Yield per Recruit Analysis of the Hawaiian Yellowfin Tuna Fishery

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Abstract

Estimates of natural and fishing mortality from two different sources were used to compute yield per recruit for yellowfin tuna fisheries in the North Pacific Ocean. The results show that increasing the size at first capture in the equatorial fisheries would increase the yield per recruit by 30%. The results for Hawaii-based fisheries are more difficult to interpret. The available data suggest that increasing the size at first capture would decrease the yield to the fishery.

Introduction

The yield per recruit (YPR) is based on the theory of exploited fish populations developed in the 1950s by Beverton and Holt (1957). It is a relatively simple approach requiring only estimates of fishing mortality (F), natural mortality (M), and rate of individual growth in weight. YPR has fallen into disuse because contemporary stock assessment methods provide more useful biomass-based information for fisheries managers. Nevertheless, YPR

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can provide insight and guidance regarding potential fishery management interventions. Estimates of age-dependent F and M are often available from age-structured stock assessments or tagging experiments.

Estimates of F and M at age for Hawaiian yellowfin tuna are available from two sources: the 2014 MULTIFAN-CL (MFCL) stock assessment (Davies et al 2014). and the 1995-2000 Hawaii Tuna Tagging Programme (HTTP) (Itano and Holland, 2000; Adam et 2003) Here I apply YPR analysis to evaluate potential effects of changing the minimum size limit in the Main Hawaiian Islands (MHI) yellowfin tuna fishery.

Estimates of Mortality and YPR

MFCL

The Hawaii Exclusive Economic Zone is split between regions 2 and 4 in the MFCL analysis (Figure 1). Region 4 extends from 10°S latitude to 20°N latitude and mainly comprises the large-scale equatorial purse seine and longline fisheries. Region 2 extends from 20°N latitude to 50°N latitude and comprises the Hawaii longline fishery and a variety of small-vessel fisheries. The boundary between these two regions passes through the MHI. The average annual yellowfin landings by the Hawaii longline fleet for the period 2009 through 2012 was 186 mt, only around 29% of the 628 mt landed by the combined Tuna Hand Line, Troll, Inshore Handline, and Aku Boat fleets over the same period. The yellowfin landings from these small boat fisheries in Hawaii are not included in the data on which the MFCL assessment is based.

The 2014 MFCL yellowfin assessment includes data from 1952 through 2012. The stock is assumed to consist of 28 quarterly age classes. MFCL model output routinely includes estimates of mean weight at age, natural mortality by age class, and fishing mortality by year, age and region. The MFCL mortality estimates are shown in Figure 2. The values of M used are the "reference case", i.e., specified values. "Natural mortality at age was recalculated for previous assessments using an approach applied to other tunas in the WCPO and EPO" (Davies et al 2014). For the purpose of YPR analysis, I average the fishing mortality at age by region from 2009 through 2014 (the most recent 5 years or 20 quarters). Fishing mortality differs sharply between regions 4 and 2. In region 4, F is generally quite high at all sizes of fish with peaks near 5kg and 30kg. In region 2, F is an order of magnitude lower with no clear modes. The lack of a mode in the smaller sizes is due to the omission of data from non-longline fleets.

The YPR analysis for regions 4 and 2 are presented in Figures 3 and 4 respectively. In region 4, either increasing or decreasing the overall fishing mortality would cause a decrease in yield per recruit. Increasing the size at first capture to around 10 kg would increase the yield from 1.5 kg/recruit to 2.0 kg/recruit, an increase of approximately 30%. In region 2 (Figure 4), the situation is quite different. Increasing or decreasing the total fishing morality increases or decreases the yield, and increasing the weight at first capture decreases the the total yield.

HTTP

Adam et al (2003) used a size- and spatially-structured tag-attrition model to estimate size-dependent fishing mortality, natural mortality and migration rates between release and recapture sites from HTTP yellowfin and bigeye tag recaptures. I used a simplified, spatially aggregated version of the same model to estimate size-dependent fishing mortality and natural mortality from the HTTP yellowfin recaptures. Elimination of spatial strata allowd and increase in the number of age groups in the simplified model to eight from three used in Adam et al. (2003).

The HTTP mortality estimates are shown in Figure 5. These estimates differ from the MFCL estimates in several ways. The size range is restricted because of the relatively few recaptures of large fish. HTTP mortality estimates are generally much higher than MFCL estimates. The corresponding YPR analyses are shown in Figure 6. The YPR in relation to current levels of fishing mortality suggests that increasing F would produce modest gains in yield. The YPR in relation to the weight at first capture suggests that decreasing the size at first capture would decrease the yield per recruit.

