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Fisheries Ecology: Hunger for Shark Fin Soup Drives Clam Chowder off the Menu

Removal by fishing of large sharks has reduced predation-pressure on shark prey and, via a trophic cascade, caused clam populations to crash. This indirect response illustrates why fisheries should be managed in a whole-ecosystem context.

Andrew S. Brierley

Snowshoe hares flourish when numbers of Canadian lynx, a specialist hare predator, decline. This classic two-species interaction, described elegantly by the Lotka-Volterra model of inter-specific competition, is familiar to most biologists because it is the example often used to introduce quantitative ecology. Terrestrial ecologists have progressed far beyond this simple duplex, explaining numerous aspects of the nested causes and consequences of population cycling at multiple trophic levels, including some relating directly to the plants that hares graze [1], and management of terrestrial ecosystems is a mature discipline in which multi-species interactions and socio-economics are often considered holistically [2]. But our understanding of processes in the oceans generally lags behind that of the more-easily observed dry-land ecosystems, and much of the global marine fishery is still managed on a single-species basis. A study by Myers *et al.* [3] exposes a trophic cascade — with ecological and economic consequence — triggered by fisheries-exploitation of apex predatory sharks, and provides a further justification for the application of an holistic 'ecosystem approach' to fisheries management [4].

Trophic cascades occur following adjustments in the levels of control exerted by predators towards the tops of food chains. Hairston *et al.* [5] were amongst the first to describe the phenomenon, pointing out that predators restrict the numbers of herbivores, enabling plants to flourish in a 'green world'. An example from the marine environment shows how plants are denuded by herbivores when predators are removed: off the coast of Alaska, forests of kelp thrive in the nutrient-rich waters, supporting communities of sea urchins that are in turn consumed by sea otters; when killer whales moved closer in shore from their usual open-ocean hunting grounds in the early 1990s and began to eat sea otters, otter numbers plummeted and urchins boomed in a chain reaction that lead ultimately to deforestation of kelp beds [6]. By adding a trophic level to the top of the food chain, immigrant killer whales repeated the ecosystem impact previously exerted by humans who had hunted sea otters for fur one hundred years previously, and again served to decrease the abundance of primary producers at the end of the line.

Trophic cascades are to be expected, and the directions of their changes can be predicted quite reliably, for simple linear food chains. Behaviours of complex, branching food webs, where trophic levels are populated not just by single species but by multi-species functional groups, render cascades theoretically less likely [7], and complex systems might be expected largely to be resilient to change. The study by Myers *et al.* [3], however, suggests that cascades can occur following relaxation of top-down control when entire guilds of apex predators are depleted, as is sometimes the case for poorly regulated commercial fisheries.

Myers *et al.* [3] catalogued the decline of 11 species of 'great' sharks (> 2 metres length), including Tiger shark (97% decline), Scalloped hammerhead shark (98% decline; Figure 1) and Blacktip shark (93% decline) from surveys along the Atlantic coast of the US between 1970 and 2005. Sharks are targeted directly by fisheries for their fins and meat, and are also caught unintentionally as 'bycatch'. One of the research surveys from which Myers *et al.* [3] obtained data caught sharks on their seasonal migration routes, suggesting that population declines were not just regional effects but were indicative of coast-wide population changes. Over the same 35-year period, Myers *et al.* [3] found that abundances of the majority of the great sharks' prey (a taxonomically diverse suite of 14 elasmobranch fish including rays, skates and smaller sharks) mirrored their predators' decline. These prey species are relatively large and are consumed almost exclusively by great sharks. They are also relatively long-lived and, under

Figure 1. Marine predators and prey.

Scalloped hammerheads (*Sphyrna lewini*) and Quahogs (hard clams, *Mercenaria mercenaria*) are linked in the food web off the east coast of the US, and have both suffered major declines as a consequence of fishing. Photographs by Bill Sanderson.

normal conditions, have stable populations: they are therefore highly suitable as indicators of a potential response to removal of the predatory great shark functional group. The near-exponential increase of elasmobranch prey over the same period as the great sharks' near-exponential decline is strongly suggestive of cause and effect. The response in one of the prey species, the Cownose ray, was particularly conspicuous, with populations achieving an order-of-magnitude increase to more than 40 million.

