COMMENTARY

Fish harder; catch more?

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Perhaps the most fundamental insight from fishery science is that ecosystems impose important and predictable constraints on food production from the sea. The familiar hump-shaped growth curve implies that the growth rate and carrying capacity of a species limit its production: Once stocks are depleted, further increasing fishing pressure will only lead to decreases in catch. This logic underpins fishery science and economics, nearly all fishery management legislation, and, most importantly, recent calls to restore fish stocks around the world (1). In PNAS, Cao et al. (2) propose a series of concrete steps for ecosystem and fishery restoration in the world's superpower of fishing, China. Their call is couched within the complex, and often misunderstood, norms of Chinese culture, and appropriately distances itself from the western view of ocean management that is often taken for granted here.

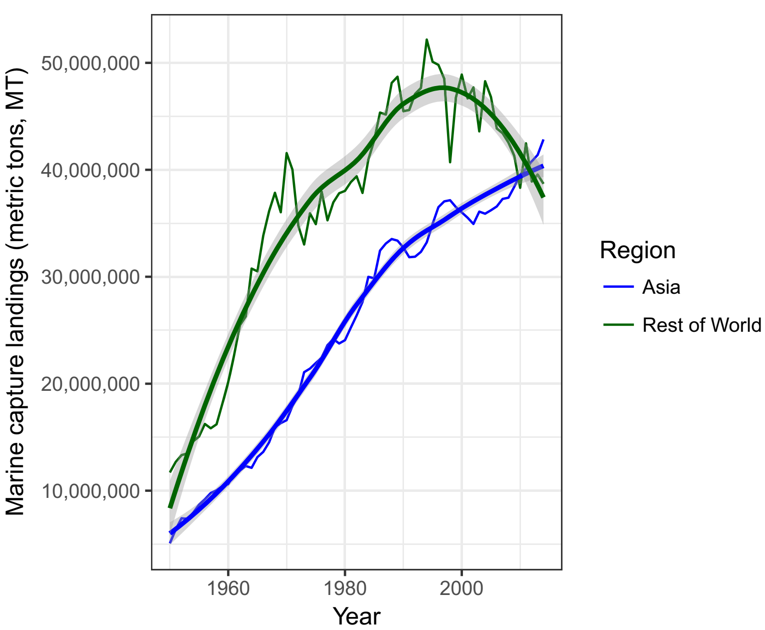

Fig. 1. Capture fisheries landings (in metric tons) in Asian waters (blue, Food and Agriculture Organization fishing regions 57, 61, and 71) and in the rest of the world (green). Trend lines are generalized additive models.

A stylized representation of "western" fishery objectives is to optimize the catch of commercially important fish stocks while ensuring a more natural ecosystem and persistence of all species. Under this approach, the fishery economy is believed to be intimately intertwined with natural ecosystems; the former cannot thrive without the latter. We are told that such ecosystem protection increases production, ensures resilience, and delivers a suite of other services (such as carbon sinks or storm protection).

However, fishery management objectives can often be quite different in Asia, where a premium is placed on food security, livelihoods of millions of small-scale fishermen, and ensuring fishing opportunities as a backstop in the labor market (3). Also, instead of demanding large, fleshy fish like salmon or halibut, Asian consumers often prefer smaller, bonier, more productive species like yellow croaker (*Larimichthys polyactis*) or largehead hairtail (*Trichiurus lepturus*). These differences in objectives between western and Asian fishery management may seem inconsequential. After all, they are ultimately both subject to the same laws of ecosystem function. However, evidence is mounting that these simple differences may have driven one of the most geographically extensive and dramatic ecosystem experiments ever undertaken on Earth.

In most of the world, wild fish catch has been stagnant or decreasing over the past two decades (Fig. 1, green line). Over that period, catch in non-Asian waters has declined by 20%; these declines continue today. There are two basic reasons for this precipitous drop. First, overfishing in many locations has decreased the productive capacity of wild fisheries, so a day's worth of fishing, which would have produced, say, 1 ton of catch 20 y ago, now produces much less. This explanation seems to be the story, for example, in much of Africa and Latin America, where overfishing has been well documented, and many countries have struggled to implement governance reforms (4, 5). To restore fishery productivity in these locales will require significant reductions

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in short-run catch to rebuild fish stocks to their historical potential. The second reason for the drop in catch in non-Asian waters is that many countries, recognizing the decline in fish abundance, have already taken bold steps to rebuild depleted stocks. During the rebuilding phase, catches will drop. This explanation seems to be the story for much of North America and Europe. Basic fishery science suggests that these short-term costs will be more than rewarded by the long-run gains in catch (6).

In contrast, largely fueled by the massive fisheries of China, Asia has continued to increase production since the 1950s (Fig. 1, blue line). In the past two decades, production in these fisheries has increased by 16%, and has overtaken production in the rest of the world combined. This enormous productivity seems to contradict the ecological principles discussed above. How can Asian fisheries, which are widely believed to have been indiscriminately overfishing for decades, continue to sustain such impressive increases in fish catch?

