VPA Evaluation of Projected SPR resulting from TAC and Bycatch Reduction for Red snapper (*Lutjanus campechanus*) in the Gulf of Mexico

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Methods.

A 2-fleet, tuned VPA was implemented, where the catch at age (CAA) for fleet 1 represented total directed catch and discards for Handline, Longline, and Recreational fisheries, and fleet 2 represented shrimp bycatch. Modeled ages were 0-15+ or 1-15+. Natural mortality at age was: "high M case" [M_0=1.0, M_1=0.6, M_{2-15+}=0.1] or "low M case" [M_0=0.5, M_1=0.3, M_{2-15+}=0.1]. A moderate penalty was imposed to link selectivities ($s_{a,y}$) in the final 3 years. The estimate of annual fishing on the oldest age group ($F_{15+,y}$) was constrained to be equal to the estimate of $F_{14,y}$ for all years. Five regional indices (units) were used for tuning, where the region was Gulfwide, Eastern Gulf, or Western Gulf: MRFSS (numbers), Video (numbers), Larval (reproductive biomass—used as index of SSB), Fall Trawl Survey (numbers), Summer Trawl Survey (numbers). For cases where the modeled age of recruitment was 1, the Fall Trawl Survey was not used as it indexes age 0 fish. All indices were given equal weighting.

The VPA estimates of fishing mortality at age and year, and estimated abundance at age and year, were used in a set of factorial projections for the years 2004-2032. The following specifications were common to all projections:

- a geometric mean of selectivity in the last 3 years (2001-2003) was specified
- the last 3 years of recruitments (2001-2003) were replaced with values predicted from the fitted Beverton-Holt
- F in 2004 was set to the estimate for 2003

The factors considered in the projection were:

1. region (Gulfwide, Eastern Gulf, Western Gulf)
2. age of recruitment (age 0 or age 1)
3. natural mortality ("low M" or "high M" to match the VPA set-up)
4. level of R0, virgin recruitment (either R0 was estimated by fitting a Beverton-Holt function from 1984-2000 VPA estimates of SSB and recruitment, or R0 was fixed at 8.5 times the average of the three lowest VPA estimates of recruitment)

When R0 was estimated, steepness was also estimated; when R0 was fixed to 8.5 times the 3 year average low, steepness was fixed at the previously estimated value. Combinations of total allowable catch (TAC) for the directed fishery in the range of 2-14 million pounds were evaluated in conjunction with bycatch reductions of 0% to 100%, and the resulting SPR isopleths were plotted. For 2004, the directed fishery operated at the estimated 2003 effort level, and then all TACs were implemented in years 2005-2032. The modeled shrimp fleet operated at the estimated 2003 level of effort through 2007, and then the level of bycatch reduction was implemented in years 2008-2032.

Results.

The values of steepness (h) and virgin recruitment (R0) for each model are given in Table 1. In all cases, steepness was estimated to be approximately 1, implying constant recruitment. Therefore, projected recruitment appears as a nearly horizontal line at some average of observed value (when R0 was estimated) or at the fixed level of 8.5 times the 3 year average low (see Figure 1 for representative plots).

Differences in SPR isopleths are negligible between the low and high M cases (true for all regions, both ages of recruitment, and both levels of R0; Figures 2-9). Predictably, when R0 is fixed at a value that is larger than was historically estimated, the SPR isopleths predict a more optimistic scenario (Figures 2-5 versus Figures 6-9). Gulfwide and western gulf projections show fairly similar predicted SPR isopleths, with the Gulfwide cases appearing to be only slightly more tolerant to larger TACs. Projections for the eastern gulf suggest that large TACS can only be supported if R0 is larger than the estimated values for 1984-2000 (i.e., only for the "high R0" cases in Figures 6-9). Otherwise, TACs less than about 4 mp would be supportable in the East if R0 is similar to estimated values for 1984-2000 (Figures 2-5). Smaller TACs in the range of 0.2-1.4 million pounds were explored for the eastern gulf only, and the projected SPR isopleths suggest that a TAC in the range of 1-2 million pounds may be sustainable (Figure 10).

Table 1. Parameter values of the Beverton-Holt stock-recruitment function used in the projections. R0 is virgin recruitment and h is steepness. (Note: a steepness of 1.0 implies constant recruitment).

