga whales. Considerable touching and rubbing is known to precede copulation (Fig. 9.35*b*). Actual copulation lasts less than a minute but is repeated frequently.

Gestation lasts for 11 or 12 months in most cetaceans. An exception is the sperm whale, which has a gestation period of 16 months. Development in most species of large baleen whales is relatively fast for a mammal of their size. It is synchronized with the annual migration to warm waters. It is remarkable that it takes 9 months for a 3-kg (7-lb) human baby to develop, but a 2,700-kg (3-ton) blue whale calf needs only about 11 months.

Cetacean calves are born tail-first (Fig. 9.36). This allows them to remain



(a)



(b)

FIGURE 9.35 Mating behavior in great whales. (*a*) Gray whales (*Eschrichtius robustus*) often mate with the help of a third party, another male that props the female against the mating male. Actual copulation is reported to last for just 30 to 60 seconds. (*b*) Courtship in humpback whales (*Megaptera novaeangliae*) includes rolling, slapping of the flukes, and pairs surfacing vertically face to face.

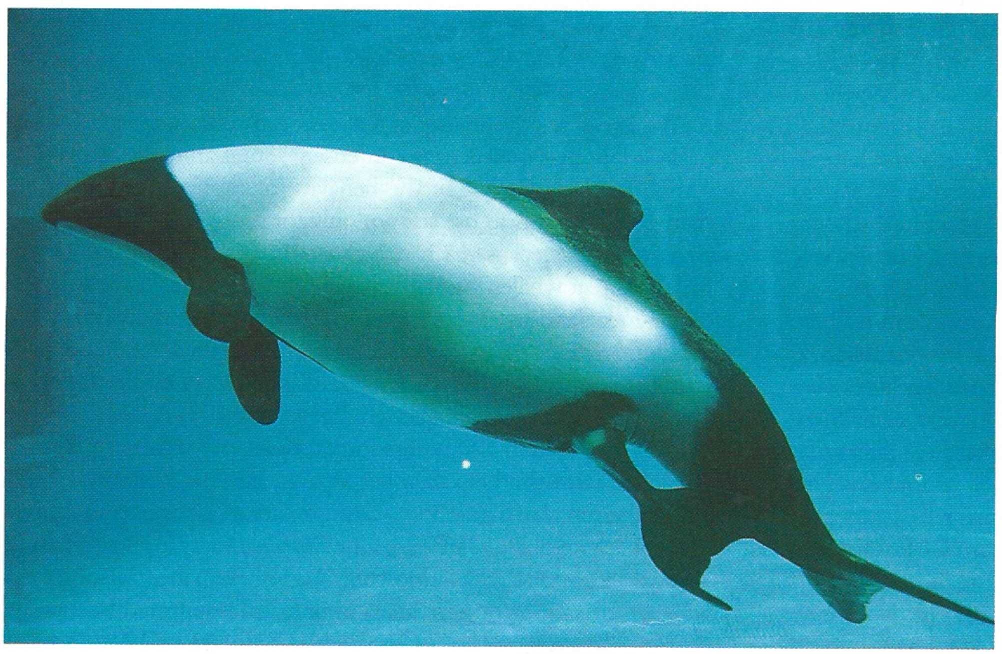


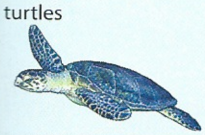
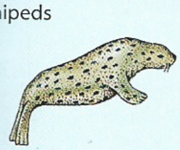
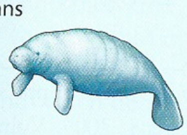
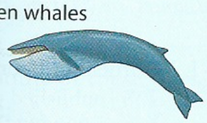
FIGURE 9.36 A Commerson's dolphin (*Cephalorhynchus commersoni*) giving birth in captivity. Not much is known about this dolphin, which is found only in southern South America.

attached to the placenta, which provides oxygenated blood from the mother, for as long as possible to prevent oxygen deprivation. The calf immediately swims to the surface. In captive dolphins, the mother or an attending female may help the calf to the surface. Fat-rich milk is responsible for the rapid growth of calves, particularly in the great whales. They are born without their full complement of blubber and must gain weight before migrating with their mothers to feeding grounds in polar waters. It has been estimated that a blue whale calf gains 90 kg (200 lb) in weight and 4 cm (1.5 in) in length every day for the first seven months of its life. The mother's milk is produced by two mammary glands with nipples located on both sides of the genital slit (see Fig. 9.15). The milk is squirted into the calf's mouth, which allows the calf to drink under water. In at least some of the great whales, females do not seem to feed much while they are nursing. The calves are not weaned until they arrive at the feeding grounds. In some species they continue to nurse for more than a year after birth.

