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# Preliminary Analyses of the Potential Impacts of Minimum Weight Regulations for Pacific Bluefin Tuna

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## Abstract

The method used for Atlantic bluefin tuna by ICCAT (SCRS/2006/091) was used as a starting point to estimate the first-order effects on yield, total biomass, and spawning stock biomass for five minimum weight restrictions on the Pacific bluefin tuna fishery. The projections included five levels of tolerated catch below the minimum size limit for a total of 25 different management scenario evaluations. Data from the 2012 Pacific bluefin tuna assessment were used to populate the simulations and the most recent five year averages for fishing mortality-at-age and numbers-at-age were used as the starting point and reference period for the projections. The results should be viewed as best-case scenarios and represent what might happen given the assumptions of the model with perfect implementation and no transfer of effort. In all scenarios explored, substantial long term increases in biomass and yield were predicted. The simulations suggest that the maximum yield per recruit occurs at a minimum weight of around 20 kg and a doubling of yield and an order of magnitude increase in spawning stock biomass are theoretically possible. Short-term losses in yield are evident for one to three years following implementation depending on the scenario. Further work is needed to determine an optimal management strategy whereby minimum size can be increased gradually as biomass rebuilds to minimize short term losses in yield.

## Introduction

The analyses presented in this report were initiated following the recent Stock Assessment of Pacific Bluefin Tuna 2012 report (ISC, 2013) which indicated that overfishing is occurring and that the stock is overfished. The results of the assessment also indicated that spawning stock biomass (SSB) was at or near their lowest historic levels, that SSB has been declining for over a decade and that a majority of the catch is comprised of age 0 and age 1 fish. The assessment evaluated four different future harvest scenarios to determine their impact on the stock. In this report, we explore the additional management option of a minimum weight restriction. While this approach would result in a reduction in mortality on the youngest age classes and likely improve the yield per recruit (YPR), spawning biomass per recruit (SSBR), and overall stock status in the long term, the impact on yield and the fishery in the short term is also a critical component. We initially followed the methodology of Porch and Turner (2007) which evaluated the minimum size limit management option for Atlantic Bluefin Tuna. Their approach includes the evaluation of accepted levels of catch below the size limit for which we added an additional formulation to be more appropriate for the existing Pacific bluefin tuna fishery.

## Methods

*Model Inputs* -Data from the Stock Assessment of Pacific Bluefin Tuna 2012 (ISC, 2013) report were used to conduct our analysis. The results from the representative run were used as a starting point for abundance and mortality rates. As a reference period, and to reduce variability in estimates, the abundance at age (beginning of the year) and the fishing mortality rate at age were averaged over the most recent five year period (2006-2010). All other model inputs were as presented in the report for the stock assessment representative run (i.e. length/weight relationship, age/growth relationship, and maturity ogive). Since no obvious stock recruitment relationship has been evident the average recruitment from 2006 - 2010 of 15.6 million fish was assumed to persist into the future.

For the per recruit analysis (e.g. YPR and SSBR) and to adequately account for changes in the composition of the age structure of the largest animals, the 5+ age group was decomposed to the full 20 year maximum age structure consistent with that used in the stock assessment. The numbers at age and mortality rates from 1985 – 2005 were projected forward to populate a full age structure for the 2006 – 2010 reference period used in our analysis.

Alternative mortality scenarios and the calculation of 'tolerated' catch below a hypothetical minimum weight were conducted in two different ways hereinafter referred to as: (1) Porch and Turner, and (2) Proportional F approaches.

*Porch and Turner Approach*- The following description of the methodology is taken directly from the Porch and Turner (2007) report unless otherwise indicated. Alternative mortality scenarios were created by multiplying catch ratios at age times the fishing mortality rate at age. Catch ratios are the expected catch at age under an alternative management scenario divided by the catch at age under the condition in which the fishing mortality rate was estimated. For example, assume that we wish to test the impact of a 10 kg minimum weight on the catch of Pacific bluefin tuna. First, in our analysis the proportion of each cohort above the minimum weight $C_a$ {>10 kg} was calculated by converting weight to size and truncating the catch at age assuming a normal distribution corresponding to the reported mean and CV of each age group (see Figure 1 for size distributions). The $C_a$ {>10 kg} was then divided by the total catch at age, $C_a$ to provide a ratio for adjusting the fishing mortality rates (F's) at age. Thus, in the case of a zero tolerance for undersized fish:

$$F\{> MinWt\} = \frac{C_a\{>MinWt\}}{C_a} F_a \qquad (1)$$

In cases where regulations permit a certain level of tolerance such that a fraction *x* of the total number caught may be below the minimum weight, then the 'tolerated' catch under the size limit (*T*) would be

$$T\{< MinWt\} = \ x(\textstyle\sum_a C_a\{\geq MinWt\} + \ T_a\{< MinWt\}) \qquad (2)$$

or after rearranging,

$$T\{< MinWt\} = \ \frac{x \sum_a C_a\{\geq MinWt\}}{1-x} \quad . \qquad (3)$$

If one further assumes that the tolerated catch will have the same proportional age composition under the hypothetical size limit as the observed catch then

$$T_a\{< MinWt\} = \quad T\{< MinWt\}\frac{C_a\{<MinWt\}}{\sum_a C_a\{<MinWt\}} \quad . \qquad (4)$$

The modified fishing mortality rates for non-zero tolerances would therefore be

$$F_a\{> MinWt\} = \quad \min\left(1, \frac{x \sum_a C_a\{\geq MinWt\}}{1-x}\right) \quad . \qquad (5)$$

Note that in the special case where all fish in an age class are below the size limit, then $C_a$ {<10 kg} = $C_a$ and (5) reduces to

$$F_a\{> MinWt\} = \quad \frac{T\{<MinWt\}}{\sum_a C_a} \ F_a \quad . \qquad (6)$$

Thus all age classes with zero observed catch above and below the hypothetical minimum weight will have the same adjustment ratio.

*Proportional F Approach* - An alternative to the Porch and Turner approach for calculating the tolerated catch was also utilized to reflect the observed size/age structure in the Pacific bluefin tuna fishery. In this approach, the numbers of undersized fish at each age were projected forward given a tolerated amount of the original estimated $F$ for each age. For example, a tolerance level of 0.1 would scale the unrestricted $F_a$ as: $F_{a,\,0.1tol} = F_{a,\,unrestricted} * 0.1$ if all fish within an age class were below the minimum size. For those age classes which contain both undersized and legal fish, the numbers at age above and below the size limit were calculated from the reported size distribution at age as described in the previous approach and projected forward independently.

Two types of YPR and SSBPR analyses were generated: 1) the normal equilibrium which used average recruitment to generate a stable age distribution given the most recent numbers at age and patterns of mortality and (2) projections for 1 year and 5 years, prior to achieving a stable age distribution, so that the short term impacts on the fishery could be evaluated.

The analysis was written in the R software and projections were done with calculations on a one year time step. It is expected that experts from the Pacific bluefin tuna working groups will evaluate the model inputs and the software will allow modifications and additional runs to be generated.