Region	Age	M	estimated h	estimated R0 (millions of fish)	8.5 X R0 (3 year average low)
Gulf	0	low M	~ 1.0	61.0	191.3
Gulf	0	high M	~ 1.0	92.3	320.2
Gulf	1	low M	~ 1.0	16.1	60.9
Gulf	1	high M	~ 1.0	19.4	72.4
East	0	low M	~ 1.0	6.6	20.7
East	0	high M	~ 1.0	14.3	40.5
East	1	low M	~ 1.0	2.8	9.4
East	1	high M	~ 1.0	3.7	12.1
West	0	low M	~ 1.0	42.1	162.8
West	0	high M	~ 1.0	67.4	263.3
West	1	low M	~ 1.0	13.3	47.9
West	1	high M	~ 1.0	15.7	55.6

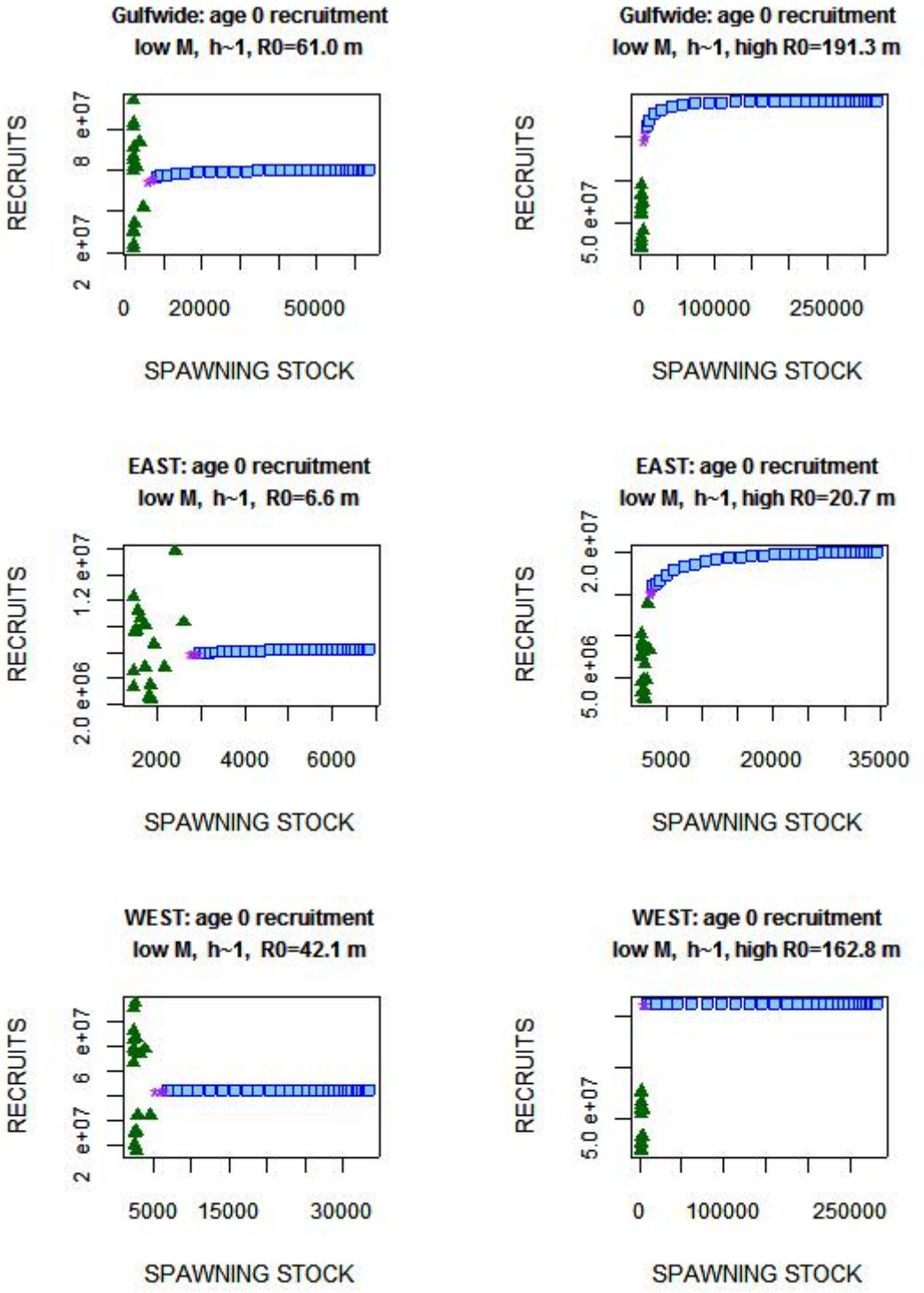

