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Sharks, Seals, and the Balance of Power at Sea

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ABSTRACT

Fur seals and penguins show up in the Southern Hemisphere; seals, puffins, and porpoises in the north. As icebergs appear on the horizon, large active sharks have vanished; orcas and leopard seals are the apex predators. The structure of marine life has changed dramatically with latitude. Why?

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Imagine, like a young Darwin on the *Beagle*, you took an ocean voyage to observe the natural history of the world. If you were to survey the great predators of the sea, you might notice a curious pattern: near tropical shorelines, 'cold-blooded' sharks and bony fish like barracuda and groupers predominate, with hardly a seal or penguin in sight. But as your ship heads to the poles, the balance shifts to warmer bodied predators. Fur seals and penguins show up in the Southern Hemisphere; seals, puffins, and porpoises in the north. As icebergs appear on the horizon, large active sharks have vanished; orcas and leopard seals are the apex predators. The structure of marine life has changed dramatically with latitude. Why?

Consult a textbook and you might learn that temperate waters are more productive than tropical ones, and warm-bodied endotherms, like mammals and birds, need to live in productive habitats to support their revved-up metabolism. Ectothermic fish, with their lower food requirements, are free to populate warm, unproductive seas. But new research on marine production undercuts this argument. Researchers now find high productivity occurs throughout much of the tropics, with warm water temperature boosting algal growth rates and great schools of bristlemouth and glowing lanternfish fish lurking just beneath the reach of light. Sharks, tuna, sea birds, and large pods of dolphin attend fish schools in these seas, but swimming birds (such as penguins, cormorants, puffins) and pinnipeds (seals, sea lions and walrus) are conspicuously absent. Enough food is there for endotherms, but only a few species seem to take advantage of it.

Something else is going on. In a recently published paper in *Science*, we provide theory and data showing that it isn't the presence of food that is driving these opposing patterns of predator diversity, but the difficulty of capturing prey that is the issue. Fish and squid form the base of most large predators' diet. The slower a fish moves the easier it is to catch, and fish movement declines exponentially in colder water. Cold water makes for better hunting ground for endotherms. Sharks, however, slow down at the same rate as their prey when the temperature drops. There is no hunting advantage gained, just tougher competition. Colder waters are also safer, from a mammal's perspective. Colder sluggish sharks are easier to avoid.

Swimming speed isn't the only thing affected by temperature. All metabolic processes are affected by water temperature in ectotherms, including neural firing that governs visual processing speeds and reaction times. In mesothermic swordfish, only the eyes and brain are heated by special tissues packed with mitochondria. A hotter brain thinks faster, so swordfish can react to prey more quickly. We show that these metabolic asymmetries between endotherms, ectotherms and mesotherms shape predatory and competitive interactions in consistent, theoretically predictable ways. To test our theory, we analyzed global datasets on marine mammal numbers and collective food consumption rates. The findings support theory: marine mammal population size and consumption increase over 50 times from the equator to the poles after controlling for food availability.

The consequences for biodiversity? Larger population sizes reduce the risk of extinction, increasing diversity. They may even promote specialization and new speciation events. For instance, orcas are in the process of speciation in several parts of the globe, with little gene flow between populations despite overlapping territory. In the North Pacific, 'resident' orca pods specialize on salmon and other fish, 'transient' pods roam the coasts searching for mammals, and 'offshore' populations are generalists that sport abrasions from ramming and consuming sharks. The ease of hunting for prey in the cold permits many strategies.

Our results have important implications for conservation. As atmospheric carbon dioxide increases, the earth warms, including at sea. Solitary, slow-moving endotherms, like seals and penguins, are particularly vulnerable to their prey heating up. These animals are not much faster than fish and do not work together to herd them into manageable groups. Indeed, our data shows a 24% decline in pinniped abundance for every 1 ºC increase in water temperature. In the Barents Sea, warming waters has coincided with an increase in capelin, a small fish that that is an important prey item for harp seal and an ectothermic competitor: cod. Despite the increase in food, harp seal populations have fallen while cod numbers have surged in this new, hotter environment. Rising temperatures are likely to shift the balance of endotherms and ectotherms toward cold-blooded predators across the globe.