## Results

The basic data obtained from the assessment is presented in Table 1. Figure 1a illustrates the size structure from the reference period by scaling the abundance in each cohort to the total number of fish in the population. Figure 1b has scaled each cohort individually to illustrate which segments of each age class correspond to each minimum size limit. The catch rate multipliers calculated from the Porch and Turner approach are presented in Table 2. The projection results for 1 year, 5 years, and equilibrium states for SSB and total biomass are in Table 3 and for projected yields in Table 4.

## Discussion

The results generated from the Porch and Turner approach indicated substantial gains in SSB, total biomass, and yield in the long term were possible given the assumptions of the model (Figures 2-4). Given a 0 tolerance for undersized fish, reductions in yield of between 22 – 76% would result in the year following implementation with a recovery to status quo yields within one to four years (Figure 2a; Table 4). In the long term, spawning stock biomass was projected to increase from between 200% to an order of magnitude greater depending on the hypothetical minimum size (Figure 2b; Table 3). The YPR analysis indicates the maximum yield will be achieved given a hypothetical minimum size of 20 kg (Figure 3c). However, the approach was insensitive to the calculated tolerance levels as illustrated in Figures 4a and 4b. This is due to the way in which the amount of tolerated catch below the minimum weight is calculated from the observed catch above the hypothetical minimum size in equation (2). In the case of the Pacific bluefin tuna fishery, only 5% of the stock in numbers is above the smallest hypothetical minimum size (5 kg) so even the highest tolerance of 0.4 results in an extremely small number of fish being allocated as tolerated catch.

Results from the proportional F approach are more applicable to the observed size structure of the catch in the Pacific bluefin tuna fishery. The calculations are grounded on the current estimated mortality rates in the fishery and provide a more appropriate representation of how undersized tolerated catch would affect the stock and yield over time. The results for scenarios which include a 0 tolerance for undersized catch are identical to those of the Porch and Turner with reductions in yield of between 22 – 76% in the year following implementation with a recovery to status quo yields within one to four years (Figure 5a; compare to Porch and Turner results in 2a). Scenarios with different levels of tolerated undersize catch substantially affect yield, SSB, and total biomass projections. See Figure 5b for the case of a hypothetical minimum weight of 30 kg and Figures 6-8 for isopleths of all scenarios investigated. Tables 3 and 4 provide results for 1 year, 5 year and equilibrium results for all scenarios. In Figure 9, additional minimum weight scenarios were projected to evaluate YPR over a larger range and the classic YPR relationship is evident. As in the Porch and Turner analysis, the maximum YPR is achieved given a minimum weight of around 20 kg, with a maximum 2.5 fold increase in the status quo yield given a tolerance of 0.

As noted in Powers (2006) and in Porch and Turner (2007), the results of this type of methodology should be treated as first-order approximations due to a number of factors. First, a single stock and single fleet was assumed and no attempt to try to predict shifting effort patterns that might result in response to a minimum size regulation was attempted. Thus, the scenarios represent what would happen given perfect implementation and are likely to overestimate the reductions in fishing mortality rates. Secondly, the undersized fish within a specific cohort are advanced to the following year assuming they will have the same mean length/weight as the size distribution for the next age group. This suggests that some compensatory growth is occurring. It is not expected that this assumption would result in substantial overestimates of the long term benefits, however a more sophisticated model could be developed to take this into account. Third, no attempt to model the potentially complex changes in selectivity that would result from the different scenarios was made. The projections assume that changes in selectivity correspond directly to each scenario and no additional factors for bycatch mortality were taken into account. The differing level of tolerated catch, however, could be utilized to draw conclusions as to how bycatch mortality might affect SSB and total biomass projections. For yield, however, the model would have to be specifically modified to take bycatch mortality into account.

Even given these caveats, the methodology here provides a framework to compare the relative impact of the different scenarios which were investigated. Experts from the Pacific bluefin tuna working groups can help refine the approach (e.g. model inputs and the basic fundamental assumptions) to address specific questions or assess different scenarios. We recommend additional research to determine the impacts of a phased in minimum size limit to allow the stock to rebuild while at the same time minimizing the short term losses to the fishery.

## Acknowledgments

Dr. John Hoenig for R coding and Dr. Clarence Porch for discussions on previous analyses. Support for this project was provided by The Pew Charitable Trusts.

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Table 1 – Basic data obtained from the assessment. *Note that the numbers at age from the 5+ group were decomposed and weight at age calculated for a full 20 year age structure prior to the analysis.

| Age | N at age (begin; 1000's) | F at Age | Wt at Age (kg; Mid) | M at Age |
|---|---|---|---|---|
| 0 | 15587 | 0.522 | 1.18 | 1.600 |
| 1 | 1776 | 0.942 | 7.07 | 0.386 |
| 2 | 488 | 0.662 | 18.80 | 0.250 |
| 3 | 176 | 0.358 | 35.71 | 0.250 |
| 4 | 75 | 0.150 | 56.45 | 0.250 |
| 5+ | 212* | 0.150 | 79.55* | 0.250 |

Table 2 – Catch ratios used to modify the fishing mortality rate vectors as calculated by the Porch and Turner approach.

| Size Limit (kg) | Tolerance (%) | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5+ |
|---|---|---|---|---|---|---|---|
| 5 | 0 | 0.000 | 0.046 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 10 | 0.009 | 0.055 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 20 | 0.020 | 0.065 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 30 | 0.034 | 0.079 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 40 | 0.053 | 0.097 | 1.000 | 1.000 | 1.000 | 1.000 |
| 10 | 0 | 0.000 | 0.000 | 0.899 | 1.000 | 1.000 | 1.000 |
| 10 | 10 | 0.007 | 0.007 | 0.900 | 1.000 | 1.000 | 1.000 |
| 10 | 20 | 0.016 | 0.016 | 0.901 | 1.000 | 1.000 | 1.000 |
| 10 | 30 | 0.027 | 0.027 | 0.902 | 1.000 | 1.000 | 1.000 |
| 10 | 40 | 0.042 | 0.042 | 0.903 | 1.000 | 1.000 | 1.000 |
| 15 | 0 | 0.000 | 0.000 | 0.081 | 1.000 | 1.000 | 1.000 |
| 15 | 10 | 0.002 | 0.002 | 0.083 | 1.000 | 1.000 | 1.000 |
| 15 | 20 | 0.006 | 0.006 | 0.086 | 1.000 | 1.000 | 1.000 |
| 15 | 30 | 0.010 | 0.010 | 0.090 | 1.000 | 1.000 | 1.000 |
| 15 | 40 | 0.015 | 0.015 | 0.095 | 1.000 | 1.000 | 1.000 |
| 20 | 0 | 0.000 | 0.000 | 0.000 | 0.965 | 1.000 | 1.000 |
| 20 | 10 | 0.002 | 0.002 | 0.002 | 0.965 | 1.000 | 1.000 |
| 20 | 20 | 0.005 | 0.005 | 0.005 | 0.965 | 1.000 | 1.000 |
| 20 | 30 | 0.008 | 0.008 | 0.008 | 0.965 | 1.000 | 1.000 |
| 20 | 40 | 0.012 | 0.012 | 0.012 | 0.965 | 1.000 | 1.000 |
| 30 | 0 | 0.000 | 0.000 | 0.000 | 0.216 | 0.995 | 1.000 |
| 30 | 10 | 0.001 | 0.001 | 0.001 | 0.216 | 0.995 | 1.000 |
| 30 | 20 | 0.003 | 0.003 | 0.003 | 0.218 | 0.995 | 1.000 |
| 30 | 30 | 0.004 | 0.004 | 0.004 | 0.219 | 0.995 | 1.000 |
| 30 | 40 | 0.007 | 0.007 | 0.007 | 0.221 | 0.995 | 1.000 |