Discussion

The MFCL stock assessment is intended to inform management of large-scale purse seine and longline fisheries in the equatorial Pacific. Application of MFCL stock assessment results to a relatively insular small-scale fishery in the North Pacific may be stretching the capabilities of MFCL. Division of the Hawaii EEZ between two regions makes application to problems in

Hawaii difficult. Furthermore, exclusion from the analysis of the substantial catch of smaller fish exacerbates the problem of applying the regional stock assessment to resolve fishery management issues in Hawaii. The results in region 4 are instructive nevertheless. Fishing mortality on yellowfin is higher for small-sized fish than for larger fish, as is the suspected case in the MHI. By analogy, it is possible that increasing the age at first capture in Hawaii could increase the yield to the fishery.

Fishing mortality on smaller-sized fish in MFCL region 2 is simulated by adding a log-normal F-at-age component with a modal age class of 4 quarters to the estimated F-at-age from MFCL. The simulated F-at-age is scaled so that the ratio of its peak to the maximum F-at-age estimated by MFCL is in proportion to the ratio of non-longline to longline landing in Hawaii (dashed red line in Figure 7A). In this hypothetical situation, increasing the total fishing effort by a factor of 5 would more than double the yield, and increasing the weight at first capture would decrease the yield, Figure 7B and C. The combined effects of increasing both the hypothetical fishing mortality and size at first capture in MFCL region 2 is shown in Figure 8. Benefits of increasing size at first capture are not apparent until the increase in fishing mortality reaches 5-fold. If fishing mortality increases are restricted to smaller sizes, benefits of increasing size a first capture are undetectable at fishing mortality increases less than 10-fold.

The high mortality estimates from the HTTP tag recaptures are troubling. To some extent, high mortality estimates reflect the lack of precision in the definition of M. “Natural mortality” is not a process that is ever observed in a way that can be easily tied to specific parameters in a statistical model as fishing mortality is tied to catch. For widely distributed, highly mobile fish such as tunas, emigration is an important component of M in addition to the biological processes usually associated with mortality, e.g. predation and senescence. Both the MFCL stock assessment and the previous HTTP analysis by Adam et al. (2003) account for movement, so the new spatially aggregated mortality estimates include emigration and could thus be biased higher. Although the new estimates are difficult to compare directly to the previous HTTP estimates because they use different size classes, the new estimates are generally slightly higher or similar to the previous estimates. The YPR analysis based on HTTP mortality estimates shows that increasing the lower size limit on yellowfin could have a deleterious effect on the fishery.

These results show clearly that current fishing mortality on yellowfin tuna in Hawaii is low relative to natural mortality. As a result, increasing the age at first capture would cause harm to the fishery and is unlikely to benefit the stock. Yield per recruit analysis only provides information about the effects of management actions on the yield to the fishery. YPR does not provide insight into stock conditions and does not offer any guidance in establishing biomass-based reference points. Therefore stock conservation decisions should not be based solely on YPR analysis. Rather, such decisions should be made on the basis of a biomass-based stock assessment model that incorporates the salient features of tuna population dynamics, namely rapid growth, high juvenile mortality, and stock mixing with adjacent areas.

Conclusions

1. The YPR analysis for MFCL Region 4 shows that increasing the size at first capture would increase the yield to the entire fishery. Whether such a change in minimum size in Region 4 would benefit the MHI yellowfin fishery is unknown.

2. The YPR analysis for MFCL Region 2 is inconclusive because only longline catches from Region 2 are included in the assessment.

3. The YPR analysis using mortality estimates from tagging data is also inconclusive because only small fish were returned and available for the analysis.

4. The WCPFC convention area stock assessment is unsuitable for addressing management issues in Hawaii because the MFCL regions are ill-addapted to Hawaii and the data do not include all of the catch.

5. There is no clear benefit to the fishery of increasing the minimum size restriction.

Computing Yield Per Recruit

Yield per recruit is an estimate of the contribution to the fishery of a cohort during its entire life span. Derivations of YPR often center around development of formulas for calculating YPR based on assumptions of constant F and M over the life of the exploited fish. Modern stock assessment methods produce estimates of F and M by age making such assumptions unnecessary. Sparre and Venema (1998) suggest an approach to computing YPR from age specific data that is easily implemented in the R programming language `http://www.r-project.org/`.

The biomass of fish of age a is the product of the number of fish of age a in the population (N_a) times the weight of age a fish (W_a) i.e., $B_a = N_a \cdot W_a$, and the contribution of age a fish to the yield is $Y_a = F_a \cdot B_a = F_a \cdot N_a \cdot W_a$, where F_a is the fishing mortality at age. The yield per recruit is thus the $\sum_a Y_a/R$, where R is the recruitment at age $a = 0$. Assuming that $R = 1 = N_0$, yield per recruit can be easily computed by these relatively simple relations

$$\begin{aligned} Z_a &= M_a + F_a & (1) \\ N_a &= N_{a-\Delta a} e^{-\Delta a Z_{a-\Delta a}} & (2) \\ Y_a &= F_a N_a W_a & (3) \\ \frac{Y}{R} &= \sum_a Y_a. & (4) \end{aligned}$$

F_a and M_a are estimated by the MFCL assessment or the HTTP tag attrition models. W_a can be computed from estimated or specified growth parameters and length-weight relationships. In the case of the MFCL assessment, W_a is a routine model output. In the case of the HTTP analysis, W_a is computed by von Bertalanffy growth parameters and the length-weight relationship from the MFCL assessment. Δa is set to 1 quarter.

