HOT TOPICS IN MARINE BIOLOGY 6.3

Great Oceanic Migrations that Dwarf the Serengeti

Until recently, we simply had no idea of the extent and fidelity of ocean-scale migrations. This changed with the advent of satellite tags, and the results were startling. We mentioned the great white shark that moved between waters of South Africa and western Australia, a distance of over 20,000 km. Is the open ocean organized on such large geographic scales? What is the driving force?

We can look to land for a model. In a relentless clockwise migration in eastern Africa, about 1.4 million wildebeest and 200,000 zebra and gazelle make the trek between the southern short-grass plains of the great Serengeti (Swahili for "endless plains") of Tanzania and southern Kenya's Masai Mara, the Serengeti's northern limit. The round-trip is about 6000 km, which, as great as it is, is dwarfed by the journey of the great white shark mentioned earlier. The migrants are tracked over this vast expanse by large and powerful predators. Every river forded is an opportunity for the great Nile crocodiles to pick off slow and unwitting victims, and every step on land may be in view of a pride of lions.

What drives this great migratory cycle? Control comes from the bottom of the food chain, which is comprised of endless plains of grass grazed by the herbivores. But the abundance of grass is strongly controlled by seasonal rain. As the rains shift between north and south, so does grass production, and the grazers that need food must migrate in response. From November to January, the rains are stronger in the southern Serengeti, and the enormous populations of herbivores graze there and produce calves. Then, seasons change and rains shift to the north, followed by June migrations: Hundreds of thousands of individual animals flock to the banks of the Grumeti River, where they cross and are picked off by the hundreds by ravenous crocs. By July and August the herds arrive at the northern part of the Serengeti and then begin to move south in October, completing the seasonal cycle.

The Serengeti teaches a simple lesson: Seasonal rains cause grass to grow, which leads larger grazers to follow the trail, which in turn attracts large predators. The macroscale pattern of migration is driven from bottom-up ecosystem effects that are strongly seasonal. To take this lesson to the ocean, we need to find out where the bottom of the food web is stimulated and whether the location of growth moves, as grass growth shifts in the Serengeti. This is easier said than done, however. We have developed important tools to plot regional and seasonal patterns of productivity in the ocean (discussed in Chapters 9 and 10), but how do we find the paths of the grazers and the large predators? Sharks and tuna cannot be so easily spotted from planes and overland vehicles.

The great white shark that moved from South Africa to Australia and back shows just how much can be learned from a satellite tag, and a large number of tuna, shark, and sea turtles have been tracked over great distances to show the enormous scales of movement of these creatures. But we needed a far more sophisticated multispecies approach to tracking, and this has led to the formation of the **Tagging of Pacific Predators (TOPP)** group of the Census of Marine Life (www.topp.org), which has followed for a decade the movements of 23 predatory species in the North Pacific Ocean. The TOPP group of over 90 scientists used implanted pop-up archival satellite tags that recorded data—including temperature, water pressure (indicating depth), and GPS location—over a period of years. Unfortunately, this tag costs several thousand dollars and can be lost by malfunction or by being swallowed by another giant predator. But the TOPP group also used Argos tags that transmit data continuously to the Argos satellite system. Marine mammals and sea turtles spend much time at the surface and are ideal for such tags. Equally important was the ecological approach of tagging **guilds** of species, which have similar use of prey species but with varying specializations. This allowed the group to understand both movements and use of different prey species over a wide region.

The results of the first decade's watch of the Pacific, using over 4,000 tags to follow approximately 1,800 tracks of 23 species, has produced the beginnings of a map of major North Pacific migration routes (Block et al., 2011). Taken one by one, many species of predators have somewhat different patterns. For example, the Pacific white shark (**Box Figures 6.4 and 6.5**) shows a consistent homing migration between the Hawaiian Islands and California (Jorgensen et al., 2010). But salmon sharks move between the waters of the Pacific subtropical ocean and Prince William Sound, Alaska. When combined with other species we see that this great system is not exactly like the Serengeti. The Pacific is a larger and more diverse theater within which the ecological play is performed.

The great marine predators are associated with highly localized and often spatially changing huge sources of food driven from the base of the oceanic food web. This association is quite evident with tuna, which are usually concentrated in upwelling regions where nutrients and plankton are abundant. Plankton-eating baleen whales show this on a very short time frame: A group of whales may be found in a very localized upwelling zone with abundant zooplankton and then move hundreds of kilometers away after the resource is exhausted. These movements demonstrate that roving predators have been able to map the locations of a large number of areas with predictable but shifting food abundance. Even seabirds that rove large expanses of the ocean for prey can smell zooplankton or detect compounds released from phytoplankton blooms, which allows them to find upwelling centers, where zooplankton and fish are both abundant (Nevitt et al., 1995; Nevitt, 2000).