Figure 1. Spawning stock biomass (SSB, in thousands of pounds) versus number of recruits. Green triangles are VPA estimated SSB, recruit pairs; purple '*' symbols are years 2001-2003 values which were predicted from the fitted Beverton-Holt; blue squares are projected values for 2004-2032, from the fitted Beverton-Holt.

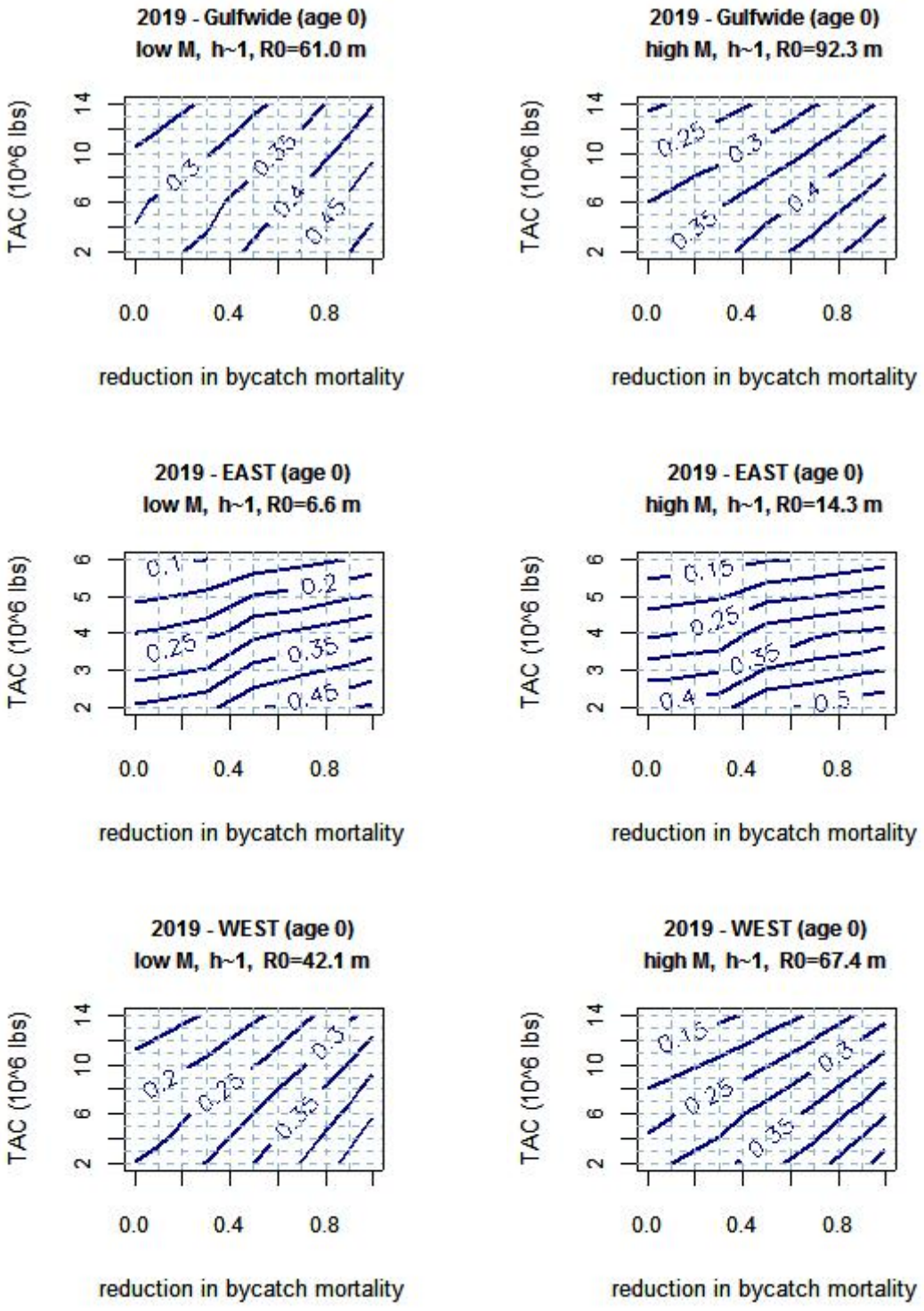

Figure 2. Predicted SPR isopleths in the year 2019 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were estimated. The age of recruitment was assumed to be 0.

