**Update on “Will Fishery Yields Go Up” Paper**

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This document summarizes current methods, results, and key next steps/critiques to address for our “Will Fishery Yields Go Up” paper.

**Research Question:**

Will recovering global wild fisheries result in an increase in yields?

**Purpose:**

The effect of recovering global marine wild fisheries is a highly debated topic. Some claim that wild fisheries have hit peak production, and that net decreases in yield are needed to ensure healthy oceans and fishing communities over time. Others have provided rough estimates based on subsets of data or flawed analyses suggesting potential increases in yield, with the most cited examples suggesting a modest (~10%) net increase in global yields stemming from fishery recovery. The goal of this project is to provide the most comprehensive and statistically robust assessment of the impacts of recovering global fisheries on fishing yields.

**Methods:**

*Databases*

Our analysis currently draws from two databases; the FAO landings database ( FAO; summarized in FAO 2011) and the RAM Legacy database (RAM, summarized in Ricard et al. 2011). FAO contains nearly 20,000 unique FAO Regions>Country>Species/Taxa entries, and is the most comprehensive source of global fishery data available. RAM contains information on ~400 fisheries that have been formally stock assessed.

The FAO data were used in Costello et al. (2012) to estimate the relative biomass status (B/Bmsy) of 1,793 “unassessed” stocks, meaning stocks not represented within RAM. These fisheries represent finfish stocks identified down to the species level. These fisheries from Costello et al. (2012) were used as the unassessed fisheries for this paper.

We pulled ~230 stocks from RAM for this analysis. Approximately 160 of these fisheries have estimates of B/Bmsy (or SSB/SSBmsy, which was used interchangeably) published in RAM. Approximately 70 did not have B/Bmsy reported in RAM but were also not included in Costello et al. (2012). For these fisheries, we used the methods of Costello et al. (2012) to estimate B/Bmsy.

Together, these 2,000+ assessed and unassessed stocks make up our sample of fisheries for this paper. While this is still a small subset of global fisheries, merging unassessed and assessed fisheries provides the most comprehensive and representative database of fisheries available to analyze the effects on yields on fishery recovery. Its most substantial gap is the omission of unidentified fisheries (“nei” stocks in FAO), and in invertebrates.

*Analysis*

The primary inputs for our analysis are, for each fishery, time series of landings, time series of B/Bmsy, and estimates of intrinsic growth rate. For RAM fisheries, where available we also stored F/Fmsy and MSY for comparison to values predicted by our methods.

Estimating the magnitude and timing of yield changes relies on estimates of current landings, B/Bmsy, F/Fmsy, MSY, and intrinsic growth rate (*r*). The difference in landings from current to recovered (where recovered in this case means B/Bmsy of 1) fisheries is simply the difference between MSY and current landings. The timing to recovery is a slightly more complex question, and will depend on a fishery’s current B/Bmsy, F/Fmsy, *r*, and the policy instrument used to recover the fishery.

Estimates of B/Bmsy are available either through RAM or Costello et al. (2012). Landings are available through RAM and FAO. Estimates of *r* were pulled from literature on a species by species basis, or pulled from average *r* values by species groups. RAM contains estimates of F/Fmsy and MSY for some but not all fisheries.

This leaves the calculation of MSY and F/Fmsy as the primary unknowns. We used three different methods to estimate MSY; Srinivasan et al. (2010) (S-MSY), Costello et al. (2013) (C-MSY) and Martell & Froese (2012) (Catch-MSY). S-MSY and C-MSY both use a regression to estimate MSY from a fisheries maximum recorded catch. C-MSY is a statistical improvement on the methods of S-MSY, though S-MSY is the basis for many of the current estimates of global yield changes. Catch-MSY uses a depletion model framework to find the parameters of a Schaefer model that best match the observed catch history and priors on initial and final levels of biomass depletion. It has the desirable principle of producing a probability distribution around its results.

