DRAFT REPORT

Yield per Recruit Analysis of the Hawaiian Yellowfin Tuna Fishery

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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 growth in weight. YPR has fallen into disuse because contemporary stock assessment methods provide more useful biomass-based information for fisheries managers. Nevertheless, YPR can provide insight and guidance regarding potential fishery management interventions.

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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. Estimates of age-dependent F and M are often available from age-structured stock assessments or tagging experiments. These estimates can be easily applied to computing YPR with fewer assumptions. Sparre and Venema (1998) suggest one approach.

Estimates of F and M at age for Hawaiian yellowfin tuna are available from two sources: the 1995-2000 Hawaii Tuna Tagging Programme (HTTP) (Adam et 2003) and the 2014 MULTIFAN-CL (MFCL) stock assessment (Davies et al 2014). 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 two 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. The boundary between these two regions passes through the MHI. The yellowfin landings from the small boat fisheries in Hawaii are not included in the data on which the MFCL assessment is based. Small boat fisheries catch in aggregate more yellowfin than the longline fishery (Figure **??**)*or simple table* .

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 because of problems reliably estimating M. "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 for each region from 2009 through 2014 (the last 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. The two modes are attributable to the purse seine and longline catches. 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 for all fisheries. Increasing the size at first capture to around 10 kg increases the yield to the whole fishery from near 1.5 kg/recruit to near 2.0 kg/recruit, and increase of approximately 30%. In region 2, the situation is quite different. Increasing or decreasing the total fishing morality simply increases or decreases the yield. Similarly, increasing the weight at first capture merely 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. The number of age groups was increased in the simplified model from three to eight because there were fewer recapture strata.

The new HTTP mortality estimates are shown in Figure 5. These estimates differ from the MFCL estimates in several ways. The size range is more restricted because of the relatively few recaptures of large fish from the longline. 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 yield only modest gains in yield. The YPR in relation to the weight at first recapture suggests that increasing the minimum size limit would have a deleterious effect total yield to the fishery.

Discussion

The MFCL stock assessment is intended to inform management of large-scale purse seine and longline fisheries in 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 of the substantial catch of smaller fish from the analysis exacerbates the problem of applying the regional stock assessment to resolve fishery management issues in Hawaii. The results in region 4 is 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 recapture in Hawaii could increase the total yield to the fishery.

The high mortality estimates from the HTTP tag recaptures are troubling. To some extend 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. M is the aggregate loss of fish from the population that cannot be attributed in some way to a fishery. 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 movement, so the new spatially aggregated mortality estimates include emigration and could thus be 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. *It should be possible to do a better comparison between old and new HTTP 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.

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.

Conclusions and Recommendations

1. The YPR analysis for MFCL Region 4 shows clearly that reducing the size at recapture would increase the yield to the entire fishery. Whether change in minimum size at recatpure would benefit the MHI yellowfin fishery is not clear.

   The US Delegation to the WCPFC should strongly advocate for minimum size restrictions in MFCL Region 4, and elsewhere in the equatorial fishery.

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

MFCL regions are ill-addapted to support management of fisheries in Hawaii.

US scientists should participate actively in the WCPFC pre-assessment workshop to assist the assessment team to find ways to include more data from Hawaii fisheries in the assessment and to redefine the MFCL regions to be more informative about the Hawaiian yellowfin population.

3. The YPR analysis using mortality estimates from tagging data are are inconclusive, but there is no clear benefit to the fishery of increasing the minimum size restrictions.

   The HTTP data should be completely reanalyzed, and if any yellowfin recaptures have been return since 2001, the new recaptures should be included in the data.

Math Stuff

Yield per recruit is an estimate of the contribution to the fishery of a cohort during its entire life span. 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) that is $B_a = N_a \cdot W_a$, and the contribution of age a fish to the yield $Y_a = F_a \cdot B_a = F_a \cdot N_a \cdot W_a$, 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

$$Z_a = M_a + F_a \tag{1}$$

$$N_a = N_{a-\Delta a} e^{-Z_a \Delta a} \tag{2}$$

$$Y_a = F_a N_a W_a. \tag{3}$$

$$\tag{4}$$

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.