Table 3 – The projected spawning stock biomass and total biomass for 1 year, 5 years, and at equilibrium for each of the minimum weight and tolerance combinations as projected using the proportional F approach.

| Size Limit (kg) | Tolerance (%) | One-Year Total Biomass (MT) | Five-Year Total Biomass (MT) | Equilibrium Total Biomass (MT) | One-Year Spawning Biomass (MT) | Five-Year Spawning Biomass (MT) | Equilibrium Spawning Biomass (MT) |
|---|---|---|---|---|---|---|---|
| Status | quo | 49,361 | 49,428 | 50,694 | 27,873 | 27,307 | 28,573 |
| 5 | 0 | 62,298 | 128,011 | 187,076 | 27,873 | 60,681 | 119,747 |
| 5 | 10 | 60,489 | 114,538 | 163,209 | 27,873 | 54,971 | 103,642 |
| 5 | 20 | 58,821 | 102,804 | 142,532 | 27,873 | 49,992 | 89,720 |
| 5 | 30 | 57,283 | 92,577 | 124,612 | 27,873 | 45,649 | 77,684 |
| 5 | 40 | 55,864 | 83,659 | 109,079 | 27,873 | 41,860 | 67,279 |
| 10 | 0 | 63,209 | 138,489 | 206,509 | 27,973 | 66,857 | 134,877 |
| 10 | 10 | 61,273 | 122,661 | 178,076 | 27,960 | 59,776 | 115,190 |
| 10 | 20 | 59,488 | 109,038 | 153,783 | 27,947 | 53,694 | 98,439 |
| 10 | 30 | 57,842 | 97,299 | 133,009 | 27,936 | 48,465 | 84,175 |
| 10 | 40 | 56,323 | 87,171 | 115,228 | 27,925 | 43,964 | 72,020 |
| 15 | 0 | 67,235 | 200,064 | 323,429 | 28,778 | 106,133 | 229,498 |
| 15 | 10 | 64,766 | 169,487 | 265,715 | 28,658 | 89,888 | 186,116 |
| 15 | 20 | 62,483 | 144,266 | 218,687 | 28,546 | 76,545 | 150,966 |
| 15 | 30 | 60,370 | 123,434 | 180,342 | 28,441 | 65,575 | 122,483 |
| 15 | 40 | 58,415 | 106,202 | 149,055 | 28,343 | 56,545 | 99,398 |
| 20 | 0 | 67,698 | 207,847 | 338,731 | 28,890 | 111,404 | 242,288 |
| 20 | 10 | 65,169 | 175,358 | 277,051 | 28,756 | 93,887 | 195,580 |
| 20 | 20 | 62,829 | 148,649 | 226,988 | 28,631 | 79,550 | 157,889 |
| 20 | 30 | 60,663 | 126,663 | 186,330 | 28,513 | 67,804 | 127,471 |
| 20 | 40 | 58,658 | 108,537 | 153,289 | 28,403 | 58,169 | 102,921 |
| 30 | 0 | 69,114 | 244,599 | 419,822 | 29,599 | 141,466 | 316,689 |
| 30 | 10 | 66,420 | 202,271 | 334,953 | 29,382 | 116,023 | 248,705 |
| 30 | 20 | 63,920 | 168,167 | 267,826 | 29,177 | 95,699 | 195,358 |
| 30 | 30 | 61,600 | 140,640 | 214,686 | 28,982 | 79,442 | 153,488 |
| 30 | 40 | 59,446 | 118,375 | 172,579 | 28,798 | 66,416 | 120,620 |

Table 4 – The projected yield for 1 year, 5 years, and at equilibrium for each of the minimum weight and tolerance combinations as projected using the proportional F approach.

| Size Limit (kg) | Tolerance (%) | One-Year Yield (MT) | Five-Year Yield (MT) | Equilibrium Yield (MT) |
|---|---|---|---|---|
| Status | quo | 20,577 | 20,807 | 20,980 |
| 5 | 0 | 15,970 | 35,081 | 42,946 |
| 5 | 10 | 17,076 | 32,709 | 39,189 |
| 5 | 20 | 17,968 | 30,627 | 35,917 |
| 5 | 30 | 18,679 | 28,798 | 33,063 |
| 5 | 40 | 19,239 | 27,188 | 30,573 |
| 10 | 0 | 14,897 | 35,303 | 44,356 |
| 10 | 10 | 16,246 | 32,909 | 40,284 |
| 10 | 20 | 17,335 | 30,802 | 36,757 |
| 10 | 30 | 18,207 | 28,947 | 33,699 |
| 10 | 40 | 18,895 | 27,312 | 31,046 |
| 15 | 0 | 8,282 | 33,769 | 50,166 |
| 15 | 10 | 11,123 | 31,833 | 44,619 |
| 15 | 20 | 13,426 | 30,067 | 39,953 |
| 15 | 30 | 15,277 | 28,462 | 36,020 |
| 15 | 40 | 16,751 | 27,007 | 32,696 |
| 20 | 0 | 7,512 | 33,311 | 50,706 |
| 20 | 10 | 10,521 | 31,511 | 45,022 |
| 20 | 20 | 12,962 | 29,846 | 40,251 |
| 20 | 30 | 14,926 | 28,313 | 36,236 |
| 20 | 40 | 16,491 | 26,910 | 32,851 |
| 30 | 0 | 4,988 | 26,678 | 49,955 |
| 30 | 10 | 8,445 | 26,860 | 44,480 |
| 30 | 20 | 11,276 | 26,635 | 39,864 |
| 30 | 30 | 13,578 | 26,138 | 35,964 |
| 30 | 40 | 15,437 | 25,473 | 32,664 |

