Benefits, tradeoffs, and timing of global fishery recovery

Christopher Costello, Dan Ovando, Tyler Clavelle, Kent Strauss, Ray Hilborn, Trevor A. Branch, Mike Melnychuk, Steve Gaines, Cody Szuwalski, Others?

[Target Journal: Science (Report), <2,500 words including references.]

Abstract: Data from >5,200 fisheries worldwide, representing 69% of global catch, were used to estimate the country-by-country benefits of alternative approaches to recovering depleted fisheries. We estimate recovery benefits for each fishery separately for livelihoods of fishermen, provision of food and protein, and conservation of fish in the ocean. We estimate unique recovery targets and trajectories for each fishery, calculate the year-by-year effects of alternative recovery approaches, and model how governance changes could change fish prices and costs. Impacts vary by country, but we find that compared to current exploitation rates we could obtain global increases of 42% in fisheries profit, 19% in food production, and 17% in fish biomass. We also find that institutional reforms that improve fisheries efficiency would increase profits more than restoring fisheries to biomass targets.

Less than a decade has passed since the widely cited projection that all global fisheries could collapse by 2048 (Worm et al., 2006). While subsequent contributions to the literature provide a more nuanced picture of the biological status of global fisheries, (Worm et al. 2009, Worm and Branch 2012, Branch et al. 2011, Costello et al. 2012), the implication of Worm et al. (2006) remains: The oceans will provide far less food, livelihoods, and biodiversity than their potential unless deliberate recovery actions are taken.

While this grim generalization has been supported by recent estimates (Sunken Billions and Sumaila et al.), there is also strong evidence that some entire countries have already undertaken effective reforms to place their fisheries on a better track (Worm et al, 2009; others) and overfishing has largely been eliminated in those countries. These reforms span a range of approaches, from scientifically informed harvest control rules to institutional reforms that restructure the incentives in a fishery to favor long term profits. In many cases these changes have successfully reduced fishing effort to more sustainable levels and resulted in the recovery of overfished stocks (*1*, *2*) (Hilborn & Ovando 2014, Costello et al. 2008). These cases of successful management contain lessons that can be applied more broadly and also suggest that the potential gains from additional reforms may be highly heterogeneous among fisheries, nations and specific policies for reform. Yet, none of these important insights can be gleaned from simple aggregate estimates of global fishery recovery.

Here we ask, what might be the future of global fisheries if we were to undertake the reforms that previous studies have stressed are urgently needed? We couple the latest fishery status and management data for thousands of fisheries to bioeconomic models, and incorporate recent empirical evidence on the effects of alternative institutional reforms, to estimate alternative scenarios of fishery recovery for individual fisheries, nations, and the globe. Our study is engineered to seek specific new policy recommendations regarding: (1) Are there strong tradeoffs or synergies between recovery efforts that emphasize fishery profits, food provision, or conservation? (2) How do the benefits of reforms based solely on regulating harvests compare to reforms that change institutional incentives? (3) How long will benefits of reform take to arrive? (4) How costly will reforms be during the recovery period? and (4) In a world with limited resources to devote to fishery recovery, which countries provide the most compelling and urgent cases for fishery reform?

To answer these questions, we develop an approach that exploits several sources of data to conduct fishery-level analysis. We amassed a database of the world’s largest 5,226 fisheries from the RAM Legacy database (*3*) and the FAO marine capture database (*4*) that collectively accounts for 68% of global catch as of 2012. For each fishery, we begin by estimating its current biological (b0=*B*0/*B*MSY) and exploitation status (f0=*F*0/*F*MSY). We extracted biomass (B) and fishing mortality (F) directly from stock assessments for the 311 fisheries included from the RAM Legacy database. The status of the remaining 4,915 “unassessed” fisheries are estimated using a two-step process involving global regression analysis and a structural modeling approach (Costello et al and Martell & Froese).

To assess the future trajectories of these fisheries under different recovery efforts, we assume each fishery can be represented by a Schaefer surplus production model, and we standardize current biomass and fishing mortality by the respective values (Bmsy, Fmsy) that would maximize sustainable yields. These standardizations scale out the carrying capacity and facilitate comparisons across diverse stocks with very different underlying biological dynamics. For each fishery, we consider a range of fishing policies F(B), which each assigns a (scaled) fishing mortality rate tailored to that specific stock (a process often called a “control rule” or “harvest policy”). Profit in a period is revenue (price times harvest) minus the cost of fishing, which is assumed to depend on the level of fishing mortality that is applied. This allows us to calculate the fish catch, fishery profit, and biomass of fish under any possible harvest policy.