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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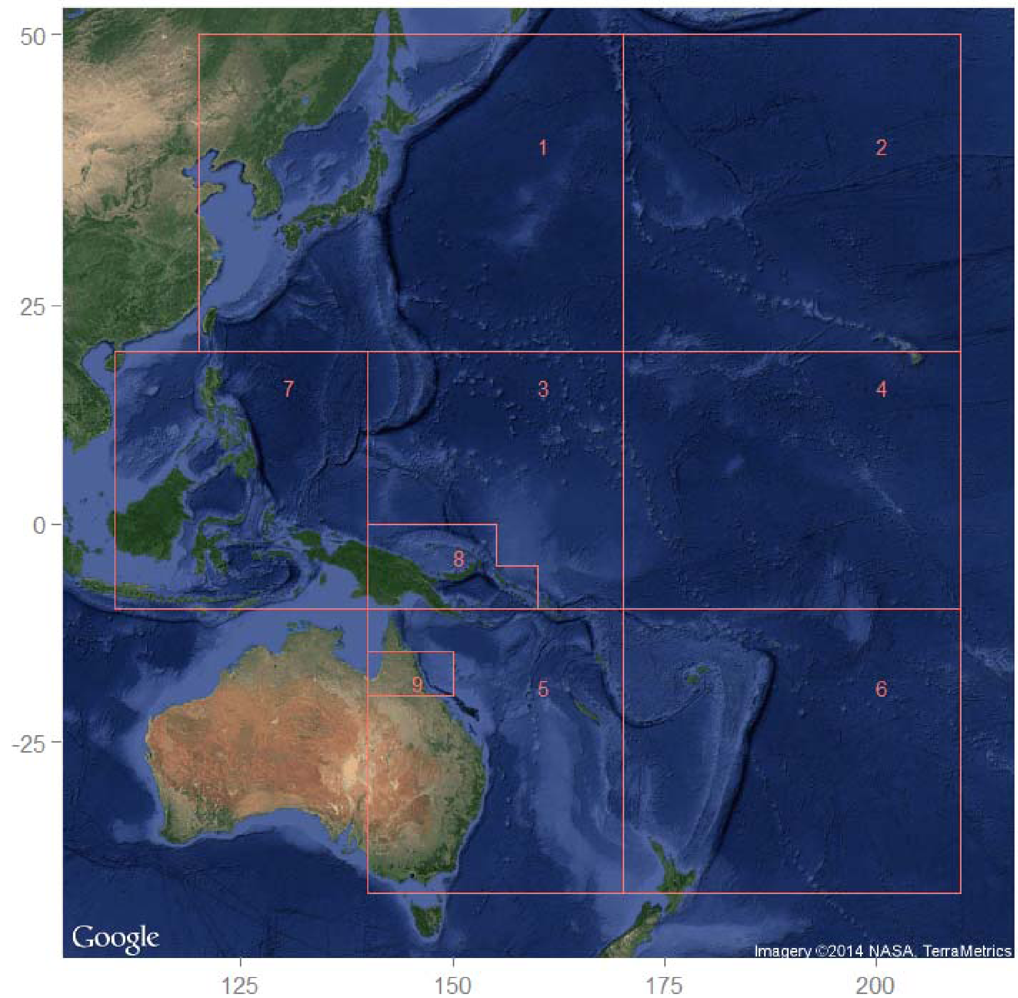

Figure 1: Regions used in the 2014 MFCL stock assessment; from Davies et al, 2014.