All computer code, data files, and draft reports in support of this analysis can be found at Github `https://github.com/johnrsibert/XSSA.git`.

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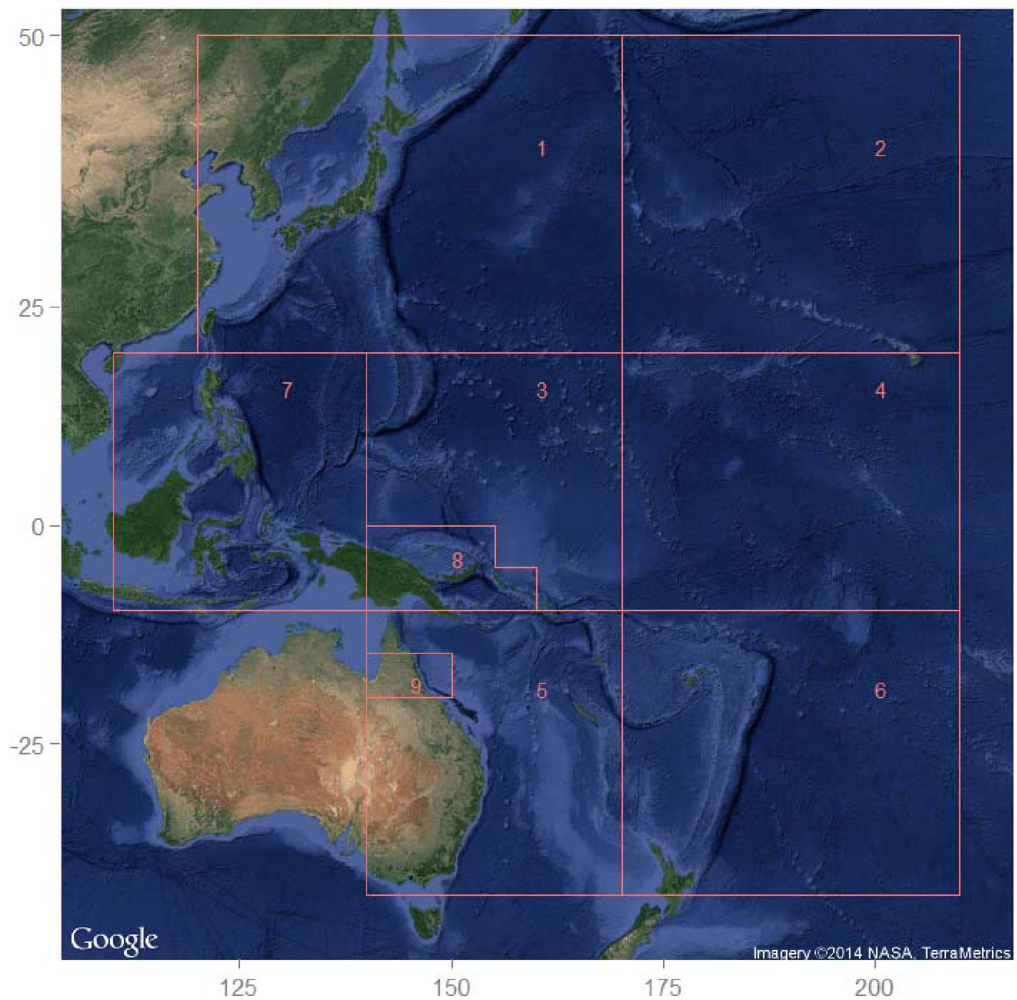

Figure 1: Regions used in the 2014 MFCL stock assessment; from Davies et al. 2014.