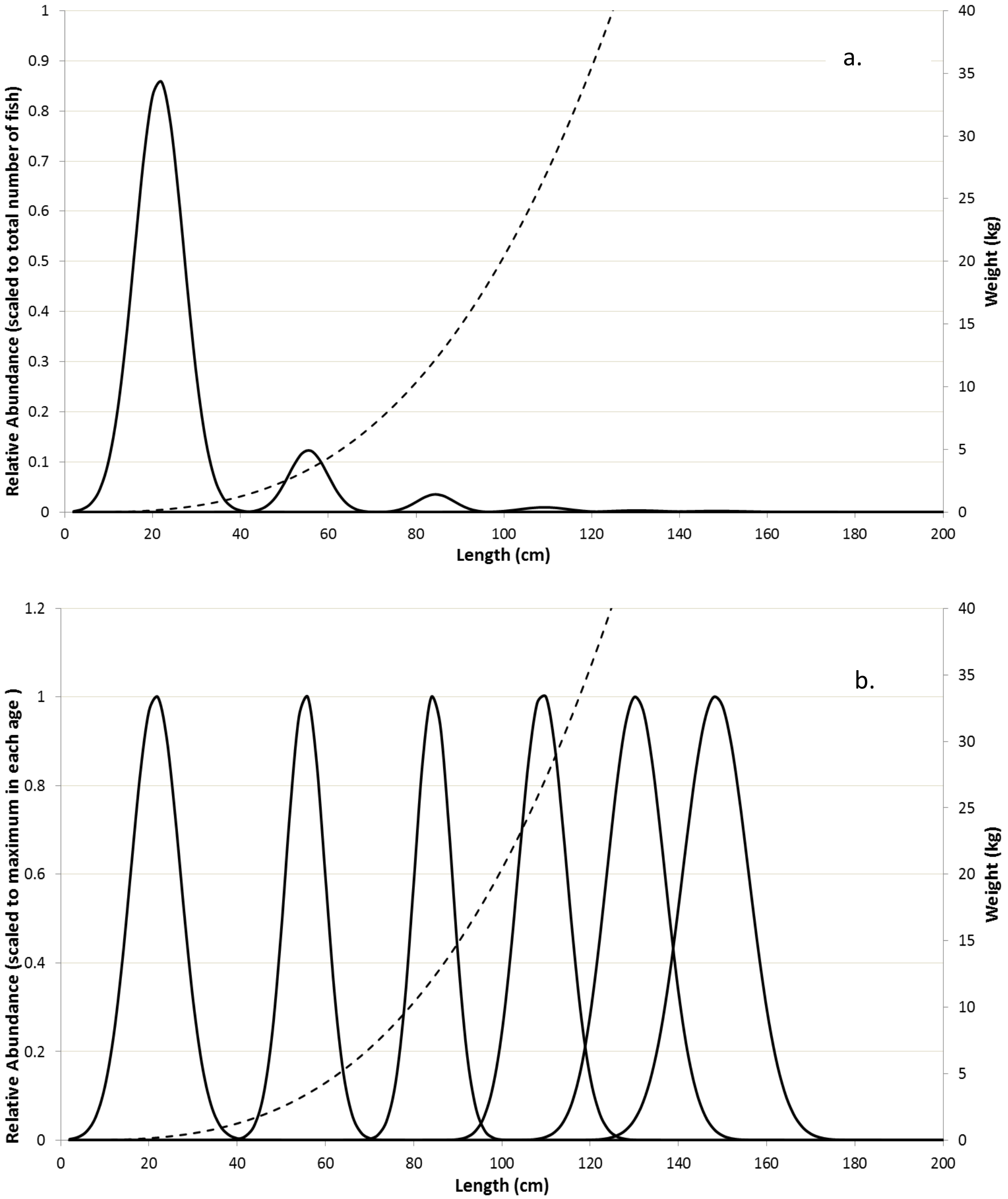

Figure 1. The relative abundance of ages 0 – 5 as scaled to the total abundance is presented in 1a. Figure 1b has normalized each cohort to the maximum number in each age. On both plates, the corresponding length weight relationship has been overlaid.

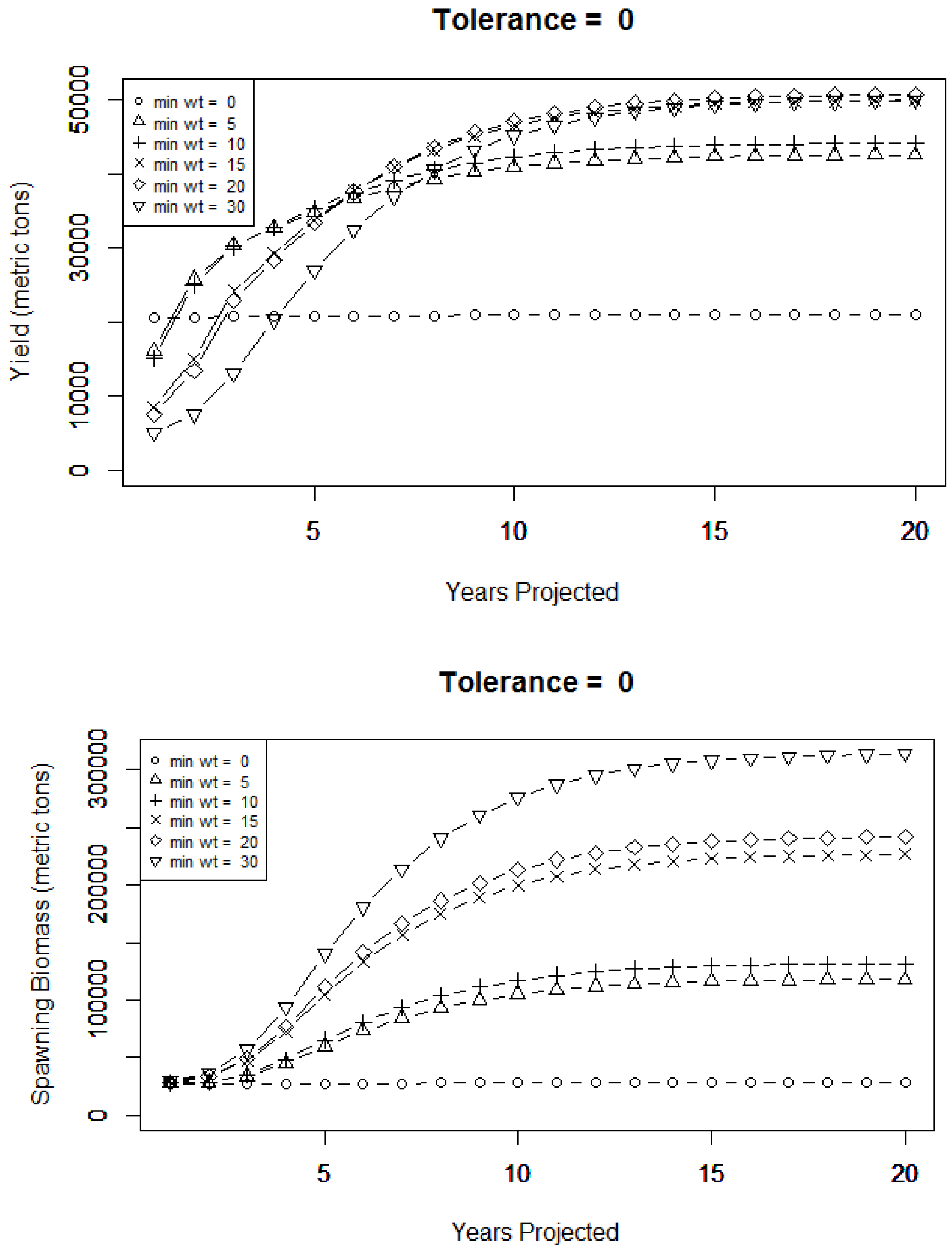

Figure 2. The projected yield and spawning stock biomass from the Porch and Turner approach given a 0 tolerance for undersized catch. The projected yield corresponding to different minimum weight scenarios is presented in 2a. The projected spawning stock biomass corresponding to different minimum weight scenarios is presented in 2b.

