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KOBE II STRATEGY MATRIX FOR THE BIGEYE AND YELLOWFIN TUNA STOCKS OF THE EASTERN PACIFIC OCEAN IN 2012

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1. INTRODUCTION

The second joint meeting of the tuna regional fisheries management organizations (tRFMOs) recommended the computation of a "strategy matrix" in order to improve further the standardization of the presentation of stock assessment results for fishery managers. The Kobe II strategy matrix "would present the specific management measures that would achieve the intended management target" (Report of the second joint meeting of the tuna RFMOs). Following this recommendation, the IATTC staff computed the following Kobe II strategy matrices and decision matrices for yellowfin tuna and bigeye tuna in the eastern Pacific Ocean (EPO) in 2012.

For this exercise, the reference points cited in Maunder and Deriso (2013) and that will be recommended by the staff to the Commission for adoption as an interim measure were used (IATTC 2013):

Stock	Target reference point	Limit reference point
Bigeye tuna	S_{MSY}; F_{MSY}	50% of S_{MSY}; 30% above F_{MSY}
Yellowfin tuna	S_{MSY}; F_{MSY}	40% of S_{MSY}; 40% above F_{MSY}

S_{MSY}: Spawning stock biomass corresponding to the maximum sustainable yield (MSY); F_{MSY}: fishing mortality rate corresponding to the maximum sustainable yield

The Kobe II strategy matrix was computed with F_{MSY}, because the IATTC staff recommendations have treated F_{MSY} as a target reference point, and the informal harvest rule used to management tunas in the EPO has been based on reducing fishing mortality to F_{MSY} if it exceeds F_{MSY}. The Kobe II strategy matrix is substantially more demanding computationally for calculating biomass reference points than for calculating fishing mortality reference points. Therefore, biomass reference points are presented only as a traditional decision table.

2. METHODS

2.1. Kobe matrix

For the Kobe II strategy matrix, the fraction δ of the current fishing mortality (F_{cur}) that is required to ensure a given probability P that it will be at or below fishing mortality target reference point (*e.g.* F_{MSY}) was computed:

$$p(\delta F_{cur} < F_{MSY}) = \mathrm{P}$$

The normal approximation method was used, due to the excessively long computational time that is required for the use of either the Bayesian or the bootstrap methods with the current bigeye and yellowfin stock assessment model (Maunder *et al.* 2012) implemented in Stock Synthesis 3 (SS3; Methot and

Wetzel 2013). The standard deviation of F_{mult}[1] = F_{MSY}/F_{cur} was estimated using the stock assessment models for yellowfin (Minte-Vera *et al*. 2013) and bigeye (Aires-da-Silva and Maunder 2013).

It follows that:

$$p(\delta F_{cur} < F_{MSY}) = p\left(\frac{\delta F_{cur}}{F_{MSY}} < 1\right) = p\left(\frac{F_{MSY}}{\delta F_{cur}} > 1\right) = 1 - p\left(\frac{F_{MSY}}{\delta F_{cur}} < 1\right) = 1 - p\left(\frac{F_{mult}}{\delta} < 1\right)$$

Assuming that $F_{mult} \sim N(\mu_{Fmult}, \sigma^2_{Fmult})$, it follows that $\frac{F_{mult}}{\delta} \sim N(\frac{\mu_{Fmult}}{\delta}, \frac{\sigma^2_{Fmult}}{\delta^2})$

The following equation was solved for δ for each probability P desired, using numerical methods:

$$1 - \Phi\left(x = 1, \frac{\mu_{Fmult}}{\delta}, \frac{\sigma^2_{Fmult}}{\delta^2}\right) = P$$

Similarly, for the limit reference points, the following equation was solved for δ for each probability P desired, using numerical methods:

$$1 - \Phi\left(x = 1/\beta, \frac{\mu_{Fmult}}{\delta}, \frac{\sigma^2_{Fmult}}{\delta^2}\right) = P$$

where $\beta = 1.4$ for yellowfin and 1.3 for bigeye are the F_{MSY} scaling factors for the proposed interim limit reference points as described above.

Two states of nature were considered: a case in which the steepness of the stock-recruitment relationship (h) is assumed to be 0.75 and the base case for the stock assessment (h = 1).

2.2. Decision tables

Decision tables were computed for biomass reference points and fishing mortality reference points for two different management options (fishing at F_{cur} or F_{MSY}).

