Benefits, tradeoffs, and timing of global fishery recovery

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Abstract: We compile micro-level data from >5,200 fisheries worldwide, representing 69% of global catch, to estimate the country-by-country benefits of alternative approaches to recovering depleted fisheries. Unlike previous studies, which lump global fisheries into a single stock, we separately estimate recovery benefits by fishery, and disentangle benefits accruing to (1) livelihoods of fishermen, (2) provision of food and protein, and (3) conservation of fish in the ocean. Among other novel methodological contributions, we estimate unique recovery targets and trajectories for each fishery, calculate the year-by-year effects of alternative recovery approaches, and we allow different reform institutions to have differential effects on fish prices and costs. Our results suggest substantial, but highly spatially heterogeneous effects of recovering global fisheries. Across countries, we estimate a median increase in fisheries profit of 42%, a median increase in food provision of 19%, and a median increase in biomass of fish in the sea of 16.5%. We also find that institutional reforms that increase the efficiency of fisheries are likely to have more significant effects on profits than will the single-minded focus on recovery to biomass targets.

Abstract option: Global demand for protein derived from the sea is increasing, but many of the fisheries that support this demand are poorly managed and depleted to sub-optimal levels. We project the benefits of recovery to food production, conservation of fish in the ocean, and livelihoods of fishermen for over 5200 individual fisheries worldwide (representing 69% of global catch) under a variety of harvest strategies. We estimate unique recovery targets and trajectories for each fishery, calculate the year-by-year effects of alternative recovery approaches, and allow different reforms to affect fish prices and costs differently. Our results suggest substantial, but highly spatially heterogeneous effects of recovering global fisheries. Across countries, we estimate a median increase in fisheries profit of 42%, a median increase in food provision of 19%, and a median increase in biomass of fish in the sea of 16.5%. We also find that institutional reforms that increase the efficiency of fisheries are likely to have more significant effects on profits than will the single-minded focus on recovery to biomass targets.

Less than a decade has passed since the infamous prediction 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, the implication of Worm et al. (2006) remains: The oceans will provide far less food, livelihoods, and biodiversity than their potential unless deliberate actions are taken.

While this grim generalization has been supported by recent estimates of the losses incurred by mis-management of fisheries (Sunken Billions and Sumaila et al.), there is also strong evidence that management of some fisheries, indeed some entire countries, have already undertaken effective reforms to place their fisheries on a better track. These reforms span a range of approaches, from scientifically informed harvest control rules to institutional reforms that completely restructure the incentives in a fishery. In many cases these changes have successfully reduced fishing efforts 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, yet these insights have not penetrated the literature on global fishery recovery.

We ask, what might the future of global fisheries be if we were to undertake the reforms that previous studies have stressed are urgently needed? We couple the latest fishery status and management data to state-of-the-art bioeconomic models, and incorporate recent empirical evidence on the effects of alternative institutional reforms, to estimate the global distributional effects of alternative approaches to fishery recovery. Our study is engineered to extract specific policy recommendations regarding: (1) Are there strong tradeoffs between recovery efforts that emphasize fishery profits, food provision, or conservation? Or do synergies exist across these objectives?, (2) How do harvest-focused reforms compare against institutional reforms?, (3) How long will benefits of reform take to arrive, what does this imply for the “recovery gap,” and how it might be financed?, 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 integrates several sources of data to conduct fishery-level analysis. We amassed a database of 5,226 fisheries from the RAM Legacy database (*3*) and the FAO marine capture database(*4*) that account for 68% of global catch as of 2012. For each of the 5,000+ fisheries in our data set, we began by estimating its current biological (b0=Bt/Bmsy) and exploitation status (f0=Ft/Fmsy). We extracted b and f directly from stock assessments for the 311 fisheries included from the RAM Legacy database. The statuses of the remaining 4,915 “unassessed” fisheries are estimated using a two-step process involving a global regression analysis and a structural modeling approach (Costello et al and Martell & Froese).In order to assess the future trajectories of these fisheries, we assume each fishery can be represented by a Schaeffer surplus production model. For each fishery, we consider a range of fishing policies f(Bt), which assign a fishing mortality rate (f) at a given biomass (Bt) tailored to that specific stock. 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 thus model alternative recovery approaches as different harvest policies, described below:

Policy P0: f(Bt) = f0 forever (Fish at the status quo level in perpetuity)

Policy P1: f(Bt) = FMSY forever

Policy P2: f(Bt) = 0 if Bt<BMSY, f(Bt)= FMSY if Bt>= BMSY

Policy P3: f(Bt) = f#(Bt) that maximizes net present value over an infinite horizon