All three of these methods produce an estimate of MSY. For any fishery *f* at time *t*, F/Fmsy can then be calculated as

where *C* is catch. Using these methods, we now haves estimates of B/Bmsy, F/Fmsy, MSY, current catch, and *r.* The global change in yields from fishery recovery (as represented by our sample of fisheries) can then be calculated simply by looking at the relative change in the sum of current landings and the sum of estimated MSY. Timing to recovery requires simulation of individual fisheries and policy instruments.

Stock assessed values of F/Fmsy or MSY were used instead of model predictions where available.

*Projections*

The above analysis provides a snapshot of current levels of B/Bmsy, F/Fmsy, MSY, and *r* for fishery in our database. We used these current levels as a starting point to evaluate the performance of alternative policy options over time. Using *b* to denote B/Bmsy and *f* to denote F/Fmsy, the population is modeled as

*f* is set by one of four policy functions that adjust fishing effort in response to biomass:

* OptNPV: *f* is set by a control rule optimized to maximize NPV over a *T* year time horizon
* StatusQuo: Each fishery maintains its current levels of *f* indefinitely
* Fmsy: Each fishery starts fishing at Fmsy today, and remains at that level indefinitely
* CloseDown: If B/Bmsy is less than 1, the fishery is closed. Once B/Bmsy >= 1, fishing is reopened at Fmsy

Profits are calculated as

where *p* is the price per unit yield, *β* adjusts the elasticity of costs, and *c* is defined by

where is the B/Bmsy value that a given fishery is fished down to under open access conditions. is set to the lower interquartile of the median predicted B/Bmsy for a given species category.

Using these parameters, OptNPV using a dynamic optimization routine to determine a control rule for adjusting next years *f* according to the current levels of *b* (Fig.1).

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*Figure 1. Sample control rules developed by OptNPV*

**Results**

*Current Status*

Our primary results center on the % change in yields form current yields to MSY (Fig.2). S-MSY found the lowest % increase of yields, at 45 %. Catch-MSY produced the next greatest mean % increase (45%), with values as low as 23% and high as 68%. C-MSY produced the highest % gain at 280%.

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*Figure 2. Percent change in total yields from current catch to MSY. Red dashed line is S-MSY, green C-MSY. Blue histogram is the distribution of Catch-MSY*

Our results of total MSY are highly biased by a few very large fisheries; 100 very large fisheries make up the vast majority of total MSY predicted by Catch-MSY (Fig.3)

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*Figure 3. Cumulative MSY distribution for Catch-MSY. Each Dot marks one stock*

Looking at our updated kobe plot, we see that among overfished fisheries there is a fairly even distribution above and below the steady state line, though many fisheries with large MSYs fisheries are concentrated below the steady state line (Fig.5).

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*Figure 4. Updated Kobe plot, using only values from Catch-MSY. Circle size is proportional to log(MSY)*

*Future*

Using the estimates of current B/Bmsy, F/Fmsy, and MSY estimated from PRM/Catch-MSY, we can now analyze the impacts on yields, profits, and biomass of alternate policy strategies.

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*Figure 5. Trajectories of metrics over time for each evaluated policy option*

Each policy was evaluated across four metrics; yields, profits, biomass, and fishing mortality (Fig.5). As these are preliminary results we will focus on broad patterns rather than specific findings. While OptNPV provided the highest long-term NPV, over time the outcomes for NPV from Fmsy and CloseDown policies are quite timilar to OptNPV, as OptNPV pursues a strategy quite similar to MSY. However, OptNPV does produce a faster accumulation of NPV, largely from calling for an increase in fishing on currently underfished stocks. B/Bmsy increases towards 1 for all scenarios except for StatusQuo, which results in a modest decline in future B/Bmsy levels. Interestingly, global yields remain fairly stable over the long term, as increases in depleted stocks are balanced out by decreases in windfall yields. Broadly, we see that pursuing a strategy of for example OptNPV or Fmsy results in an increase in profits, a modest increase in yields, and an increase in biomass.