We model 5 alternative recovery approaches each representing a specific harvest policy. The first four policies focus exclusively on managing the biomass of fish through controls on harvest. The last policy draws on an emerging body of evidence that the economics of a fishery can be dramatically impacted by fishery management institutions, above and beyond its direct effect on the biomass of fish harvested or in the water. For example, rights based approaches have been shown to increase product prices (primarily due to opportunities that permit increased product quality, see XXX) and reduce fishing costs (primarily due to a reduced race to fish, see YYY). Therefore, two identical fisheries that each adopts the same harvest policy, f(bt), but where one fishery relies solely on fleet-wide regulatory controls (e.g. by limiting season length or restricting fishing gear) and the other fishery couples harvest control rules with secure harvest rights (e.g., individual quotas), will likely lead to higher profits for the latter fishery. The policies are summarized as follows:

Policy P0 – Status quo:

f(bt) = f0 forever except for fisheries currently undergoing rebuilding (i.e., bt<1 and ft<1), which rebuild until b=1 then fish at f=1 forever.

Policy P1 – : Fish at Fmsy in perpetuity

f(bt) = *F*MSY forever

Policy P2 – Maximize rate of rebuilding by closing all overfished fisheries until rebuilt:

f(bt) = 0 if bt<1, f(bt)=Fmsy if bt>=1

Policy P3 – Maximize net present value over an infinite time horizon:

f(bt) = f#(bt) FNPV

Policy P4 – Maximize net present value with higher prices and lower costs from institutional reforms:

f(bt) = f\*(bt) how do you define higher prices and lower costs, exactly? This seems very hairy to me.

For each fishery we estimate future trajectories of profit, food, and biomass under each of the 5 harvest and institutional policies. Aggregating over time (with discounting) provides estimates of the net present value of the fishery, and aggregating over fisheries (for example within a country) provides regional estimates of the consequences and tradeoffs of alternative strategies for reforming fisheries.

Bioeconomic theory provides some predictions for the tradeoffs across alternative objectives of profit, food, and conservation. Perhaps the most salient point is that the three objectives typically go hand-in-hand, at least in comparison to a collapsed status quo. For example, consider a small-scale open access fishery in the developing tropics, which might have b0=.3 (overfished) and f0=1.7 (overfishing). Such a fishery would be in bioeconomic equilibrium, so biomass and profit would be very low, but stable from year-to-year. Because the stock has been overfished, the harvest is also small – in this case it is just half of maximum sustainable yield (MSY). Recovering such a fishery would eventually increase profits, food, and conservation objectives.

But there are nontrivial cases in which tradeoffs do exist. For example, consider a relatively young fishery with b0=.7 and f0=1.8, so biomass is lower than optimal and declining. Current fish profit and yield, however, are quite large (yield is 25% larger than MSY!), owing to the high degree of fishing pressure. While such pressure will ultimately reduce the stock substantially, the inevitable economic and food provision consequences of that overexploitation have yet to be realized. Implementing recovery in such a fishery is likely to increase biomass, but will probably reduce profits and yields, at least relative to their current levels. This second example illustrates the importance of the counterfactual scenario: We will examine the effects of fishery recovery against both what would have occurred (under status quo fishing) in the absence of intervention and against the current levels of profits, yield, and biomass.

A final example captures the idea that many fisheries have already undertaken their own recovery efforts. Suppose a fishery has been overfished, but its exploitation rate has been dropped, so b0=.6 and f0=.8. We would expect such a fishery to ultimately recover (at least to Bmsy) when exploitation rates can increase to Fmsy. Our alternative harvest policies and institutional reforms allow us to examine the additional benefits that could be generated by optimizing the recovery path [f#(b)] rather than just maintaining the status quo until recovery.