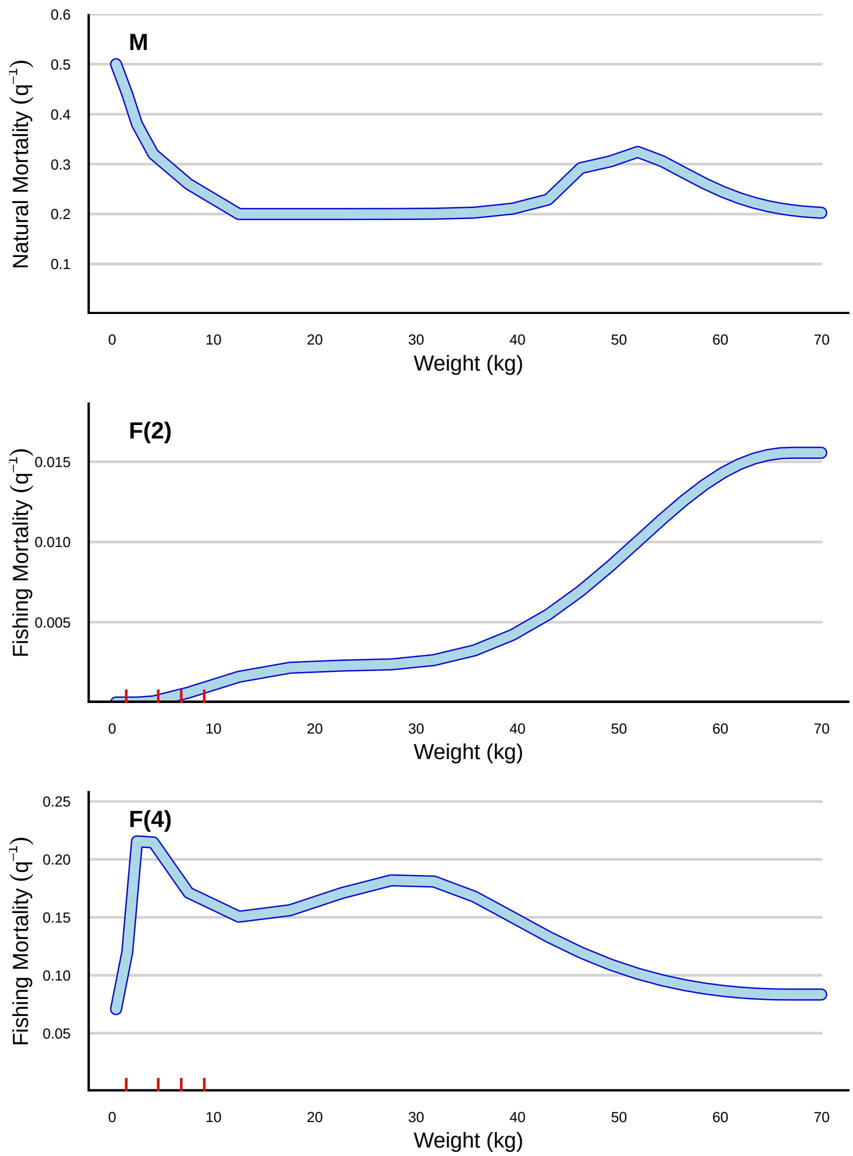

Figure 2: Natural and fishing mortality from the 2014 MFCL yellowfin stock assessment. The upper panel (M) shows the "reference case" natural mortality at age plotted against mean weight at age. The lower two panels, F(2) and F(4), show the MFCL estimated fishing mortality for regions 2 and 4 respectively, 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; that is at 3, 10, 15, and 20 pounds.