Policies P0-P3 focus exclusively on managing the biomass of fish. But there is an emerging body of evidence that the economics of a fishery can be dramatically impacted by the fishery management institution, above and beyond its direct effect on the biomass of fish. For example, property-rights approaches have been shown to increase product prices (primarily due to increased product quality, see XXX) and reduce fishing costs (primarily due to a reduced race to fish, see YYY). Consider two identical fisheries that each adopt a new harvest policy, f(bt), but where fishery A relies solely on harvest control methods (e.g. by regulating season length or fishing gear) and fishery B couples harvest control rules with a property-rights approach. The data suggest that even if the biological status and harvests are identical across A and B, the profits will be higher in B. We account for this with a final policy scenario:

Policy P4: f(Bt) = f\*(Bt) that maximizes net present value under a higher price and lower cost than scenarios P0-P3.

The approach outlined above provides fishery-by-fishery estimates of profit, food, and biomass under a range of harvest and institutional policies. Aggregating over time (with a discount rate of XX) provides estimates of the net present value of a 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 expectations 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; figure 1). Such a fishery would be in bioeconomic equilibrium, so biomass and profit would be very low, but stable. 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 by any means would simultaneously increase profits, food, and conservation objectives in the long run.

But there are nontrivial cases in which tradeoffs do exist. For example, consider a relatively young fishery with b0=.7 and f0=1.8 biomass is low and on a falling trend (figure 1; point B). 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 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 both against 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 (figure 1; point C). We would expect such a fishery to ultimately recover (in this case, to a value greater than Bmsy). Our alternative harvest policies and institutional reforms will 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 f0).

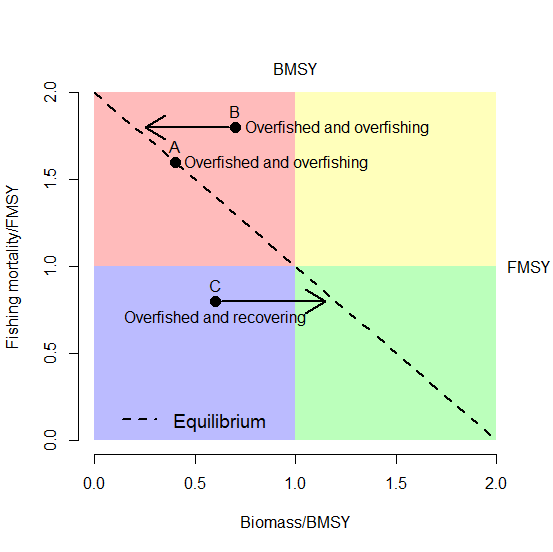


Figure Kobe plot describing the movements of stocks in fishing mortality and biomass phase space based on the present levels of fishing mortality and biomas. The dashed line represents an equilibrium at which a stock will stay provided no changes occur in fishing.

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 sea food consumption by 50% over the next six years[[1]](#footnote-1). The extent to which this will be possible from wild fisheries will depend on the harvest policies being implemented, and can be estimated here. If a country is interested primarily in the livelihoods of its fishermen, then it is likely to focus most on harvest policies which maximize net present value of profits [f#(b)] and reform institutions and optimizes harvest [f\*(b)]. 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 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-2) 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 2 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.

Figure : 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 2 also suggests a prioritization: countries with the greatest potential gains in conservation are farthest east, those with greatest gains in food are farthest north, 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. Policies P1-P4 are all expected to give rise to increases in biomass of fish, relative to today (this is the definition of “recovery”), though to different levels; we expect biomass of stocks managed under policy P4 to increase by the largest percentage.[[3]](#footnote-3) 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 3 illustrates these tradeoffs for the aggregated global fishery and for a few select regions of interest. Achieving a triple bottom line is possible for some fisheries, but tradeoffs still exist (Figure 3). This suggests that clearly articulating the objectives of fishery reform are crucial to targeting the right policy.

Figure : Tradeoffs between P1 (blue), P2 (green), P3 (purple), and P4 (red) for select fishing nations and the world

Figure 3 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 property rights 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 approaches, the evidence of increases in prices and decreases in costs is robust across 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. 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 enormous 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 (figure 4). 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.

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

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. Current results suggest that our methods for estimating biomass and fishing mortality relative to their respective reference points 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. 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 possible: At a global scale we estimate that it is possible to simultaneously 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 the laser 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 catch shares) and the harvest policies of fisheries we can achieve much more substantial gains in benefits across multiple objectives.

So, as a thought experiment, by reforming fisheries today, where might they be by the year 2048? We ran that experiment, and found that the mean time to recovery would be 5.3 years (standard deviation of 3.46). By the year 2048, this model predicts that such a global movement would 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-1)
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-2)
3. P4 will tend to have higher biomass than P2 and P3 because P4 is an economic objective and there are stock-dependent costs (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-3)