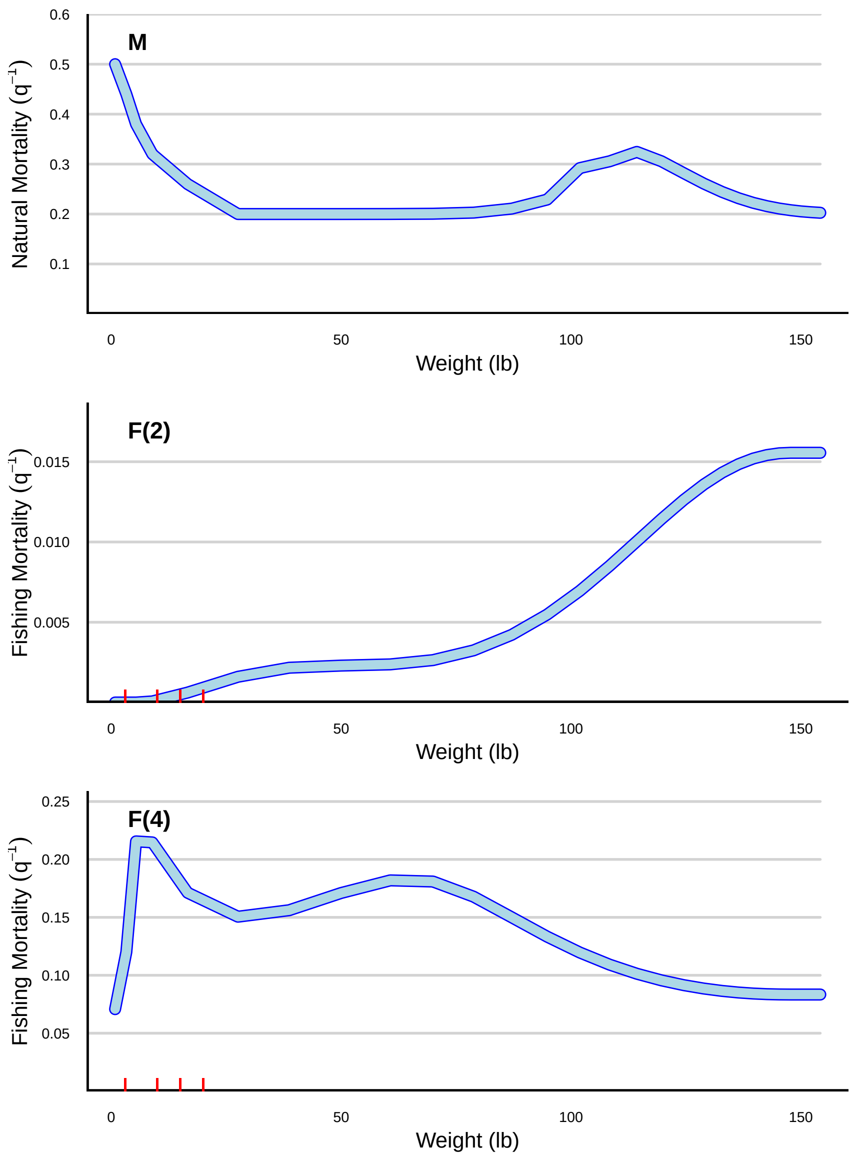

Figure 2: Natural and fishing mortality from the 2014 MFCL yellowfin stock assessment. The upper panel (M) shows the "reference case" natural mortality at age plotted against mean weight at age. The lower two panels, F(2) and F(4), show the MFCL estimated fishing mortality for regions 2 and 4 respectively, averaged over the period 2009 through 2014. The red marks on the abscissa are placed at the current lower catch weight limit and at three other weight limits sometimes discussed at 3, 10, 15, and 20 pounds.