The probabilities of the spawning biomass being greater than the spawning biomass that corresponds to the MSY (S_{MSY}) in 5 and 10 years in the future were computed. The standard deviations of $d = S/S_{\mathrm{MSY}}$ were estimated using the current stock assessment models implemented in SS3. The probabilities were obtained using a normal approximation, as follows:

$$p(S_t > S_{MSY}) = p\left(\frac{S_t}{S_{MSY}} > 1\right) = 1 - \Phi(x = 1, \mu_d, \sigma_d^2)$$

Similarly, the probability of the spawning biomass falling below the proposed biomass limit reference point was obtained by:

$$p(S_t > \theta S_{MSY}) = p\left(\frac{S_t}{S_{MSY}} > \theta\right) = 1 - \Phi(x = \theta, \mu_d, \sigma_d^2)$$

where $\theta = 0.4$ for yellowfin and 0.5 for bigeye are the S_{MSY} scaling factors for the proposed interim limit reference points as described above.

The probability of the fishing mortality falling below the proposed reference point is:

$$(F < \beta F_{MSY}) = 1 - \Phi\left(x = 1/\beta, \frac{\mu_{Fmult}}{\delta}, \frac{\sigma^2_{Fmult}}{\delta^2}\right)$$

where $\beta = 1$ for target reference points; for limit reference points, $\beta = 1.4$ (yellowfin) and 1.3 (bigeye),

[1] F multiplier (F_{mult}): the number of times the effort would have to be effectively increased relative to the average fishing mortality during 2010-2012 to achieve MSY.

and $\delta = 1$ for F_{cur} and $\delta = F_{mult}$ for F_{MSY}.

The calculations were performed assuming that the current mix of fisheries and selectivity patterns would be maintained. The future recruitment is assumed to be the same as the average recruitment estimated in the current stock assessments (Aires-da-Silva and Maunder 2013; Minte-Vera *et al*. 2013).

2.3. Misspecification cases

In order to assess the implications of wrong assessments, two “misspecification”cases were run. In the first case, the true state of nature was assumed to have a steepness (*h*) of the stock-recruitment relationship of 0.75, while the assessment was performed using a model that assumes $h = 1$. In the second case, the true state of nature was assumed to have a steepness *of* 1 while the assessment was performed using a model that assumes $h = 0.75$. The management advice from the assessment model was then applied when projecting from the model that represented the true state of nature.

3. RESULTS

3.1. Kobe matrix

3.1.1. Yellowfin

The Kobe II strategy matrix for yellowfin was computed using two variability scenarios. For case 1 (low variability), the standard deviation of the F_{mult} estimates from SS3 was used. As this value appears to be unrealistically low (coefficient of variation, CV = 2.32%), a second case (high variability) was computed, in which the average CV of the quarterly summary *F* estimated for the last three years in the assessment model (CV = 6.25%) was used as a proxy for the standard deviation of F_{mult}. The results for these two cases are presented in Table 1.

The risk of each management option may be better visualized in a risk plot (Figure 1).

3.1.2. Bigeye

The Kobe II strategy matrix for bigeye is shown in Table 2. The risk curves are shown in Figure 2.

3.2. Decision tables

3.2.1. Yellowfin

The probabilities of yellowfin being above the biomass reference points and below the fishing mortality reference points are shown in Tables 3 and 4, respectively.

3.2.2. Bigeye

The probabilities of bigeye being above the biomass reference points and below the fishing mortality reference points are shown in Tables 5 and 6, respectively.

3.3. Misspecification cases

3.3.1. Yellowfin

The implications of giving management advice for yellowfin based on assessments that fail to match the true stock-recruitment steepness are given in Tables 7 and 8.

3.3.2. Bigeye

The implications of giving management advice for bigeye based on assessments that fail to match the true stock-recruitment steepness are given in Tables 9 and 10.

4. CONCLUSION

This exercise shows how the Kobe II strategy matrix may be computed using the normal approximation method for yellowfin and bigeye stocks in the EPO. Calculations for fishing mortality reference points are less computationally demanding than those for biomass reference points, which is convenient since the informal decision rule used to manage tuna in the EPO is based on fishing mortality. The results indicate that there is a high probability that the current fishing mortality of bigeye is below the fishing mortality limit reference point even if the steepness of the stock-recruitment relationship is low (0.75).

