Tracking top marine predators in a dynamic ocean

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Like the vast African plains, two huge expanses of the North Pacific Ocean are major corridors of life, attracting an array of marine predators in predictable seasonal patterns, according to final results from the Census of Marine Life Tagging of Pacific Predators (TOPP) project published in the June 23 edition of the journal *Nature*.

The paper culminates the TOPP program's decade-long effort to track top marine predator movements in the Pacific Ocean. It presents for the first time the results for 23 tagged species and reveals how migrations and habitat preferences overlap - a remarkable picture of critical marine life pathways and habitats, according to the authors

The study found that major hot spots for large marine predators are the California Current, which flows south along the U.S. west coast, and a trans-oceanic migration highway called the North Pacific Transition Zone, which connects the western and eastern Pacific on the boundary between cold subarctic water and warmer subtropical water - about halfway between Hawaii and Alaska.

"These are the oceanic areas where food is most abundant, and it's driven by high primary productivity at the base of the food chain," said co-authors and project originators Barbara Block of Stanford University's Hopkins Marine Station and Daniel Costa, professor of ecology and evolutionary biology at the University of California-Santa Cruz.

"These areas are the savanna grasslands of the sea," they said. "Knowing

where and when species overlap is valuable information for efforts to manage and protect critical species and ecosystems."

Census of Marine Life

Costa and Block were joined by Steven Bograd of the National Oceanic and Atmospheric Administration (NOAA) Southwest Fisheries Science Center, Randy Kochevar of Stanford and others to launch the TOPP project in 2000 as part of the Census of Marine Life, a 10-year research initiative that investigated the diversity, distribution and abundance of marine life in the global ocean. TOPP became the world's largest-ever biologging study, eventually involving more than 75 biologists, oceanographers, engineers and computer scientists across five countries.

"It's been a bit like looking down on the African savanna and trying to figure out, where are the watering holes that a zebra and a cheetah might use?" said Block, professor of biology and senior fellow at the Woods Institute for the Environment. "Where are the fertile valleys? Where are the deserts that animals avoid, and the migratory corridors that animals such as wildebeest use to travel from place to place? We've come to a vast oceanic realm in the Pacific and answered these questions for animals as diverse as bluefin tuna, blue whales and leatherback sea turtles."

"This is the first publication that pulls all of the pieces together in one place," said Costa, who oversaw the tracking of marine mammals, birds, and turtles. "We brought together a large team of investigators to study diverse species and look at how these organisms use the ocean. It is an unprecedented examination of so many species over such a large scale."

Tracking technologies

The scientists used a variety of technologies to track the locations of different species, as well as environmental variables, such as water temperature, salinity and depth. Altogether, the project deployed 4,306 electronic tags on the 23 species, yielding a huge amount of data for analysis.

Working with census scientists at Dalhousie University in Halifax, Canada, and its Future of Marine Animal Populations (FMAP) project, the scientists spent two years synthesizing data sets with advanced statistical techniques and discerned intersecting hotspots and highways of ocean life and how marine conditions influenced where animals hang out.

"One of the challenges for this study was to take distinctly different types of location data - some very precise from Argos satellites and others far less precise from ambient light level readings and bring them together using a powerful statistical framework that enabled identification of high use areas" said co-author Ian Jonsen of Dalhousie.

The results suggest that water temperature is key to the seasonal migrations of many species. This was particularly evident in the large marine ecosystem defined by the cool, nutrient-rich water of the California Current. The study revealed the current to be a vast marine savanna to and within which a large number of whales, sharks, seals, seabirds, turtles and tunas migrate loyally every year. In fact, many highly migratory marine species return to the same ocean regions, homing with astonishing fidelity to the places they were first tagged, following a predictable seasonal pattern.

"For me, the homing capacity of species which routinely return to the California Current or shelf waters of North America has been the biggest surprise," Block said.

"It is akin to a student from London studying in far-off Rome and returning home each summer at the same moment - but doing it all in the dark, without a map or compass, using only their internal sense of position and direction," Costa added.

Seasonal significance

According to the authors, the mechanisms and cues that allow species to home with such fidelity to seasonal pathways are not yet fully understood, "but may represent a capacity to discriminate among areas of seasonal significance for foraging or reproduction."

Some predators, such as California sea lions, spend their whole lives within the California Current, but others migrate vast distances across the Pacific Ocean to reach abundant prey, such as krill, sardines, anchovies and squid.

"How or why a young bluefin tuna less than two years of age wakes up in the light of the Japan Sea and decides to swim to Baja remains completely unknown," Block said. "Once they get here, tagging data indicate they reside for years, taking advantage of the rich forage off North American coastlines. These tunas become vulnerable to oceanic fisheries across the Pacific during both this highly migratory period and this retentive period lunching on our coast."

The project found that several species - including leatherback sea turtles, black-footed albatrosses, sooty shearwaters, bluefin tunas and salmon sharks - migrate more than 1,200 miles (2,000 kilometers) from the western, central or south Pacific basin to reach the California Current's rich food resources - a commute equal to that between Seattle and San Diego.

Species making seasonal north-south migrations included bluefin and

yellowfin tunas; mako, white and salmon sharks; blue whales; male elephant seals; and leatherback sea turtles.

Other species moved between near-shore and offshore waters, residing within the California Current or the Gulf of Alaska for a while, then migrating to points that ranged into the North Pacific transition zone (female elephant seals, salmon sharks and Laysan albatrosses), the subtropical gyre and north equatorial current (blue and mako sharks and leatherback sea turtles), or the "café" regions of the eastern Pacific and the Hawaiian Islands (where species like white sharks, albacore tunas, and black-footed albatrosses meet).

"In this region we see a great deal of coastal upwelling, especially during the late summer and fall," said co-author Bograd of Dalhousie. "This is when cold, nutrient-rich water rises to the ocean surface, causing phytoplankton blooms and creating a rich food source for a variety of ocean animals."

Temperature data

The researchers found that ocean productivity from upwelling was also associated with the north-south migratory patterns exhibited by several species. And for the first time, the TOPP team has been able to link the movements of tunas, sharks and blue whales north and south along the southwestern US coastline with seasonal changes in temperature and chlorophyll concentrations.

"Using satellite observations of temperature and chlorophyll concentrations alone, we can now predict when and where individual species are likely to be in a given ocean region and begin to understand factors that control their movements," Costa said. "This is fundamental to the concept of ecosystem-based management."

The researchers also used distinctly different types of tracking data to examine the partitioning of habitats by closely related species. Different tuna species, for example, prefer particular water temperatures, and these preferences correlate with physiological differences between the species.

"We clearly have an amazing African-like game park in our waters off the west coast," Block said. "It will take enormous vision to protect this wild place. I hope our study stimulates the discussion of how best to do this. Without effective management of open ocean realms, the bluefin tuna, leatherback sea turtles, blue whales and white sharks seen in the central and eastern Pacific or off our North American shores in 2011 might not be there for future generations. This work has created an opportunity to protect this marine wilderness and keep North American waters teeming with predators."

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