On the grand scale, there are two great belts of predatory activity and migration in the North Pacific Ocean. First, the **California Current Large Marine Ecosystem**, along the west coast of North America (**Box Figure 6.6**) includes a large number of tuna, whale, seabird, and other large fish species that move over tracks stretching hundreds to thousands of kilometers, usually in annual migrations with high site fidelity between zones of high productivity, often related to upwelling. Overall, many species are migrating seasonally between eastern and central North Pacific and the Gulf of Alaska.

Another large group of species move across the Pacific through the **North Pacific Transition Zone**, another region of high productivity that extends as an approximate east–west belt across the

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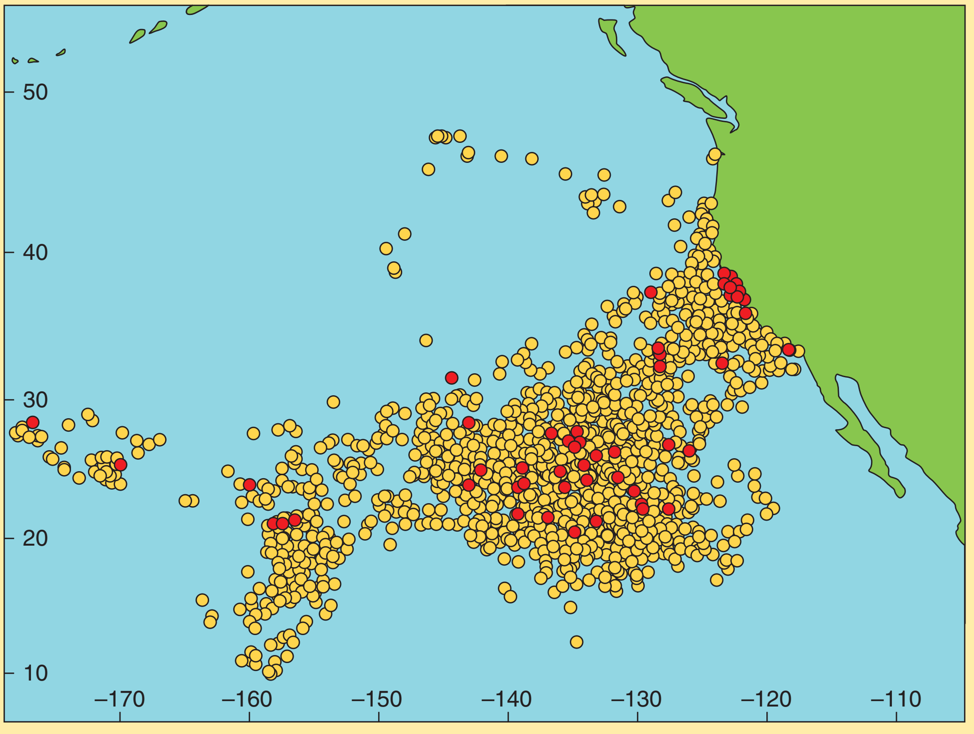
North Pacific Ocean between approximate latitudes of 32˚ N and 42˚ N. This zone is bounded by strong oceanic fronts where primary production is very high, which attracts prey of large predators. Prominent species included the white shark, elephant seal, sea turtles, and sea birds. In August 2011, Pacific bluefin tuna caught off the coast of southern California were found to have radioactive cesium-134, which has a half life of 2 years. This means that they had picked up contaminated material from the region of the Fukushima, Japan nuclear power plant meltdown (following the March 2011 tsunami and peak of leakage in April), and had swum across the entire

BOX FIG. 6.4 This Pacific white shark, photographed at the Farallon Islands off Northern California, has been tagged with an acoustic tag (front) and a pop-up satellite tag (rear) as part of the TOPP research program.



BOX FIG. 6.5 Tagging locations together identify the migration pattern of the Pacific white shark, *Carcharodon carcharias*, which migrates between coastal California waters and the Hawaiian Islands.