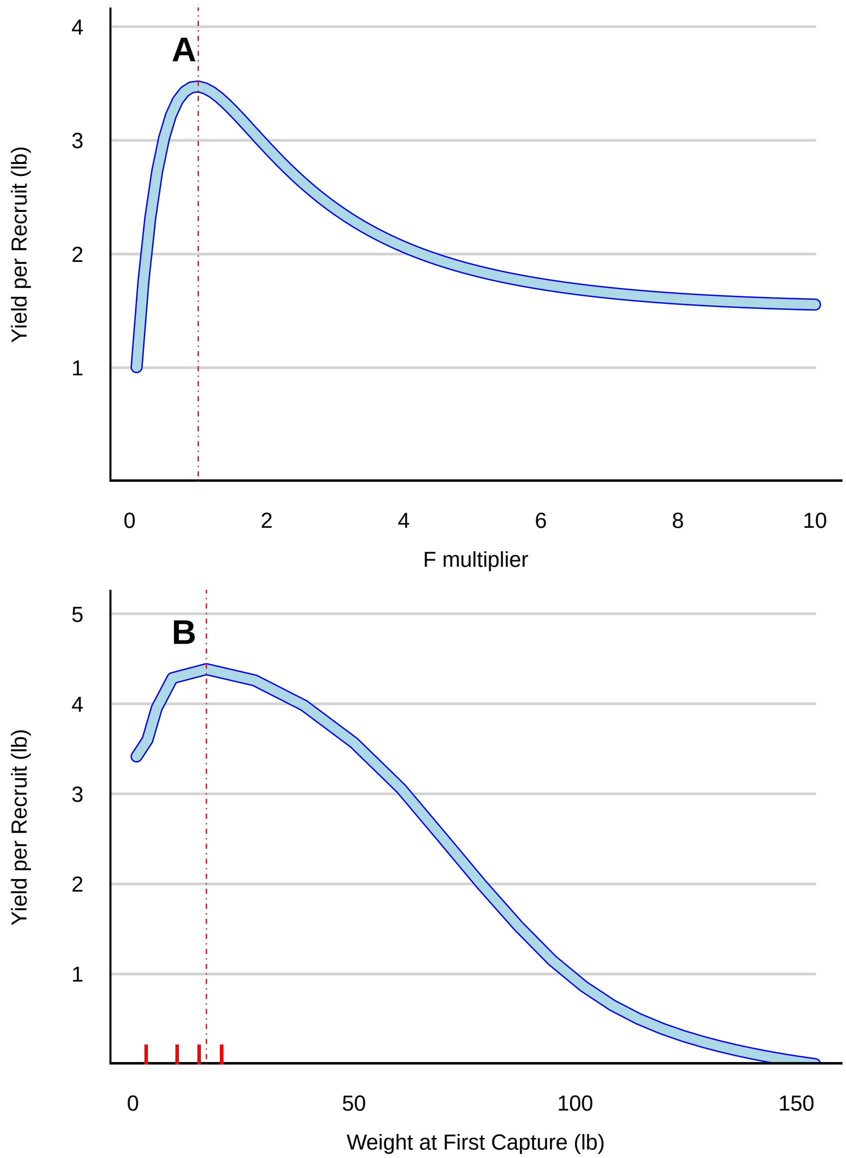

Figure 3: Yield per recruit in MFCL region 4 as a function of fishing mortality and weight at first capture. Panel A shows the change yield per recruit due to multiplying the fishing mortality at all ages by constant factor ranging from 0 to 10, that is, from essentially closing all fisheries to expanding all fisheries by a factor of 10. The dashed vertical red line is drawn at 1, the current fishing mortality. Panel B shows the change in yield per recruit of increasing the minimum size limit in the fishery from 0kg to 70kg. The dashed vertical red line is drawn at the weight producing the highest yield per recruit.

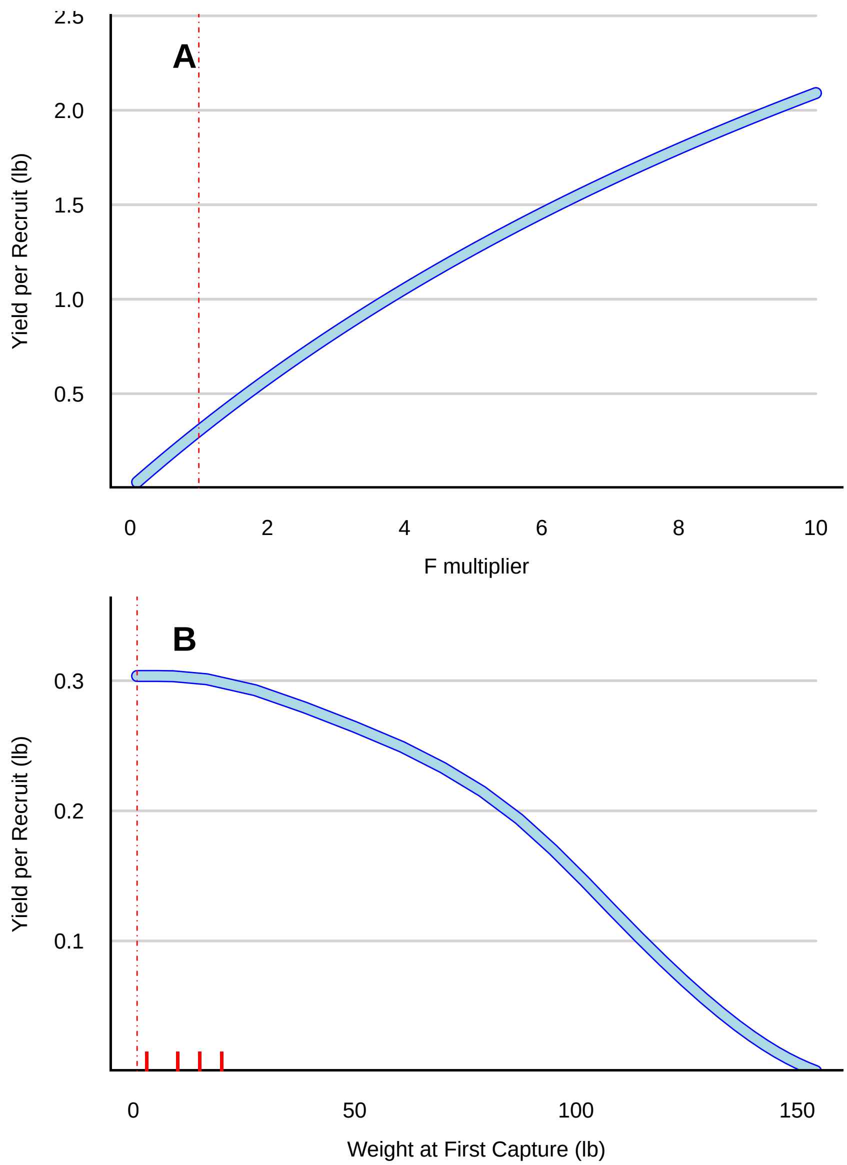

Figure 4: Yield per recruit in MFCL region 2 as a function of fishing mortality and weight at first capture. See caption in Figure 3 for details.