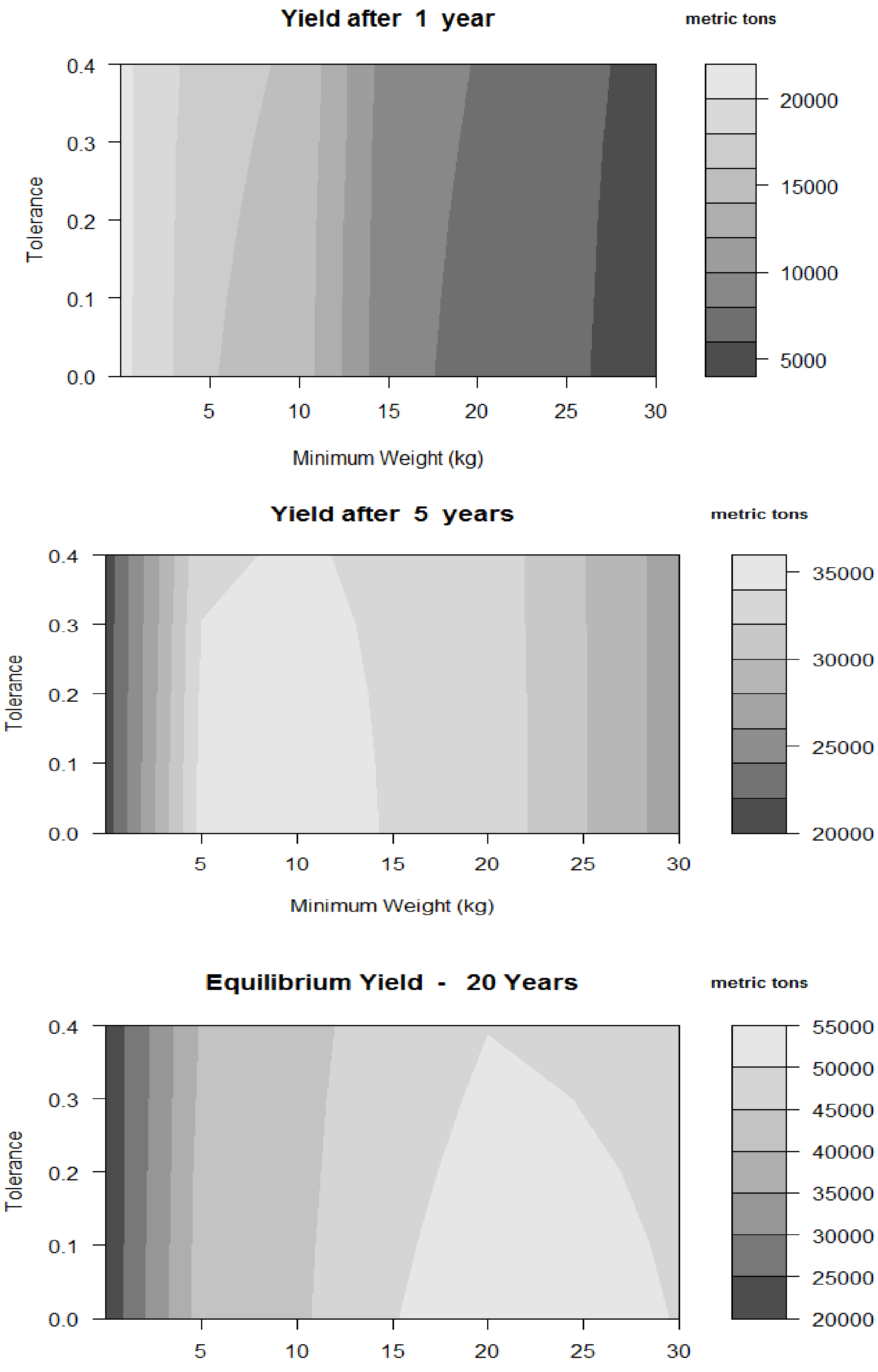

Figure 3. Isopleths of yield given 1 year, 5 year, and equilibrium (20 yr.) projections from the Porch and Turner approach.