Any given harvest policy will have effects that play out differently over time. Because we explicitly model the dynamics for each fishery under each harvest policy, we can examine the timing of effects in detail. Naturally, the way in which a given harvest policy affects a given fish stock will depend on biological parameters; we estimate these parameters using a structural low-data assessment approach (Martell and Froese). This approach allows us to estimate the year-by-year effects on profit, food, and biomass of following any particular fishery recovery strategy over time. Timing of effects may be of particular importance when considering food provision and profit motives. For example, the largest fishing country in the world (China) has proposed new goals to increase seafood consumption by 50% over the next six years[[1]](#footnote-2). The extent to which such an objective will be possible from wild fisheries will depend on the harvest policies implemented and can be estimated here. Similarly, if a country is interested primarily in the livelihoods of its fishermen, then it should focus on harvest policies f#(b) (which maximizes net present value of profits) and f\*(b) (which reforms institutions and optimizes harvest). These harvest policies often call for sharp reductions in current fishing to allow rapid rebuilding of stocks (though under this model, it is rarely optimal to completely close the fishery during rebuilding). Such measures often impose significant short-run economic losses, but by definition, the long run gains of recovery will outweigh the short-run losses (or else the chosen policy could not have been economically optimal). This raises the question of how to finance this “recovery gap;” we return to this issue in the discussion.

At a global scale, we find that a triple bottom line of increases in fishery profitability, food production, and conservation is a realistic outcome of fishery recovery in 58% of global fisheries.[[2]](#footnote-3) Consider the case in which all global fisheries adopt management approaches that allow them to control harvest in an economically efficient manner (Policy #4 above). Figure 1 shows the change in steady state biomass (horizontal axis) and fishery yield (vertical axis) relative to status quo fishing (P0) by the year 2032. Each point represents a country, and the size of the dot represents the increase in fishery profits. Across all fisheries, we estimate median changes of \_\_% increase in biomass, \_\_% increase in food provision, and \_\_% increase in profits under P4 compared to under P0.

Figure 1: Changes in steady state biomass, fishery yield, and profit by 2046 under economically optimal harvest strategy

While the majority of countries stand to gain in all three dimensions, some countries show declines in biomass relative to the status quo. This situation may arise if the current exploitation levels in a country’s large fisheries are estimated to be low, in which case the status quo will result in less than optimal exploitation after recovery. Figure 1 also suggests a prioritization: countries with the greatest potential gains in conservation are farthest to the right, those with greatest gains in food are farthest to the top, and those with greatest gains in profits are the largest dots.

While the results thus far suggest that nearly every country in the world stands to gain from fishery recovery regardless of its objective, some important tradeoffs also emerge across recovery policies. All four policies are all expected to give rise to increases in biomass of fish, relative to today (this is the definition of “recovery”), albeit to different levels; we expect P4 to recover to the largest stocks.[[3]](#footnote-4) Policies P1 and P2 are “food maximizing” in the sense that both will result in fishery recovery to Bmsy (though P2 will recover more quickly), and will thus return larger yields than will P3 or P4. And by their very design, P3 and P4 are engineered for economic profitability, though P4, which adopts institutional reform that raises prices and lowers costs, will return larger profits than does P3. Figure 2 illustrates these tradeoffs for the aggregated global fishery and for a few select regions of interest.

Figure 2: Tradeoffs between P1 (blue), P2 (green), P3 (purple), and P4 (red) for select fishing nations and the world Get rid of the dark ggplot grid. Use open circles with different colors (otherwise they create new colors where they overlap).

Figure 2 demonstrates that while a triple bottom line is possible relative to status quo, tradeoffs still exist across policies for the magnitude of gains for different objectives. As a result, clearly articulating the objectives of fishery reform is crucial to targeting the right policy.