Somewhat surprisingly, OptNPV results in mean B/Bmsy slightly below 1 (Fig.6). For some species, such as sandbar sharks, the final B/Bmsy value decided by OptNPV was 0.26. Exploring this relationship further, final B/Bmsy is positively correlated with *r*, *boa*, and *b0.* This may indicate that the current time horizon of the model (30 years) is too short for some species (further evidenced by the fact that even under the Fmsy strategy some species have not reached B/Bmsy of 1 by the end of the time period, Fig.6). Under these slow growing, long way to recovery situations, OptNPV may be producing a low B/Bmsy strategy since recovery to higher producing levels of biomass is not feasibly under the time frame of the model.

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*Figure 6. Boxplot of B/Bmsy at end of model projection under each policy scenario*

We also evaluated regional differences in outcomes resulting from the OptNPV policy (though the same process could be repeated for the other policies. We chose the present results for the countries with the ten largest total MSY values. As specific results will change dramatically over time, we present two sample results here to illustrate the types of results this analysis can produce. Broadly, the outcomes of the regional analysis vary widely depending on the metrics being measured and the statistics used to present said metrics. Comparisons can be made either between future and current metrics, or future and business as usual (BAU) metrics. We present the comparison to current values in this draft since it provides clearer results. Looking at the median % change metrics, we see that most countries are able to produce a median increase in either profits or biomass by pursuing OptNPV. However, some countries with exceptionally high current Y/MSY values result in a loss in profits over time, since no sustainable strategy exists to increase yields over the windfall levels currently experience by that country (e.g. China; Fig.7).

However, looking at total changes in profits and biomass produces a very different set of positions for each country. We now see that many countries (e.g. USA) have a net decrease in biomass, due to increased exploitation of large and currently underfished fisheries (Fig.8). These results show that along with determining a final set of data for use, we will need to carefully consider the story we want to tell with our data (e.g. what is the median fishery doing vs. what is the net change for a given country).

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*Figure 7. Median percent of current B/Bmsy and profits resulting from each countries pursuit of the OptNPV strategy. Color and circle size is scaled to log of a countries total MSY.*

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*Figure 8. Total change of current B/Bmsy and profits resulting from each countries pursuit of the OptNPV strategy. Color is scaled to the variability of a countries position on the grid, size is scaled to log of total MSY.*

**Main Concerns**

The primary concerns with our current results, mostly from Ray and Trevor, concern the aggregation of data and the appropriate incorporation of errors. Since we are likely to use Catch-MSY for our results Trevor’s individual critiques of C-MSY aren’t too important (but primarily center on the odd behavior of C-MSY when max catch is very high, with MSY becoming greater than max catch, but stocks still potentially below Bmsy).

Aggregations scale is a major challenge for this analysis. As demonstrated by Fig.3, a small handful of stocks make up the majority of our predicted total MSY. This means that errors in predictions for a small number of stocks can dramatically alter our results. In other words, while we say that we have 2000 + fisheries that we are using to calculate total MSY, in reality we are basing almost all of our total MSY on about 100 fisheries. While this may very well be true, it means that our results are highly sensitive to the accuracy of these individual stocks.

Along with aggregation we need to determine the final list of fisheries to include. At present we account for approximately 25% of global catch. Including the newest iteration of RAM will expand this number somewhat (by incorporating Peruvian anchoveta for example), but much of global catch is currently represented by the “nei” entries; catches aggregated at very course levels, often to the degree of “miscellaneous marine fishes”. We will simply be unable to account for a large amount of global catch unless we can address these fisheries. Our current proposal is to explre the ability of the PRM (or Catch-MSY) methods to predict B/Bmsy for aggregations of stocks, rather than as individuals. To this end we will explore the impacts of rerunning the PRM process on varying levels of aggregation of the RAM stocks.

Secondly, since we rely on catch history ensuring that we are using the right catch history obviously greatly influences our results. While many of our unassessed fisheries are “lumped” (aggregated at the FAO region level rather than at the country level), the majority of our fisheries are reported at the country level. This can dramatically inflate MSY is this is incorrect. Suppose we have 10 snapper fisheries (FAO region>Country>Snapper combinations) in FAO region 71. If we assume that each are indeed separate stocks and calculate 10 MSYs, the sum of these MSYs will likely be much greater than the MSY that would be produced if we aggregated all 10 catch histories into 1 and calculated MSY from the aggregated max catch. It is hard to know what the best approach is, but perhaps aggregating everything at the FAO region level would be a more conservative approach to trying to decide which to aggregate based on species types.