The relationship between mother and calf during the nursing period is very close. Frequent contact and vocalizations are used in communication. Dolphin mothers modify their swimming behavior to allow calves to glide alongside. Mothers are known to defend their calves when there is danger. Sperm whale calves are watched by "babysitting" adults when mothers deep-dive for food. There is a report of a female gray whale lifting her calf onto her flipper to save it from the attacks of killer whales. The bond between mother and calf probably lasts for several years. Captive young dolphins are known to return to their mothers for comfort in times of danger or stress.

Great whales have been estimated to live at least 30 to 40 years on average. Humpbacks are known to live at least 50 years, bowheads 150 years.

Table 9.3 Most Important Characteristics of the Marine Reptiles, Seabirds, and Marine Mammals

Group	Distinguishing Features	Temperature Regulation	Feeding	Reproduction	Significance in the Marine Environment
Sea turtles 	Body covered by shell, scales on exposed parts of body, legs modified as flippers, found mostly in tropical seas	Poikilotherms, ectotherms	Toothless jaws adapted for crushing hard invertebrates or for picking soft invertebrates	Oviparous, laying eggs on sandy beaches	Predators of jellyfishes and bottom invertebrates, grazers of seagrasses and seaweeds
Sea snakes 	Skin with scales, no legs, laterally flattened for swimming, venomous, found only in tropical Indian and Pacific oceans	Poikilotherms, ectotherms	Small teeth adapted for capturing small prey	Ovoviviparous, giving birth at sea, or oviparous, laying eggs on land	Predators of bottom fishes; some feed mostly on fish eggs
Marine iguana 	Skin with scales, tail laterally flattened for swimming, found only in the Galápagos Islands	Poikilotherms, ectotherms	Three-cusped teeth adapted for grazing	Oviparous, laying eggs in nest on land	Grazer of seaweeds
Saltwater crocodile 	Skin with scales, massive jaws and tail, found in coastal regions in Australia, Southeast Asia, and some western Pacific islands	Poikilotherms, ectotherms	Heavily toothed jaws for capturing wide range of prey	Oviparous, laying eggs in nest of mud and vegetation on land	Predator of wide variety of coastal animals, including fishes, seabirds, sea turtles, crabs
Seabirds 	Feathers for insulation, webbed feet, light bones as adaptation for flight, found in all coastal regions	Homeotherms, endotherms	Beaks adapted for capturing wide range of prey, including filtering	Oviparous, laying eggs in nest on land	Predators of fishes and many groups of surface-dwelling and shallow-water invertebrates, including plankton
Pinnipeds 	Seals, sea lions, walrus: blubber, flippers, reduced hair (fur in some), found mostly in temperate and polar waters	Homeotherms, endotherms	Teeth for capturing and eating prey	Viviparous, giving birth on land	Predators of mostly fishes, crab-eater seal filters water for krill, leopard seal hunts mostly seabirds, walrus feeds on clams and bottom invertebrates
Sea otter 	Dense, dark fur, dorsoventrally flattened tail, flattened hind feet, found only in northern and northeastern Pacific Ocean	Homeotherms, endotherms	Flattened teeth for capturing and crushing prey	Viviparous, giving birth at sea or on land	Predator of sea urchins and wide range of bottom invertebrates and fishes in kelp forest
Polar bear 	Dense, white fur, found in Artic region, mostly on drifting ice	Homeotherms, endotherms	Powerful jaws and teeth for capturing and eating prey	Viviparous, giving birth on land	Predator of seals
Sirenians 	Manatees, dugong: blubber, reduced hair, front flippers, paddle-shaped tail, tropical seas (one species only in fresh water)	Homeotherms, endotherms	Teeth as thick ridge pads for crushing vegetation	Viviparous, giving birth at sea	Grazers of seagrasses and other coastal vegetation
Baleen whales 	Blubber, streamlined body, reduced hair, front flippers, tail fluke, blowhole, found in all seas	Homeotherms, endotherms	Baleen on upper jaw for filtering small plankton	Viviparous, giving birth at sea in warm waters	Filter feeders of plankton and small fishes, mostly in polar waters; gray whale feeds on small animals (mostly amphipods) in soft bottoms
Toothed whales 	Blubber, streamlined body, reduced hair, front flippers, tail fluke, blowhole, found in all seas (some dolphins live in fresh water)	Homeotherms, endotherms	Conical teeth for capturing prey	Viviparous, giving birth at sea	Predators of fishes, squids, other marine mammals, and some large bottom invertebrates such as lobsters