Figure 2 also suggests an intriguing opportunity: In comparing results for P3 vs. P4, we see only small differences in biomass and food, but very large differences in fishery profitability. Policy P4 is meant to simulate a rights based or catch share system, such as a cooperative (cite Deacon), a TURF (cite Cancino Wilen), or an ITQ (cite Newell, Costello et al.). While much debate exists about allocation, distribution, and equity under these rights based approaches, the evidence of increases in prices and decreases in costs is robust across diverse case studies. We surveyed the literature and adopted mid-point estimates of these values: prices increase by 20% and the cost parameter decreases by 20% under P4 (see supporting information for list of studies). These changes cause the optimal management approach (P3 vs. P4) to change (See Figure SX in supplement for examples of policy functions under P3 vs P4), typically by harvesting slightly more aggressively and equilibrating at a slightly lower steady state resource stock. But most impressively, these price and cost changes can have large economic consequences. Our global estimates suggest that moving from P3 to P4 could increase fishery profit by 32% - this is more than half of the entire gain in profit that would arise in moving from P0 to P3. These results are displayed in Figure 3, which shows the percentage increase in profits, by country for the top 20 fishing nations. The bottom segment of each bar represents the upside from managing the biological stock more efficiently (going from P0 to P3). The top segment represents the additional upside from engaging in institutional reforms that increase economic efficiency (going from P3 to P4). For many countries, and for the globe as a whole, the likely additional gains from institutional reforms are nearly as significant as the gains that would arise from even perfectly fine-tuning harvests over time. By increasing prices and (decreasing?) costs in a manner reflective of many catch shares, we can increase the value of country/globe fisheries by XX percent over a policy that simply rebuilds biomass of fish in the sea. This suggests that some of the greatest economic improvements in fisheries may come from improving institutions. Furthermore, these gains in profit can occur immediately following the reform, and can help offset many of the costs associated with stock recovery when yields necessarily (but temporarily?) decline.

Figure 3: Economic gains from pursuing the optimal harvest strategy relative to the status quo (red bar) and additional gains from implementing catch shares (blue bars)

To ensure model tractability and to apply it at a global scale required making a number of simplifying assumptions. The SOM contains an extensive set of robustness checks and sensitivity analyses; we note a few here. First, since our entire analysis is built on estimates of the current fishery status, it is natural to ask how sensitive our results are to those estimates. We performed numerous jackknifing routines to estimate our model’s ability to predict out of sample, broken out by region and fishery size. Results suggest that our methods for estimating b and f are more robust for fisheries in the developed world that are not extremely overfished and that are experiencing relatively larger levels of catch. Second, the economic upside, and the optimized policies P3 and P4, depend on our estimates of economic parameters (prices and costs). Because price data are not available for most countries, we adopt global average prices by species category derived from export values available from the FAO. We model costs by identifying the unassessed fisheries estimated to be in bioeconomic equilibrium and setting costs such that profits equal zero (the expectation at equilibrium in an open access fishery). We (will) conduct(ed) a sensitivity analysis examining the effects of a range of these biological and economic parameters … MORE HERE.

To our knowledge this is the first attempt to estimate the distributional benefits, tradeoffs, and timing of recovery for individual fisheries at a global scale. Our main finding is that with appropriate reforms, a triple bottom line is realistic: At a global scale we estimate that it is possible to eventually increase fisheries profits (59%), food from the sea (52%) and fish in the water (30%). To the extent that a country favors one of these objectives over the others, several policy options are available, and our analysis provides guidance about how to recovery fisheries to best achieve that objective. We also found that a sole focus on managing the size of the fish stock (by fisheries scientists, economists, and managers over the past 20 years) may be missing the broader picture, particularly if we value economic performance. Rather, by reforming both the institutions (for example, through cooperatives, TURFS, or individual quota systems) and the harvest policies of fisheries we can achieve much more substantial gains in benefits across multiple objectives. Wait, what about improvements in fishing technology?

Finally, as a thought experiment, we return to the prediction of global fishery collapse by 2048. Our model allows us to make predictions of the status of global fisheries by then. We find that under the status quo, XXX % of global fisheries are likely to be collapsed by 2048. In contrast, if reform efforts are put in place now, the mean time to recovery would be just 5.3 years (standard deviation of 3.46), and by 2048, such a global movement could fully recover 98% of the world’s overfished stocks.

References

1. Figure includes consumption from freshwater aquaculture and mariculture. (China Food and Nutrition Development Guideline 2014-2016). [↑](#footnote-ref-2)
2. For these results, we restrict attention to the 60% of global fisheries that we estimate have some need for recovery; i.e. those with b0<1. Gains are also possible for fisheries with with b0>1, though the gains are from fishing harder on underexploited stocks; we leave that for future analysis. [↑](#footnote-ref-3)
3. P4 will tend to have higher biomass than P2 and P3 because P4 is an economic objective, and there are stock-dependent costs that reduce the costs of catching a fish as biomass increases (cite XXX). P4 will tend to have higher biomass than P5 because P5 involves lower cost and higher price, both of which tend to drive the economically optimal stock to a lower level. [↑](#footnote-ref-4)