For example, the Kobe II matrix suggests that, for bigeye, fishing mortality would have to be reduced by only 4% to have a 90% probability of being below the fishing mortality limit reference point (1.3 F_{MSY}) if the steepness is 0.75 (Table 2). In contrast, under the same conditions, fishing mortality of yellowfin would have to be reduced by 14% to 17% (Table 1).

The probability of being above the biomass limit reference point with current fishing mortality is high for both yellowfin and bigeye even if the steepness of the stock-recruitment relationship is low (0.75) (Tables 3 and 5). However, if the steepness is 0.75 and the fishing mortality is set appropriately at F_{MSY} for that assumption, the bigeye population would not rebuild to the biomass corresponding to MSY within 10 years. For both yellowfin and bigeye, there is a high probability of being above the limit biomass reference point even if the fishing mortality is set based on F_{MSY} under an assessment that assumes a stock-recruitment steepness of 1 when in fact the real steepness is 0.75 (Tables 7 and 9). However, there is a low probability of being below the limit fishing mortality reference point for yellowfin if the fishing mortality is set based on F_{MSY} under an assessment that assumes a stock-recruitment steepness of 1 when in fact the real steepness is 0.75 (Table 7). This indicates that there may be an inconsistency between these fishing mortality and biomass limit reference points. Other model structure uncertainty and misspecification (*e.g*. natural mortality, and the average length of old individuals) should also be included in the evaluation of the Kobe II strategy matrix and limit reference points.

The analyses presented in this report evaluate the current informal harvest control rule used for managing tunas in the EPO (*i.e*. set the fishing mortality at F_{MSY}). This is a form of management strategy evaluation (MSE). We evaluated the harvest control rule under different states of nature through two assumptions about the steepness of the stock-recruitment relationship. This evaluation should be extended to include additional states of nature. Other harvest control rules could also be evaluated.

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TABLE 1. Kobe II strategy matrix for yellowfin tuna in the EPO in 2012, using two assumptions for steepness of the stock-recruitment relationship and two cases for the variability. δ: fraction of the current (2010-2012) fishing mortality required to ensure the given probability that the fishing mortality is below F_{MSY} (target) or 1.4 F_{MSY} (limit).

Proposed reference point	State of nature steepness	Variability	δ required to ensure the following probability of being below the target or limit			
			95%	90%	80%	50%
Target $F = F_{MSY}$	Base case	Low	0.972	0.980	0.991	1.010
		High	0.906	0.929	0.957	1.010
	h = 0.75	Low	0.604	0.613	0.624	0.644
		High	0.578	0.592	0.610	0.644
Limit $F = 1.4\ F_{MSY}$	Base case	Low	1.361	1.372	1.381	1.415
		High	1.269	1.301	1.323	1.415
	h = 0.75	Low	0.809	0.829	0.854	0.902
		High	0.846	0.858	0.873	0.902

TABLE 2. Kobe II strategy matrix for bigeye tuna in the EPO in 2012, using two assumptions for steepness of the stock-recruitment relationship. δ: fraction of the current (2010-2012) fishing mortality required to ensure the given probability that the fishing mortality is below F_{MSY} (target) or 1.3 F_{MSY} (limit).

Proposed reference point	State of nature steepness	δ required to ensure the following probability of being below the target or limit			
		95%	90%	80%	50%
Target $F = F_{MSY}$	Base case	0.899	0.933	0.974	1.053
	h = 0.75	0.713	0.738	0.767	0.825
Limit $F = 1.3\ F_{MSY}$	Base case	1.168	1.213	1.266	1.369
	h = 0.75	0.927	0.959	0.998	1.072

TABLE 3. Yellowfin decision table: probabilities of being above the target and limit biomass reference points for yellowfin tuna in the EPO in 2012 under different states of nature and timeframes. F_{cur} is the average fishing mortality for the last three years in the current assessment (2010-2012).

Proposed reference point	State of nature *steepness*	Time frame (years)	Probability of being above the target or limit by fishing at	
			F_{cur}	F_{MSY}
target $S = S_{MSY}$	Base case	0	0.082	0.082
		5	0.519	0.500
		10	0.520	0.500
	h = 0.75	0	0.000	0.000
		5	0.000	0.221
		10	0.000	0.481
limit $S = 0.4\ S_{MSY}$	Base case	0	1	1
		5	0.996	0.997
		10	0.996	0.997
	h = 0.75	0	1	1
		5	0.832	0.992
		10	0.897	0.996

TABLE 4. Probability of being below the proposed reference point for yellowfin tuna in the EPO in 2012.