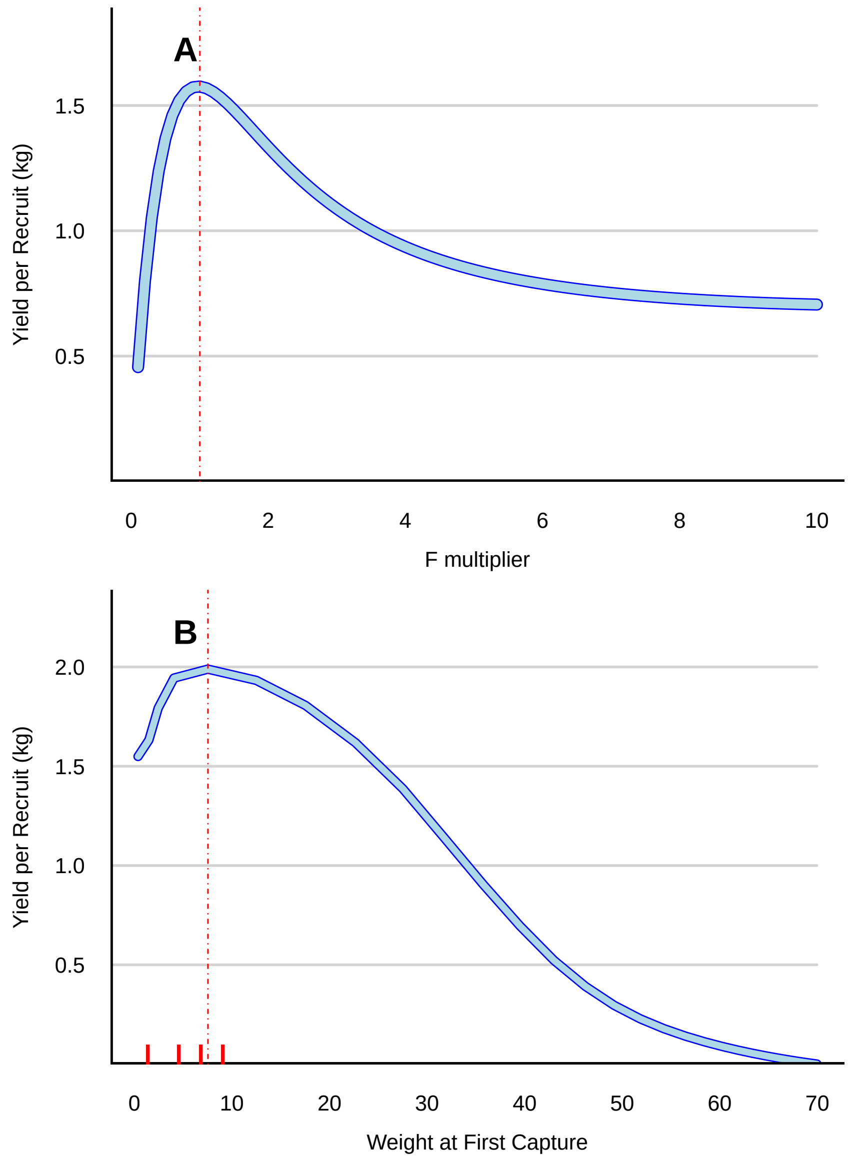

Figure 3: Yield per recruit in MFCL region 4 as a function of fishing mortality and age at first recapture. Panel A shows the change yield per recruit due to multiplying the fishing mortality at all ages by constant factor ranging from 0 to 10, that is from essentially closing all fisheries to expanding 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.