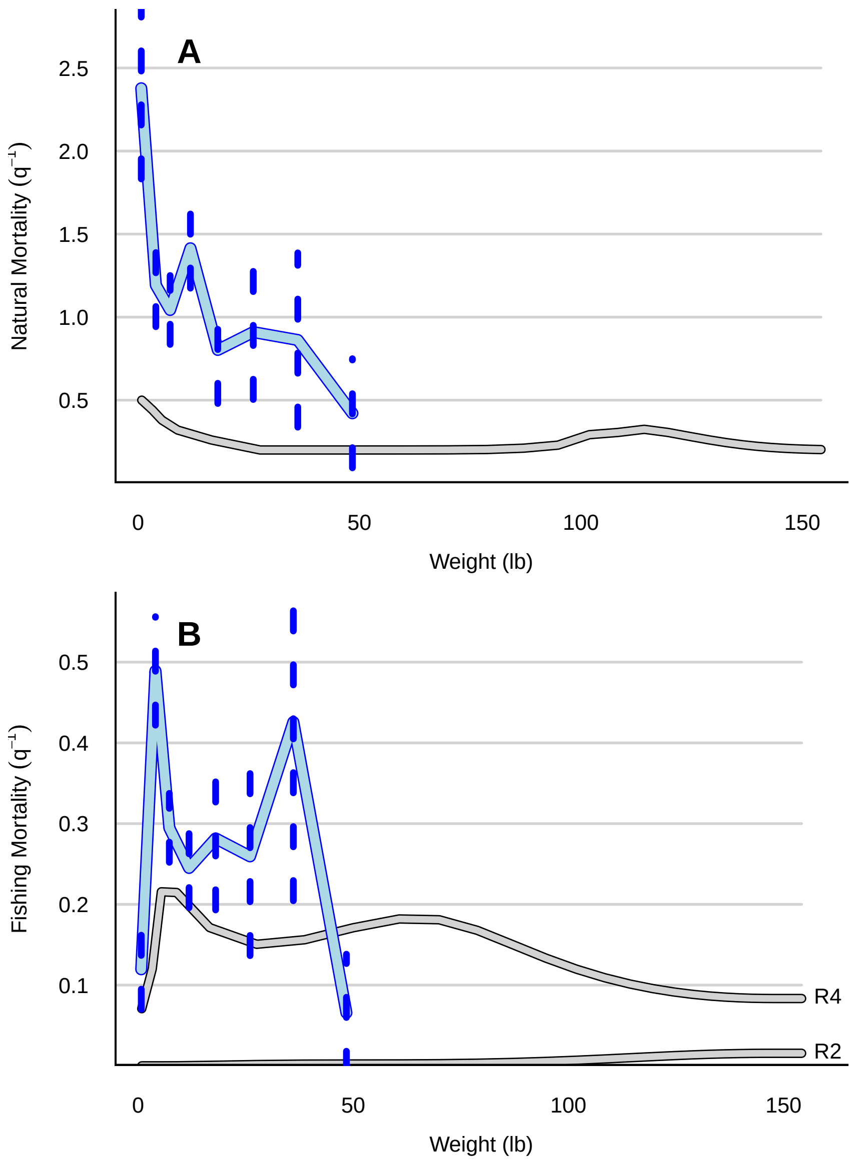

Figure 5: Natural mortality (A) and fishing mortality (B) estimates from the HTTP tag recaptures. The blue bars are the point estimates $\pm$ two standard deviations. The light gray lines are MFCL estimates shown for comparison.