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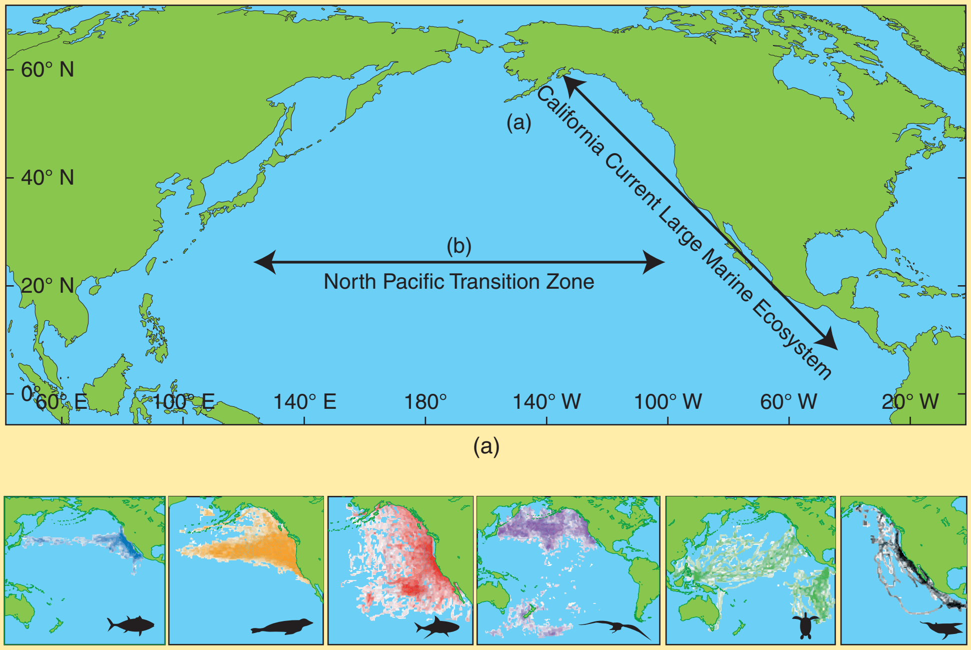

BOX FIG. 6.6 (a) Tagging of many large-bodied oceanic predators shows two major routes of migration, one along the eastern Pacific within the California Current Large Marine Ecosystem and the other through the North Pacific Transition Zone; (b) migration routes of individual migrating species groups, as indicated by tagging locations (after Block et al., 2011).

Pacific Ocean to California in only 4 months (Madigan et al., 2012). Luckily the tuna have cesium at levels that are not dangerous for human consumption, but the detection shows how important and rapid the migration route can be.

These two major realms capture only part of the diversity of migrations, but a statistical analysis shows strong associations of predator abundance and chlorophyll *a* concentrations, showing a link to productivity. Temperature is inevitably the major correlative factor in most distributions, since current structure, upwelling, and therefore food abundance are strongly linked to ocean climate. Recently, the TOPP program has been linked to climate change models, projecting changes of temperature and productivity patterns in the Pacific in the coming decades. A study by Elliott Hazen and colleagues (2012) predicts that the greatest disruption and loss of fisheries will be within the North Pacific Transition Zone. On the other hand, little effect is projected for the more coastal California Current Large Marine Ecosystem.

The broad expanse of the North Pacific appears to have considerably more complexity of migration and resource exploitation than in the Serengeti, which involves grazing species with similar food requirements that follow the same shifting seasonal patterns of water and grass distribution. Consider the black-footed albatross, which breeds on a series of remote islands such as the northwest Hawaiians throughout the North Pacific, but adults feed principally throughout the northern Pacific, especially in the northeast Pacific oceanic region where preferred fish and squid are plentiful. These requirements differ completely from the white sharks mentioned earlier. But the overall features of a large geographic scale of migration and the general rule of fidelity to multiple sites are shared by large Pacific marine predators and wildebeest alike. We are now beginning to have the tools needed to track oceanic predators wherever they swim or dive. Many other current systems in the world ocean, for example, the Canary Current off northwest Africa, are also being investigated on this oceanic megascale. ■

The hallmark of larval production and dispersal is a complex life cycle. An adult stage gives rise to a dispersing larva, which moves to a new site and completes the cycle by establishing itself and eventually growing to reproductive maturity. **Figure 6.13** shows an example of such a cycle. Although there is a continuum of dispersal distances, several qualitatively different types of release and spread of larvae result in modes of dispersal distances. **Direct release** of individuals next to adults is the shortest type of dispersal. Many species are **viviparous**; that is, they bear live embryos and then release juveniles as crawling miniature adults. Such young may crawl directly onto the mud or rocks. The Atlantic periwinkle *Littorina saxatilis* broods fertilized eggs in a modified oviduct, and fully shelled young snails are later released. Many Antarctic species of feather star (comatulid crinoids) develop their eggs in brood chambers