Proposed reference point	State of nature steepness	Variability	Probability of being below the target or limit by fishing at F_{cur}
Target $F = F_{MSY}$	Base case	low	0.671
		high	0.565
	h = 0.75	low	0
		high	0
Limit $F = 1.4\ F_{MSY}$	Base case	low	1
		high	1
	h = 0.75	low	0.002
		high	0.041

TABLE 5. Bigeye decision table: probabilities of the spawning stock biomass (*S*) being above the target and limit biomass reference points in the EPO in 2012 under different states of nature and timeframes. F_{cur} is the average fishing mortality for the last three years in the current assessment (2010-2012).

Proposed reference point	State of nature *steepness*	Time frame (years)	Probability of being above the target or limit by fishing at	
			F_{cur}	F_{MSY}
Target $S = S_{MSY}$	Base case	0	0.794	0.794
		5	0.485	0.349
		10	0.579	0.488
	h = 0.75	0	0.259	0.259
		5	0.125	0.124
		10	0.179	0.333
Limit $S = 0.5\ S_{MSY}$	Base case	0	0.998	0.998
		5	0.904	0.995
		10	0.931	1
	h = 0.75	0	0.997	0.997
		5	0.808	0.981
		10	0.796	1

TABLE 6. Probability of being below the proposed reference point for bigeye tuna in the EPO in 2012.

Proposed reference point	State of nature *steepness*	Probability of being below the target or limit by fishing at F_{cur}
Target $F = F_{MSY}$	Base case	0.714
	h = 0.75	0.005
Limit $F = 1.3\ F_{MSY}$	Base case	0.999
	h = 0.75	0.793

TABLE 7. Misspecification cases for yellowfin: probabilities of being at or above the biomass reference point.

Steepness		Proposed reference point	Probability of being above the reference point in		
True state of nature	Assessment assumption		0 years	5 years	10 years
h = 0.75	h = 1	target $S = S_{MSY}$	0	0	0
		limit $S = 0.4\ S_{MSY}$	1	0.838	0.905
Base case	h = 0.75	target $S = S_{MSY}$	0.082	0.952	0.952
		limit $S = 0.4\ S_{MSY}$	1	1	1

TABLE 8. Misspecification cases for yellowfin: probabilities of being below the reference points when fishing at F_{MSY} based on the assessment results. F_{mult} is the fraction of the current (2010-2012) fishing mortality required to ensure that fishing mortality is at F_{MSY}.

Steepness		Variability	Probability of being below	
True state of nature	Assessment assumption		target $F = F_{MSY}$	limit $F = 1.4\ F_{MSY}$
h = 0.75	h = 1 (F_{mult} = 1.01)	low	0	0.007
		high	0	0.027
Base case	h = 0.75 (F_{mult} = 0.64)	low	1	1
		high	1	1

TABLE 9. Misspecification cases for bigeye: probabilities of being above the biomass reference point if fishing at F_{MSY} based on the assessment results. F_{mult} is fraction of the current fishing mortality (2010-2012) that is requires for ensuring the fishing mortality to be at F_{MSY}.

Steepness		Proposed reference point	Probability of being above the reference point in		
True state of nature	Assessment assumption		0 years	5 years	10 years
h = 0.75	h = 1 (F_{mult} = 1.05)	target $S = S_{MSY}$	0.259	0.012	0.004
		limit $S = 0.5\ S_{MSY}$	0.997	0.912	0.940
Base case	h = 0.75 (F_{mult} = 0.82)	target $S = S_{MSY}$	0.794	0.799	0.971
		limit $S = 0.5\ S_{MSY}$	0.998	0.999	1

TABLE 10. Misspecification cases for bigeye: probabilities of being below the reference points. F_{mult} is fraction of the current fishing mortality (2010-2012) that is required for ensuring that fishing mortality is at F_{MSY}.