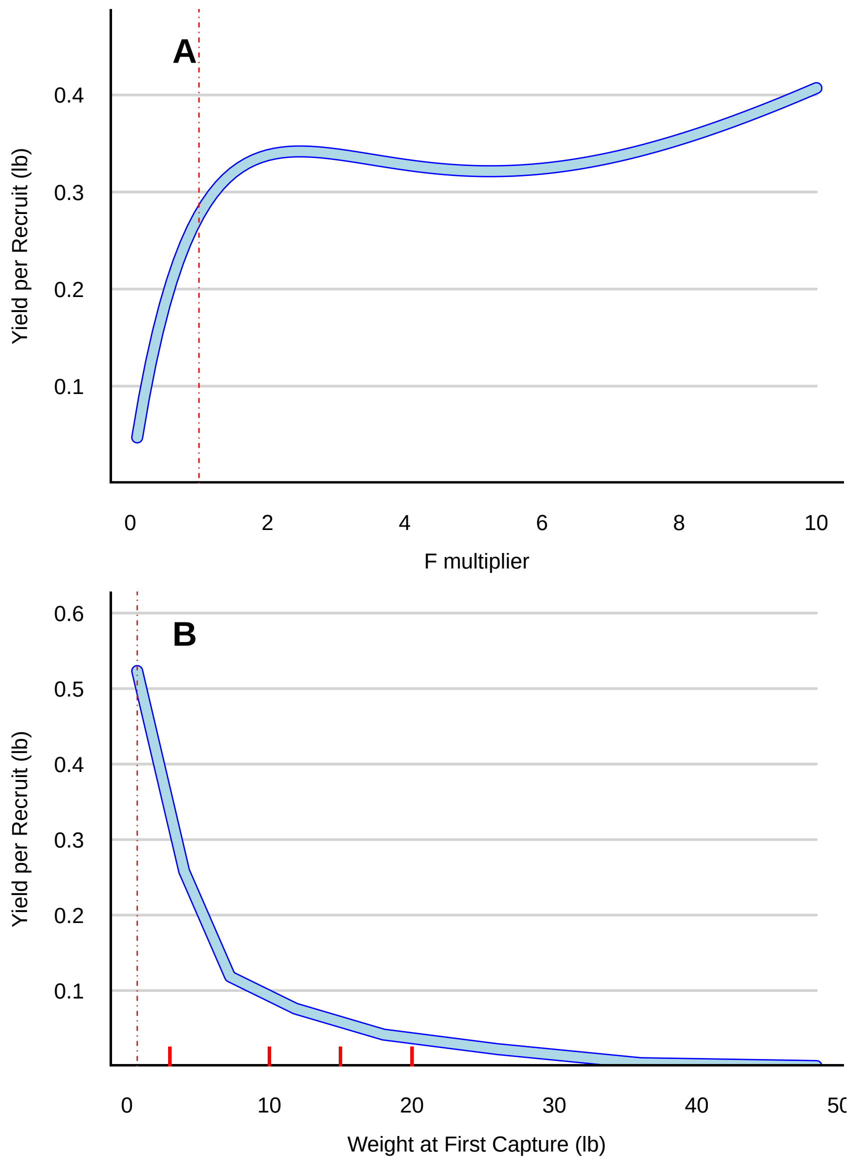

Figure 6: Yield per recruit in the Main Hawaiian Islands based on HTTP mortality estimates. See caption in Figure 3 for details.