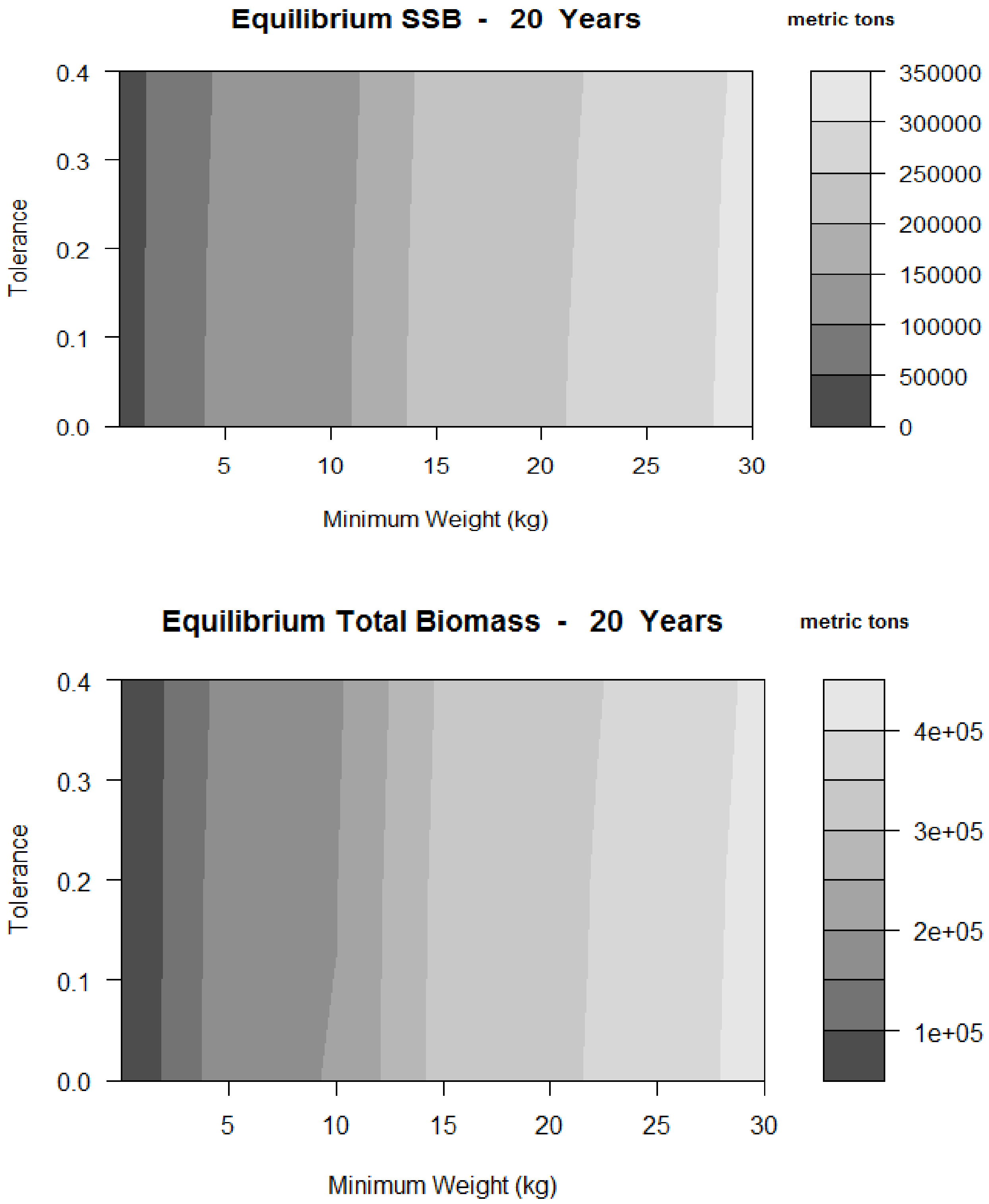

Figure 4. Isopleths of equilibrium spawning stock biomass and total biomass as projected from the Porch and Turner approach. Note the relative insensitivity of results to the levels of tolerance.

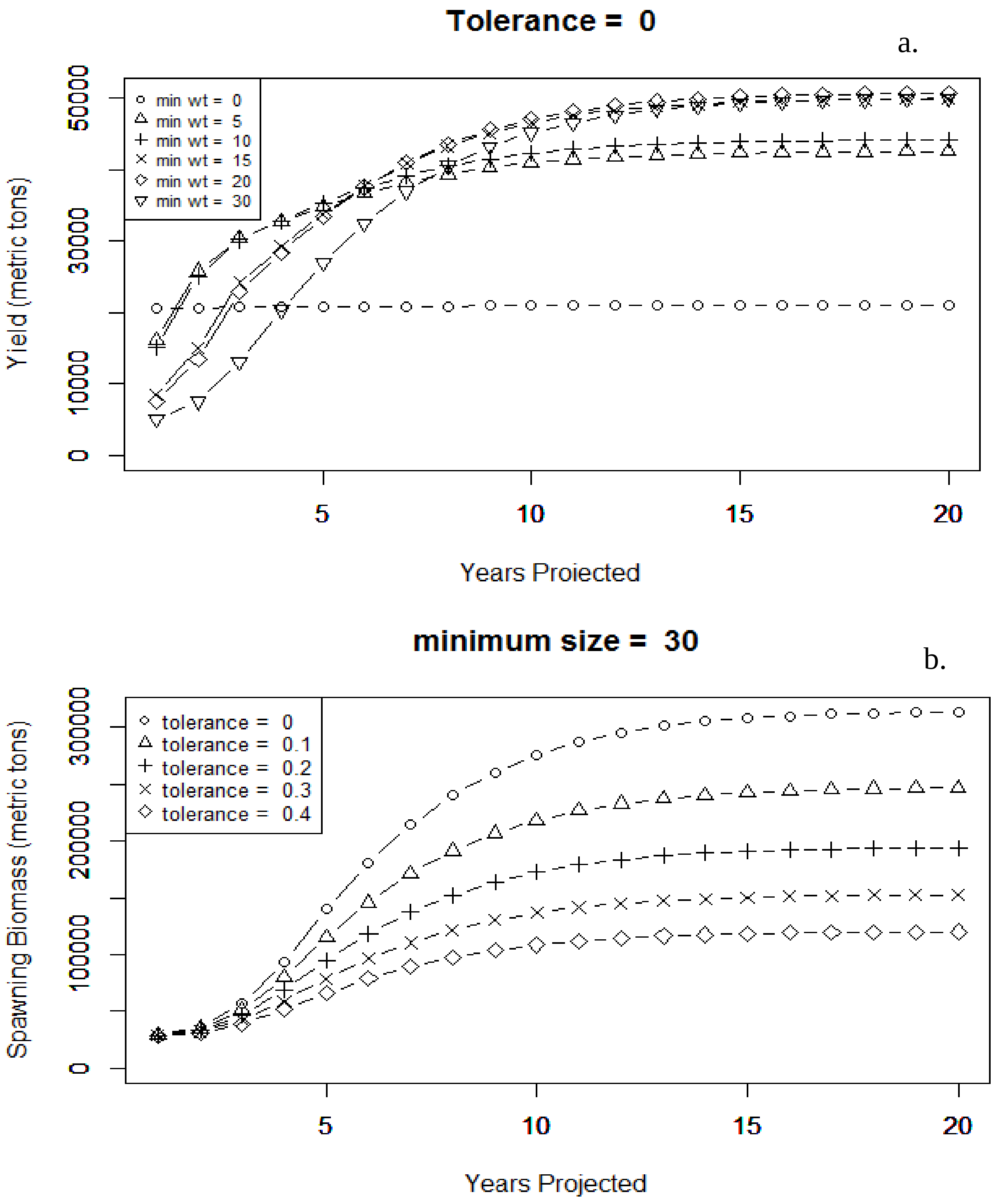

Figure 5. The projected yield and spawning stock biomass for two scenarios given the proportional F approach. The projected yield corresponding to different minimum weight scenarios given a tolerated undersize catch of 0 is presented in 5a. The projected spawning stock biomass corresponding to a minimum size of 30 kg under different tolerated catch scenarios is presented in 5b.