Steepness		**Probability of being below**	
True state of nature	**Assessment assumption**	**target** $F = F_{\mathrm{MSY}}$	**limit** $F = 1.3\ F_{\mathrm{MSY}}$
h = 0.75	h = 1 (F_{mult} = 1.05)	0.0004	0.598
Base case	h = 0.75 (F_{mult} = 0.82)	0.993	1

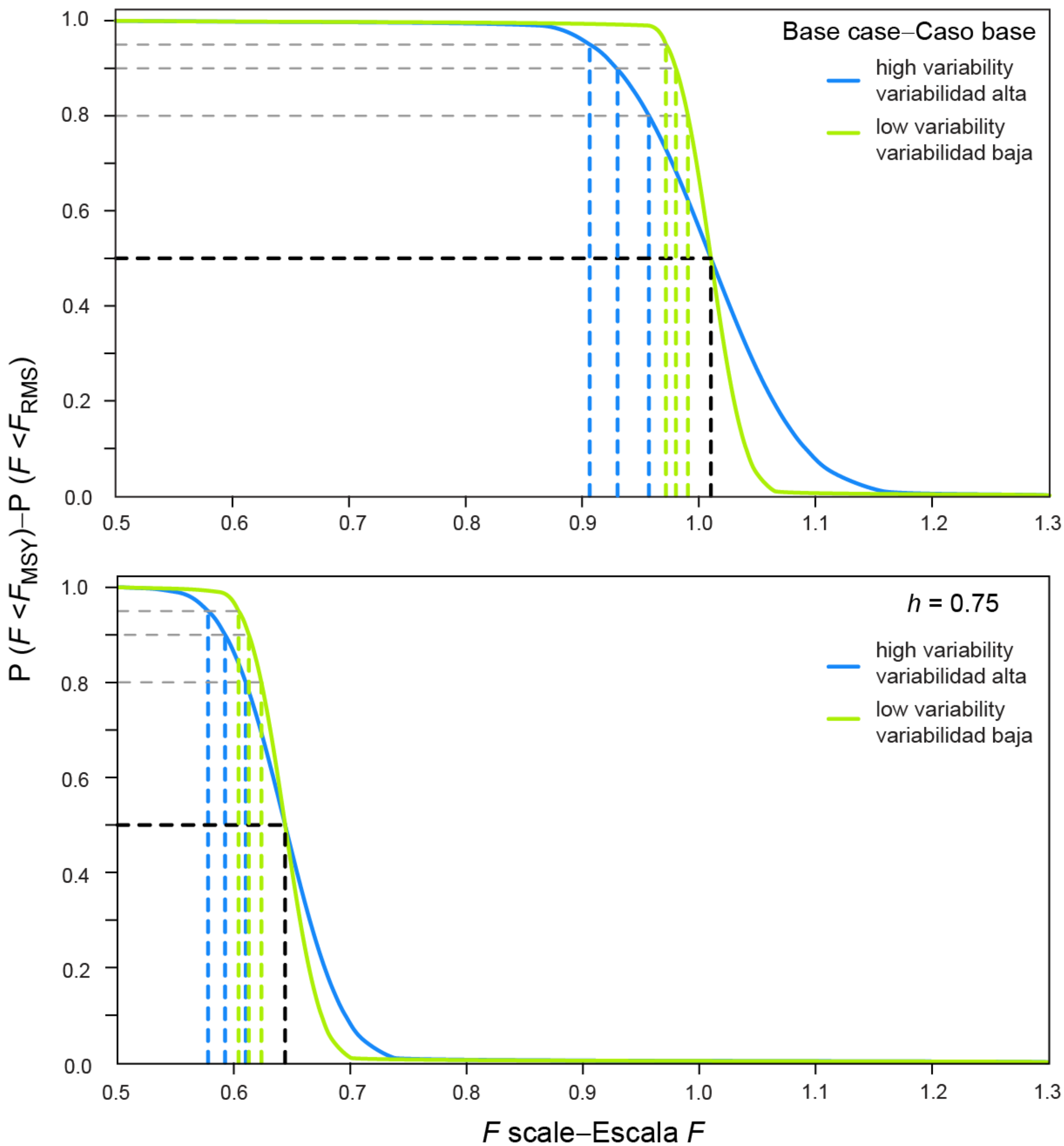

FIGURE 1. Risk curves for yellowfin: Probability that the fishing mortality (*F*) is below the level corresponding to MSY (F_{MSY}) for different fractions (δ = *F* scale) of the current fishing mortality (2010-2012). The grey dashed lines represent 80%, 90% and 95% probabilities. The black dashed line represents 50% probability, which, for the base case, is the current management advice. The top panel corresponds to the base case and the lower panel corresponds to the case when the steepness (*h*) of the stock-recruitment relationship is assumed to be 0.75.