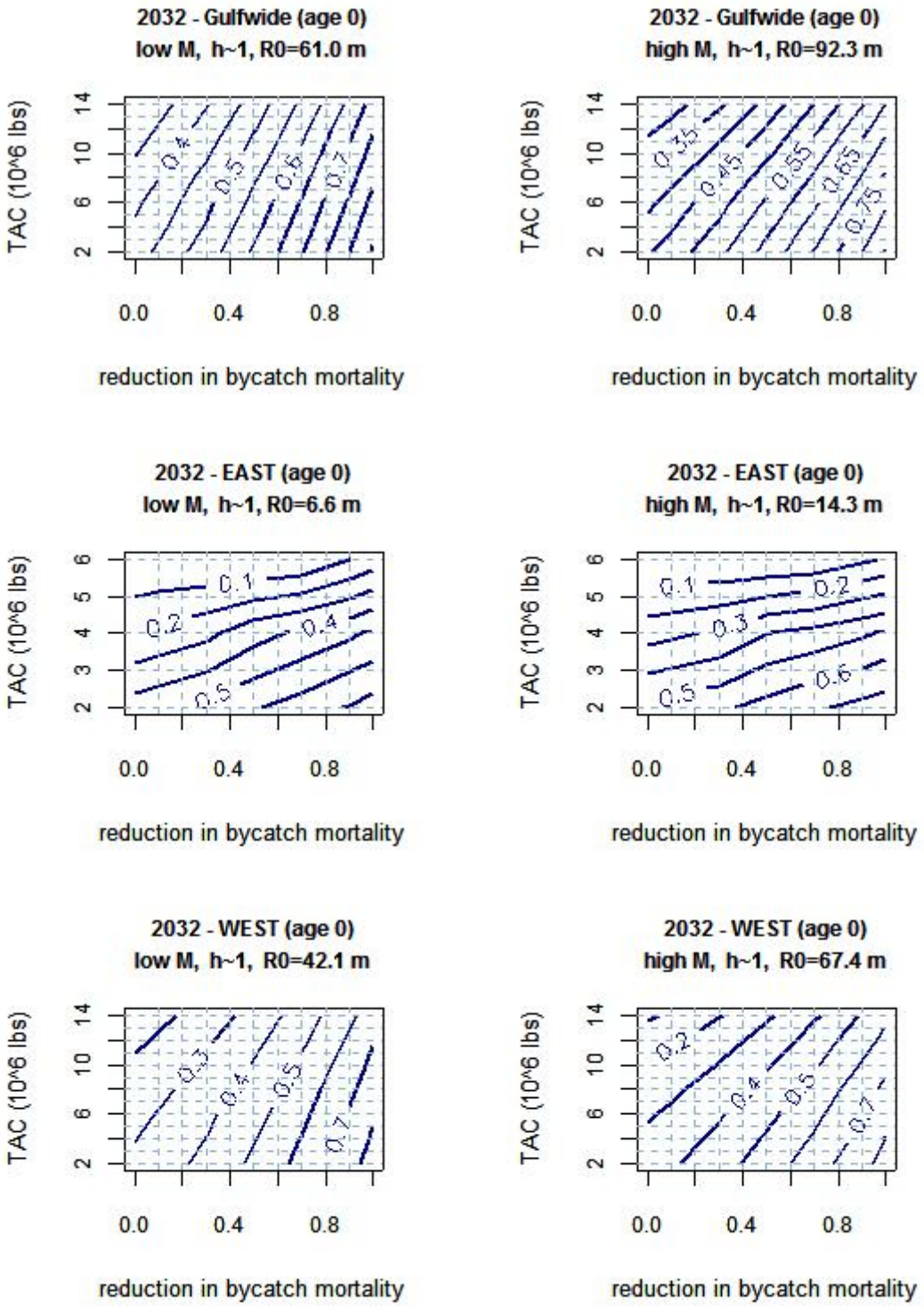

Figure 3. Predicted SPR isopleths in the year 2032 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were estimated. The age of recruitment was assumed to be 0.