Since our estimates of MSY are coming form Catch-MSY, potential errors in population input values are already reflected in the distribution of MSYs. However, we do not explore errors in the catch history itself, a factor that is likely to be especially prominent in small-scale fisheries. As we have discussed before, this isn’t really a huge issue so long as the errors in catch history have roughly mean 0; that would simply mean that we are underestimating the width of our confidence intervals. The more concerning possibility is systemically biased catches, which could dramatically alter our results. W should explore the sensitivity of our results to a variety of potential catch bias scenarios.

Errors in our estimates of B/Bmsy and F/Fmsy only really come into play in our calculation of the kobe plot and our analysis of recovery scenarios. At the moment, we are only accounting for errors in F/Fmsy, and are assuming that B/Bmsy is fixed. This is obviously not true, and incorporating appropriate errors around B/Bmsy will substantially change the outputs of our kobe plots. However, I feel that we could still produce a good-looking heat map of kobe plot densities. Incorporating errors in B/Bmsy will also increase the variability in our timing to recovery plots (Fig.6 for an example).

Ray has pointed out that the combination of errors in catch data and estimating B/Bmsy will result in systemically overestimating F/Fmsy, often substantially. The good news is that this doesn’t influence our estimating of MSY, though it would be good to see if a similar problem exists with the estimation of MSY itself. Also, from the perspective of the kobe plot overestimating F/Fmsy will visually underestimate the amount of stocks that might show improved yields form recovery (since it will inflate the number of stocks that are above the steady state line).

To get to Trevor’s comment:

“Global catches are around 80 million t (highest ever 86 million t),  
and on average stocks are slightly below Bmsy for assessed stocks, and  
well below Bmsy for unassessed stocks (Costello et al. 2012). This  
means that most of the stocks have been fished at or above MSY. Which  
means that it is impossible for global MSY to be much above 80-100  
million t. If global MSY was say 200 million t, this implies that most  
big stocks have been lightly fished and we should be able to double  
global catches.”

I’m not actually sure this is true, due to Kent’s point that not all stock shave been fished at the same time. If we look at max lifetime production (sum each fisheries max catch, whenever it is), and compare that to our estimates, I think the improvements will look more modest. Looking at it this way could explain why we can get global landings at MSY so much greater than current landings.

Lastly, there are the high values of predicted increase in yields predicted by S-MSY. When we ran this with out first draft database we got a predicted % increase in yields very similar to those reported by Sumaila et al. (2012) using S-MSY. However, with our new database we now predict much higher % increases in yields. This suggests then that the higher values of increased yield that we are reporting are more of a function of the data we are using than an improvement in methods. Ideally we would reproduce Sumaila et al. (2012) exactly, and using the same data show a higher potential yield increase using the same data with either C-MSY or Catch-MSY. Baring that, we should try and understand what about the data we are using is producing such substantially higher increases for the S-MSY method than those reported in Sumaila et al. (2012).

In summary, from my perspective the biggest challenges we face form my perspective are 1) determining at what scale to aggregate catches 2) how to account for potential errors/biases in catch data 3) incorporating all sources of error/possibly accounting for biases in F/Fmsy 4) Dealing with the apparent oddness of our results (per Trevor’s comments).

**Next Steps**

1. Try and determine why S-MSY increases are so much higher than those reported by (Sumaila et al. 2012).
2. Talk with Ray/Trevor about the aggregation question
3. Put some thought in to analytical solution to bias in F/Fmsy estimation
4. Get better price data
5. Get upated RAM, decide on final database
6. Decide on what to do about neis
7. Explore alternatives
   1. Focus on average/median % change in yields by region, rather than total increase. Less sensitive to large outlier fisheries
   2. If we want to the absolute total, we could just focus on some of the largest fisheries and try and do a bit more of a deep dive for these, rather than worrying about strong estimates for the hundreds of really small fisheries