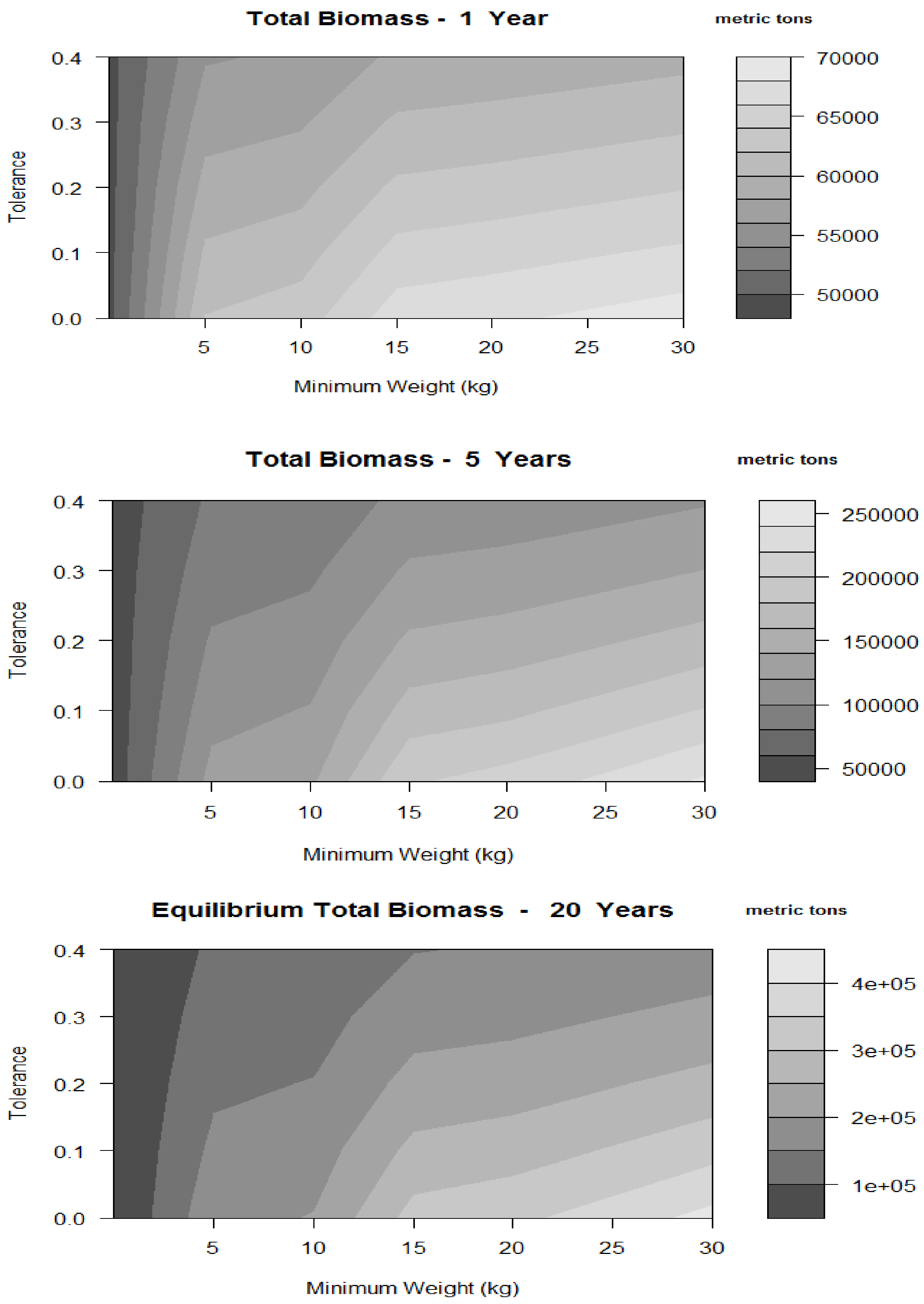

Figure 6. Isopleths of total biomass given 1 year, 5 year, and equilibrium (20 yr.) projections from proportional F approach.

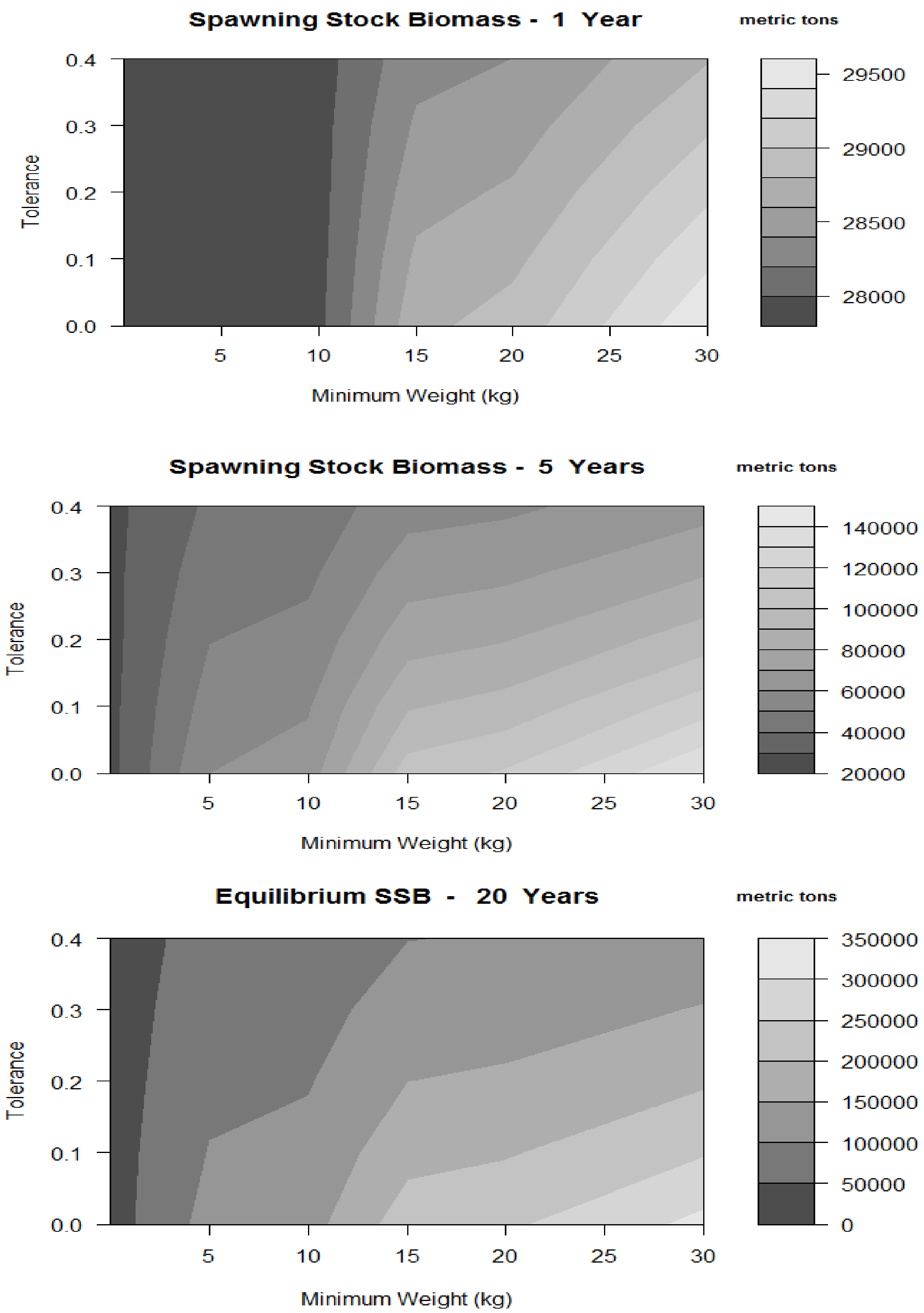

Figure 7. Isopleths of spawning stock biomass given 1 year, 5 year, and equilibrium (20 yr.) projections from proportional F approach.