The most comfortable and convenient explanation is that, recognizing that fish are increasingly hard to come by, fishermen use increasingly aggressive fishing techniques to make a living. As long as these increases in fishing "effort" outpace the declines in fish stocks, this could, in theory, lead to increased catch over time. Indeed, this explanation has held true in many ecosystems of the world, and underpins the general desire to reduce fishing pressure to restore fish stocks. The problem with this explanation is in the timing; a strategy of fishing harder in order to catch more can succeed only for a short while. Eventually, of course, this approach is doomed, and will spell the collapse of fish stocks and the associated catches. The fact that Asian fisheries have sustained increases in catch for decades, despite evidence of overfishing for the duration, suggests that the "increasing effort" explanation cannot fully explain the phenomenon.

A less comfortable, and certainly more controversial, explanation is that, by aggressively, and nonselectively, fishing out predatory fish, the prey have become much more abundant (7) (see also ref. 8). Ask any midwesterner why there are so many deer eating her lawn and she will quickly agree that, without predators, prey can dramatically increase in population. This is why so many deer and elk hunters prefer to keep predator numbers in check. It also explains why the most productive agricultural and aquacultural systems typically exclude species that forage on crops. The theoretical underpinnings of this phenomenon are widely held and arise from trophic dynamics: Due to efficiency losses as energy moves up the trophic web, it takes about 10 pounds of prey to make 1 pound of predator (9). So, to maximize food production, might we be better off without predators? Could Asian fisheries have (deliberately or accidentally) executed this strategy on the scale of an entire ocean? Could fishing down the food web actually make more food on the planet (10)?

A recent paper, also in PNAS, tackles these questions using size-spectrum models and empirical data from China (11). The authors find strong evidence in support of this hypothesis: Fishing out predatory fish through intense indiscriminate fishing does a good job of explaining the time series of catches and fish sizes in the East China Sea. A less-advertised, but possibly more impactful, finding from that work is that reverting to "single-species management," which corresponds to our western approach whereby all species are individually managed to achieve optimal catches, would likely result in a loss in long-term catch. This ecosystem view illuminates an important tradeoff that is often assumed away in conventional species-by-species analyses.

This emerging body of evidence seems to suggest that there are two alternative states of the world in ecosystem-based fishery management, both of which are, in some sense, sustainable. World A consists of closer-to-natural ecosystems, high biodiversity, a range of fish sizes, and relatively modest sustainable yield. World B consists of somewhat degraded ecosystems (at least relative to their unexploited state), lower diversity, smaller fish, and very high yield of very productive stocks whose predators have been suppressed. World A is the one pursued by the United States, Europe, New Zealand, Australia, and a handful of other countries. World B is the likely outcome of the current fishing trajectory in much of Asia (and perhaps elsewhere). This dichotomy gives rise to a huge range of additional questions such as the following: (*i*) Even if fishery catch is smaller in world A, might fishery value be larger (e.g., if large fish are more valuable)? (*ii*) Is the low-diversity ecosystem in world B more susceptible to collapse? For the remainder of this commentary, I will focus on the following question: (*iii*) Just because a country has historically chosen to pursue world B, does that mean they will continue to prefer it in the future?

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In the early 1990s, economists began to observe what seemed to be a peculiar relationship between environmental quality and per capita income (12). Early in a country's development trajectory, environmental quality fell as incomes rose. However, when a country's populace became sufficiently wealthy, this trend reversed, so environmental quality seemed to rise with income. Although the causes for this phenomenon continue to be debated, the empirical observation has been documented across a wide range of measures of environmental quality. One common-sense justification is that, early in a country's development, it lacks the luxury of devoting resources to environmental protection; high environmental quality simply isn't worth the tradeoff. However, as incomes rise, so, typically, does the demand for environmental quality, so the environmental-quality-vs.-income curve eventually bends back up. When researchers have been able to document these curves, the turning point seems to be at a per capita income of between $5,000 and $15,000. China's per capita income is $8,000 and is rising sharply.

Will strong income growth in China spur a shift in demand for environmental quality? If history is any guide, the answer is likely to be an emphatic yes. Indeed, early signs already exist. China was an early endorser of the Paris Climate Change Agreement, an impressive grass-roots campaign has led to a substantial decline in demand for shark fins, and the Chinese government recently declared a complete ban on the trade of ivory. These are emblematic of an increasingly wealthy population that shows signs of a willingness to trade off economic production for environmental quality.

It seems reasonable to expect marine policy to follow suit, and recent announcements in China are encouraging (see ref. 2 for specifics); however, this does not necessarily imply that China will ultimately make the transition from world B to world A. Perhaps a third option is possible, where marine ecosystems are cleaned up and restored to deliver a suite of services, but where large catches of small-bodied fish are still emphasized. Such an outcome seems more in line with Chinese values and preferences, even as they evolve in the coming years, and this may represent a path that is quite different from the one we view as ideal in the western world of marine ecosystem management.

Whatever the destination, the impressive scale of the ecosystem engineering that has taken place in China frames many unanswered questions about how to get there from here. What will it take for China, and possibly the rest of Asia, to make the transition? Will it take 5 y or 50 y? What sacrifices or tradeoffs will be required along the way? For these and related questions, few concrete answers can be provided, but one thing is for sure: The science, economics, institutional design, and cultural awareness embodied by refs. 2 and 11 and others will serve as useful starting points in a research program to address these enormous challenges.

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