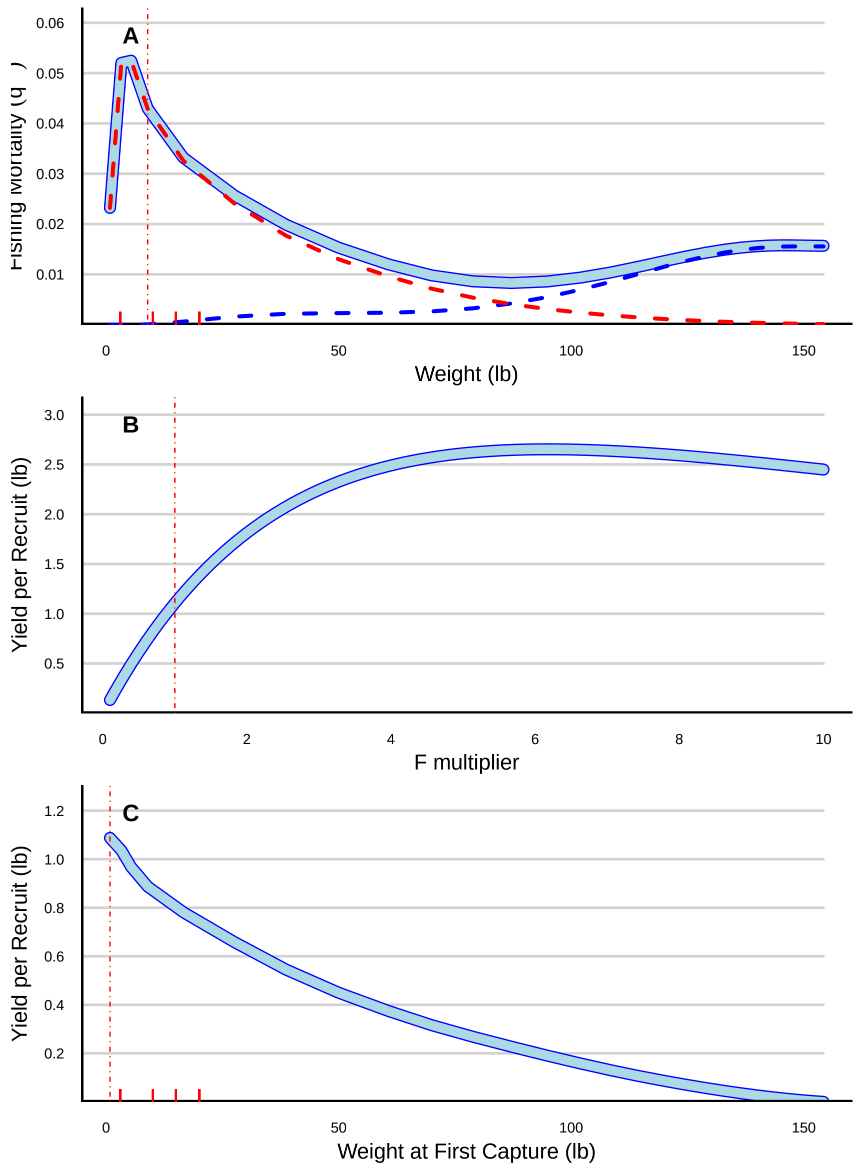

Figure 7: Effect of increasing catch of small fish on yield per recruit in MFCL Region 2. Panel A shows increased fishing mortality, light blue, as augmented by the catch of small fish shown as dotted red line. The dotted blue line is the MFCL estimate of fishing mortality by age. Panels B and C show the resulting YPR as described in Figure 3.

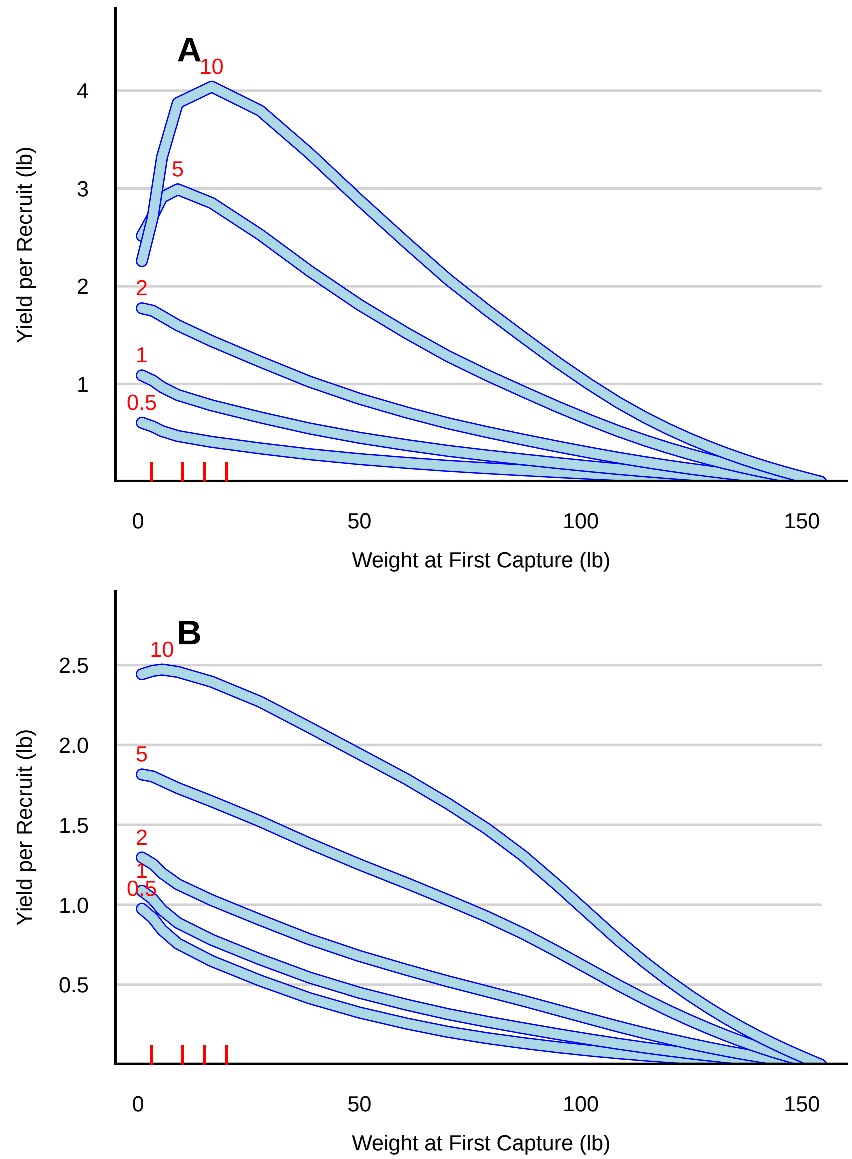

Figure 8: Panel A shows the effects of increasing weight at first capture at different multiples of current fishing mortality, red numbers over the peak of each curve. Panel B shows the effects of increasing weight at first capture at different multiples of current fishing mortality on only the smaller size classes (dashed red line in Figure 7A).