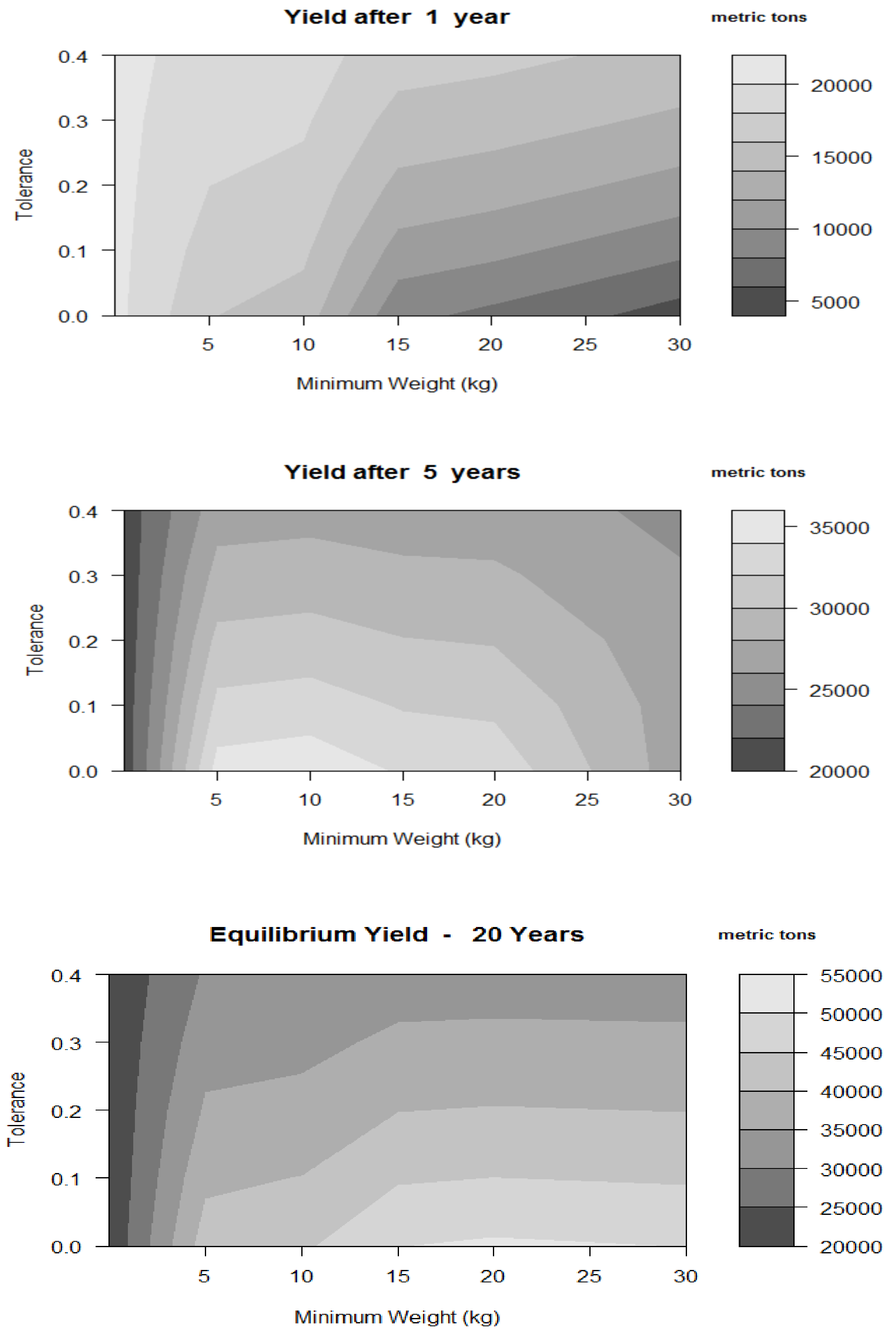

Figure 8. Isopleths of yield given 1 year, 5 year, and equilibrium (20 yr.) projections from proportional F approach.

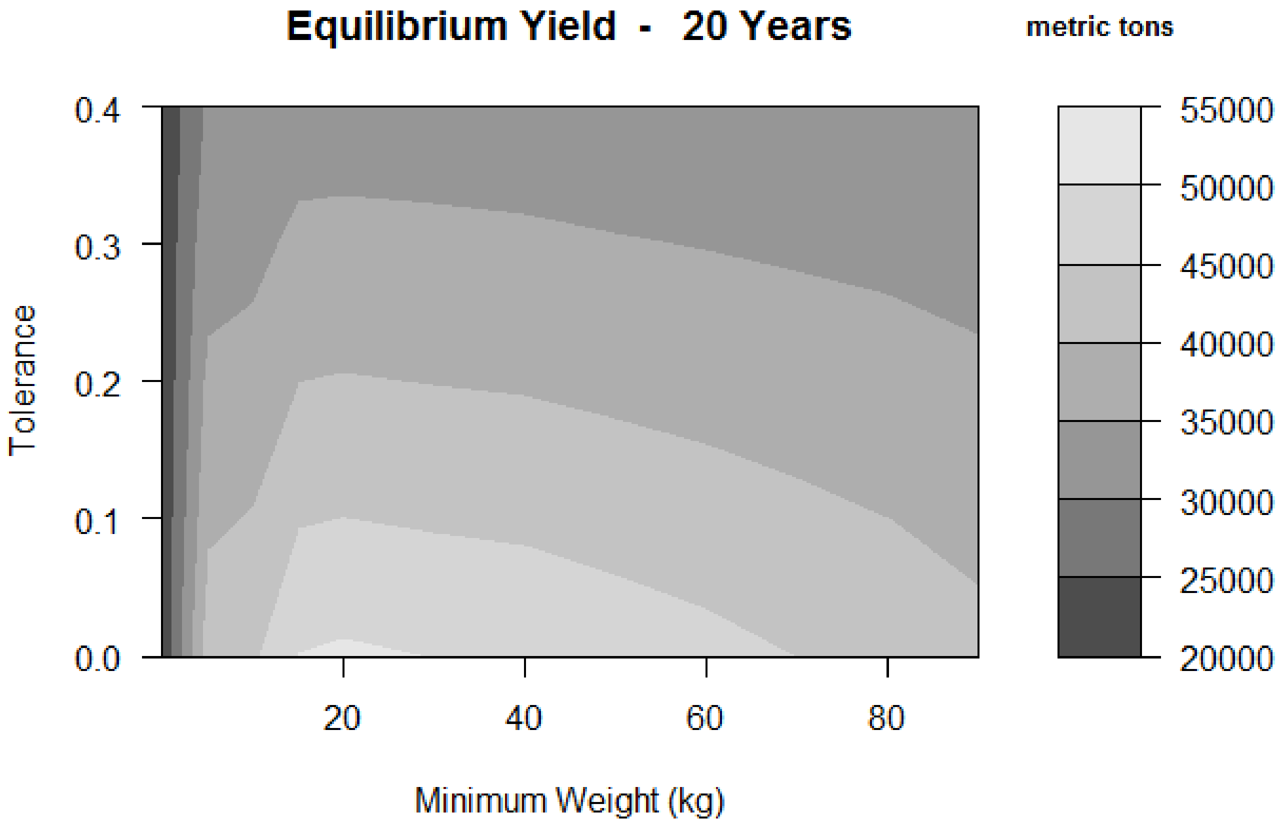

Figure 9. Isopleths of equilibrium yield given expanded minimum weight range to explore the YPR relationship. Note the rapid rise in yield that starts at approximately a 10 kg minimum weight and reaches a maximum around 20 kg.