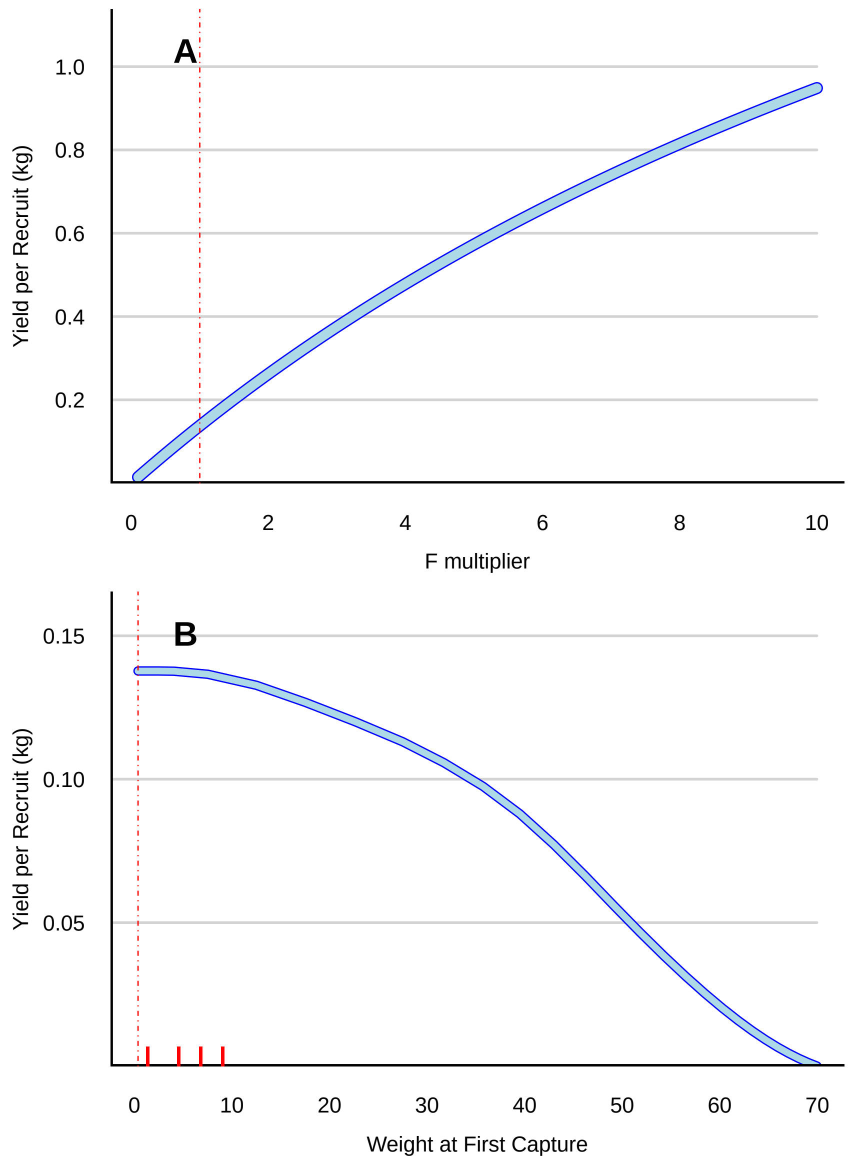

Figure 4: Yield per recruit in MFCL region 2 as a function of fishing mortality and age at first recapture. See caption in Figure 3 for details.