The elasmobranch prey of the great sharks are themselves 'meso-predators'; that is, they are predators occupying a mid trophic level that prey in turn on animals further down the food web. Cownose rays are bottom-feeders that consume a variety of bivalve-molluscs including commercially important scallops, oysters and clams. In Chesapeake Bay alone the burgeoning Cownose rays might now consume 840,000 metric tonnes of bivalves annually: by contrast the entire commercial bivalve harvest for the Bay's neighbouring states of Virginia and Maryland was only 300 metric tonnes in 2003, a much lower catch than the historic norm. Surveys in the early 1980s suggested that Cownose rays had no significant predatory impact on scallops, but exclusion experiments — in which rays were kept out of scallop beds by barriers — suggest that since 1996 Cownose rays have been responsible for almost complete scallop mortality. Migrating rays are not subject to the control measures that prevent commercial fishers catching scallops until after they have spawned, and by 2004 ray predation on pre-spawners had left too few scallops to sustain the century-old Bay scallop fishery in North Carolina: the fishery remains closed today. Another of the clam species depleted by marauding rays is the hard clam, *Mercenaria mercenaria*, known colloquially as the Quahog (Figure 1). This species takes its Latin name from the fact that the Algonquin Native Americans used its shells for money. The trophic cascade brought about by the increasing demand for shark fin soup has not only left once economically valuable bivalve fisheries in crisis, but has precipitated an ecological and culinary bankruptcy: in many east-coast eateries the famous clam chowder is resoundingly off the menu.

Myers *et al.* [3] mention briefly that the trophic cascade initiated by shark fishing could have consequences for sea grasses, but do not discuss the possible impacts of great shark removal for planktic primary production. The ultimate trophic response in this shark-depleted ecosystem could be at the basal phytoplankton level, and the next logical question is, to paraphrase the terminology of Hairston *et al.* [5], "will apex predator removal have consequences for a 'green ocean'?" Bivalves like the Quahog filter water through their gills and feed on the phytoplankton and particulate material they remove. Like a swimming pool with a broken filter, a coastal environment without bivalves could choke with blooms of uncontrolled algae. Superficially, more phytoplankton could be viewed as beneficial, because it may fuel more zooplankton and in turn more pelagic fish, and could even use up more carbon dioxide and potentially alleviate climate change, but experiments in ocean fertilization with these objectives have largely failed [8]. Ecosystem responses to human interventions are often unexpected — as with the hackneyed example of the cane toad introduced to Australia — and model predictions of ultimate outcomes of food web manipulations are characterized by their uncertainty. When hake fisheries off south-west Africa fell in to decline, there were calls from some quarters to cull furseals at the top of the food web because of the perceived conflict between furseals and fisheries. The potential shortcomings of this management option were made evident by the observation that for even a simple 29-species version of the regional food web, there were more than 28 million unique feeding pathways [9]: for a system of such complexity the probability of a control having the desired effect, and only that effect, is slim.

The exposure by Myers *et al.* [3] of some of the consequences of the effective elimination by fishing of an entire functional group of apex predatory great sharks should provide further impetus for the widespread adoption of the ecosystem-based approach to fisheries management. But their study is by no means the first to demonstrate a calamitous chain reaction in a marine ecosystem perturbed by fishing. Analysis of a previously cod-dominated ecosystem in the north-east Atlantic revealed cascading effects in a complex open-ocean setting [10], and widespread collapse of coastal ecosystems due to fishing have been reported [11]. Although the direction of trophic control (top-down, bottom-up, wasp-waist) may vary between ecosystems [12], few if any species exist in isolation. The grand challenge for marine science is to progress from the apparently interminable documentation of ecosystem decline to establishment of robust management policies for sustainable use of entire ecosystems, taking account of species interactions at multiple trophic levels and the services that ecosystems provide [13]. If protein-rich marine food resources are to be secured into the future for the growing human population, and the continuing slide of fisheries 'down the food web' [14] to the ultimate jellyfish-dominated end point [15] is to be averted, theory needs to be put into practice and ecosystems that often span international geo-political boundaries will need to be managed in a framework with defined ecosystem-based objectives and outcomes [16]. Ransom Myers passed away on March 27th 2007, just 3 days before the study he led was published [3,17]. He will not see implementation of such a policy, but one fitting legacy to a man who has done much to expose the degraded state of the world's ocean [18] would be widespread adoption of the ecosystem approach to fisheries management.

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Polarization Vision: How Insects Find Their Way by Watching the Sky

Scientists have long studied how some animals exploit celestial cues to solve navigational tasks. Recent discoveries show how locusts obtain unambiguous information from time-dependent patterns of polarized and unpolarized light in the sky.

Holger G. Krapp

After leaving a London underground station I have never been to before, on my way to a museum a few blocks west, I check two things: the position of the sun and the time on my watch. These two cues allow me to head in the right direction, and my simple strategy works quite well as long as I get a glance of the sun. Many animal species have developed navigational skills based on the sun's position which do not require them to even see the sun or to carry a watch around. And yet, they are probably much better than I am at finding their way under partly overcast conditions. How do they do it? The secret lies in a sophisticated sensory mechanism some animals employ to navigate: the detection of celestial cues related to the position of the sun. Electrophysiological studies, reported recently in *Current Biology* [1], have now demonstrated how identified