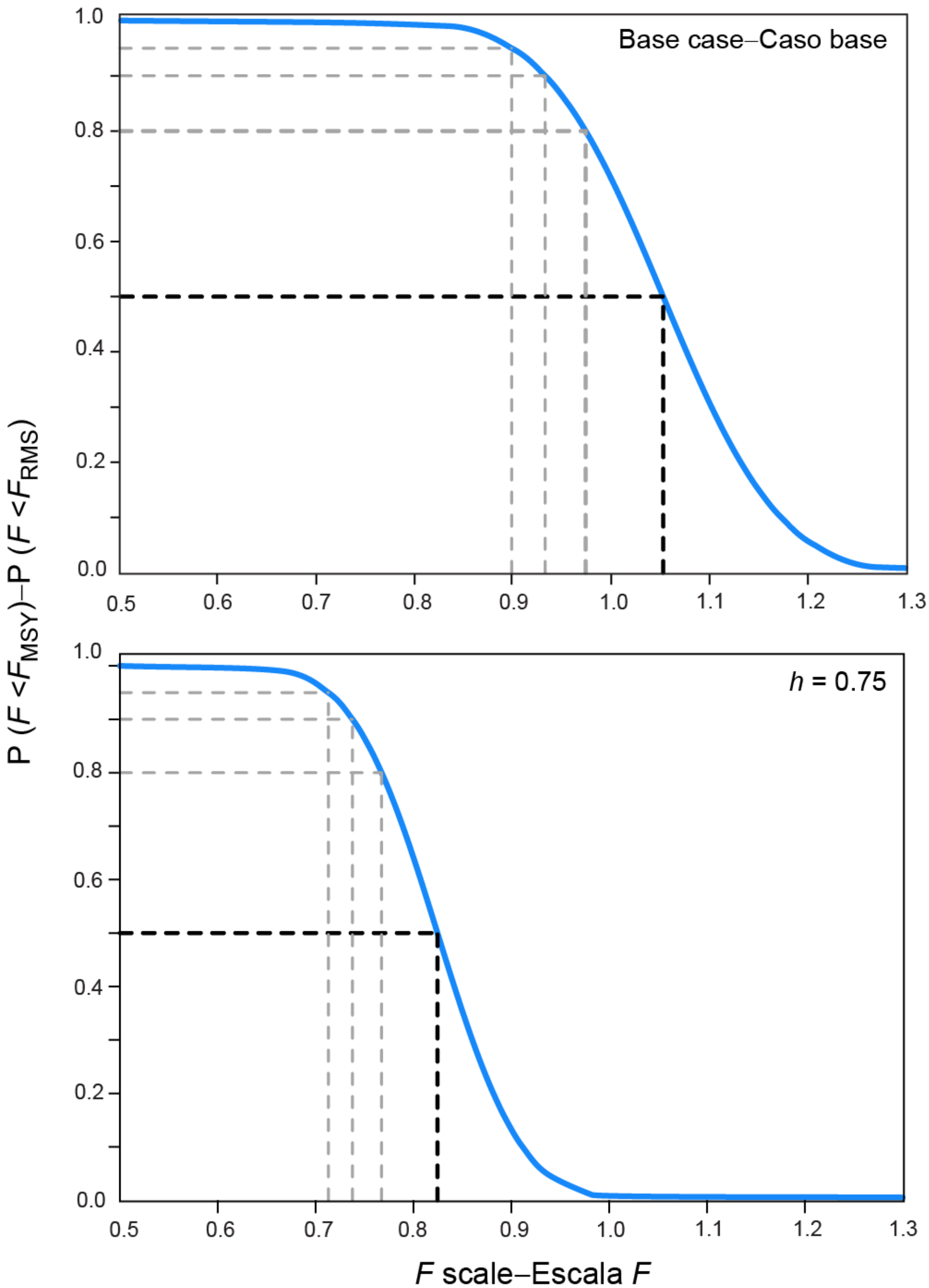

FIGURE 2. Risk curves for bigeye: Probability that the fishing mortality (*F*) is below the level corresponding to MSY (F_{MSY}) for different fractions ($\delta = F\ scale$) of the current fishing mortality (2010-2012). The grey dashed lines represent 80%, 90% and 95% probabilities. The black dashed line represents 50% probability, which, for the base case, is the current management advice. The top panel corresponds to the base case and the lower panel corresponds to the case when the steepness (*h*) of the stock-recruitment relationship is assumed to be 0.75.