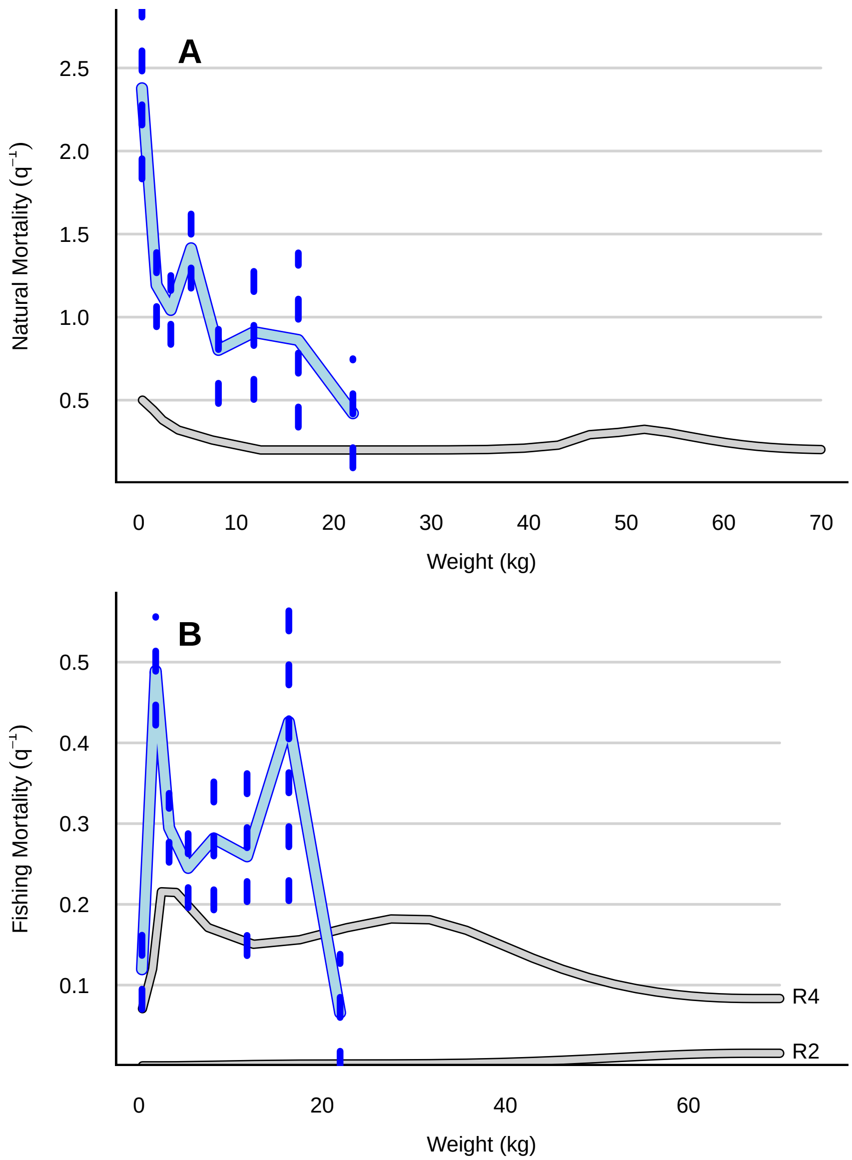

Figure 5: Natural mortality (A) and fishing mortality (B) estimates from the HTTP tag recaptures. The blue bars are the point estimates ± two standard deviations. The light gray lines are MFCL estimates shown for comparison.

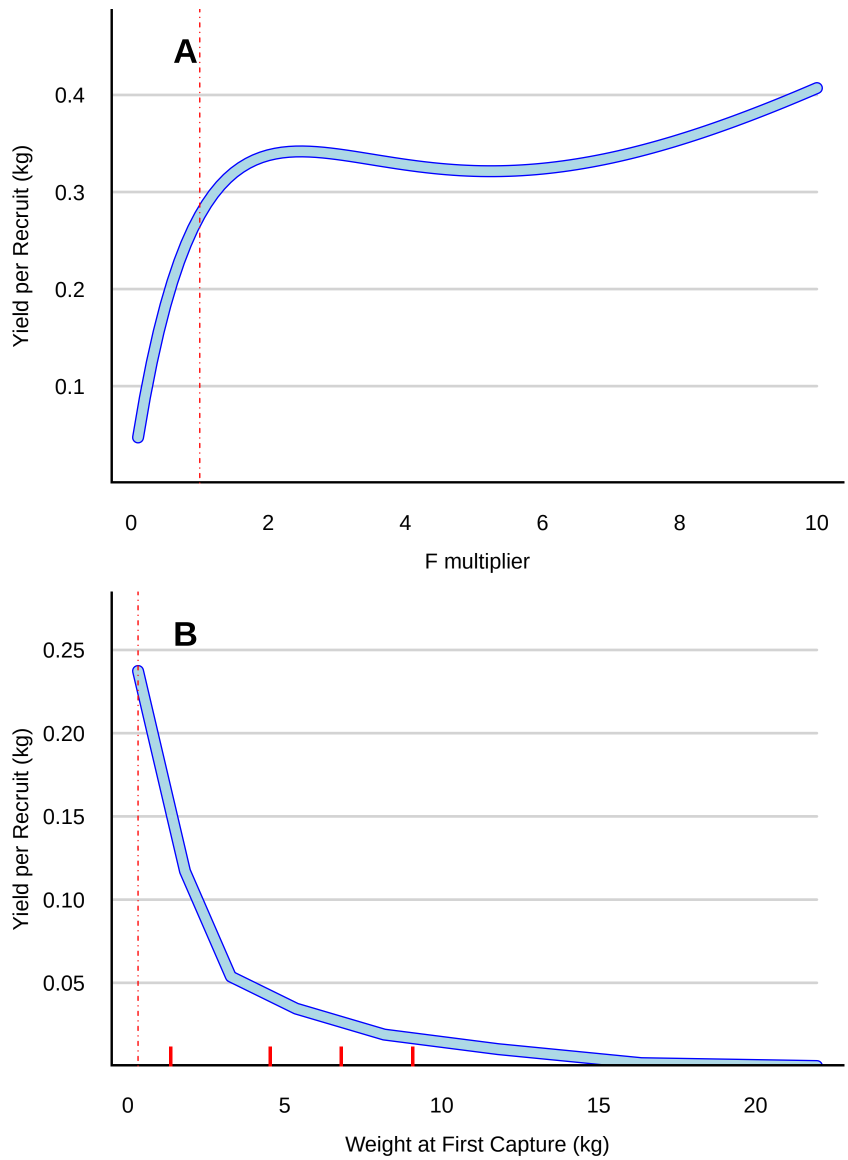

Figure 6: Yield per recruit in the Main Hawaiian Islands based on HTTP mortality estimates. See caption in Figure 3 for details.