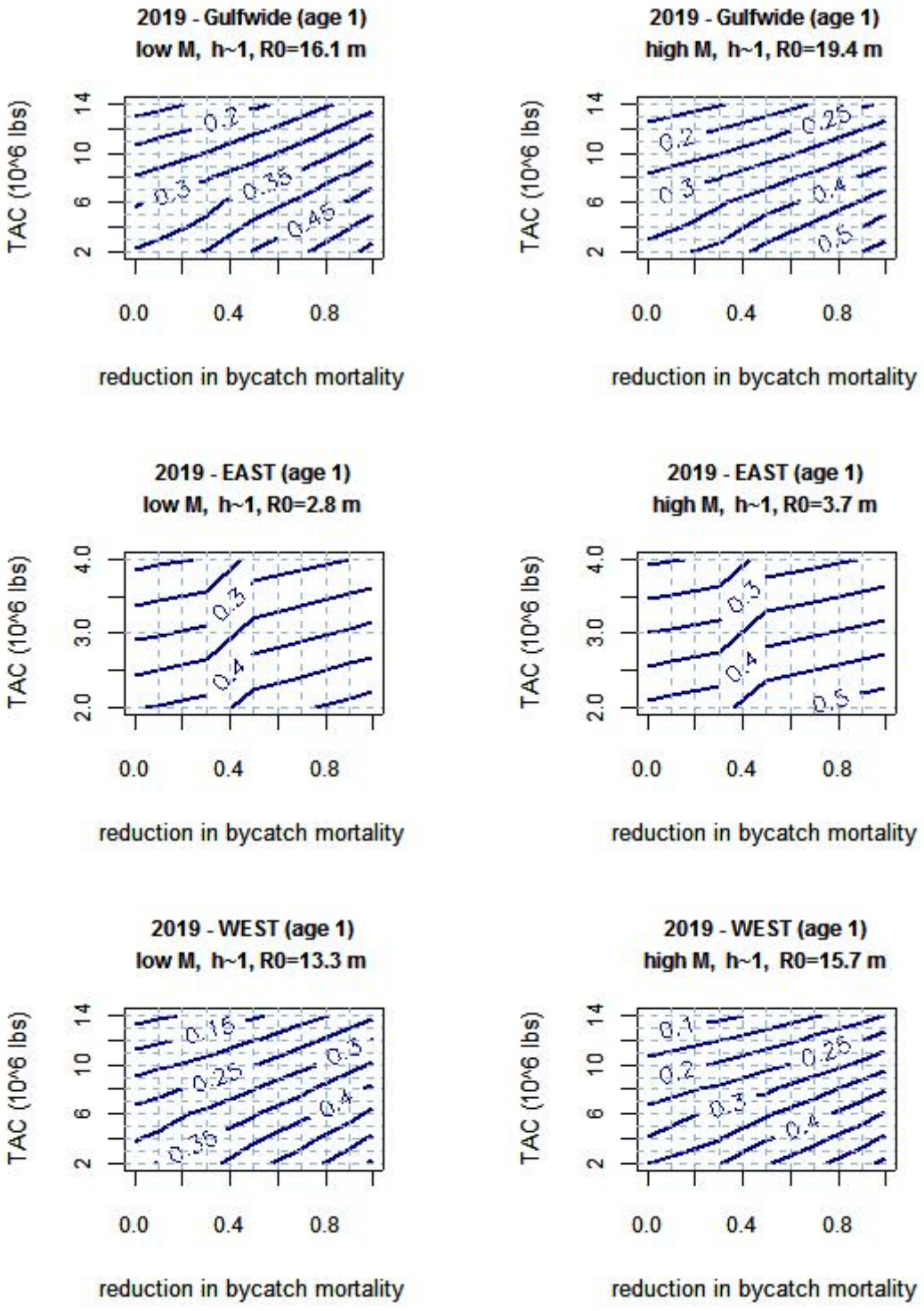

Figure 4. Predicted SPR isopleths in the year 2019 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were estimated. The age of recruitment was assumed to be 1.

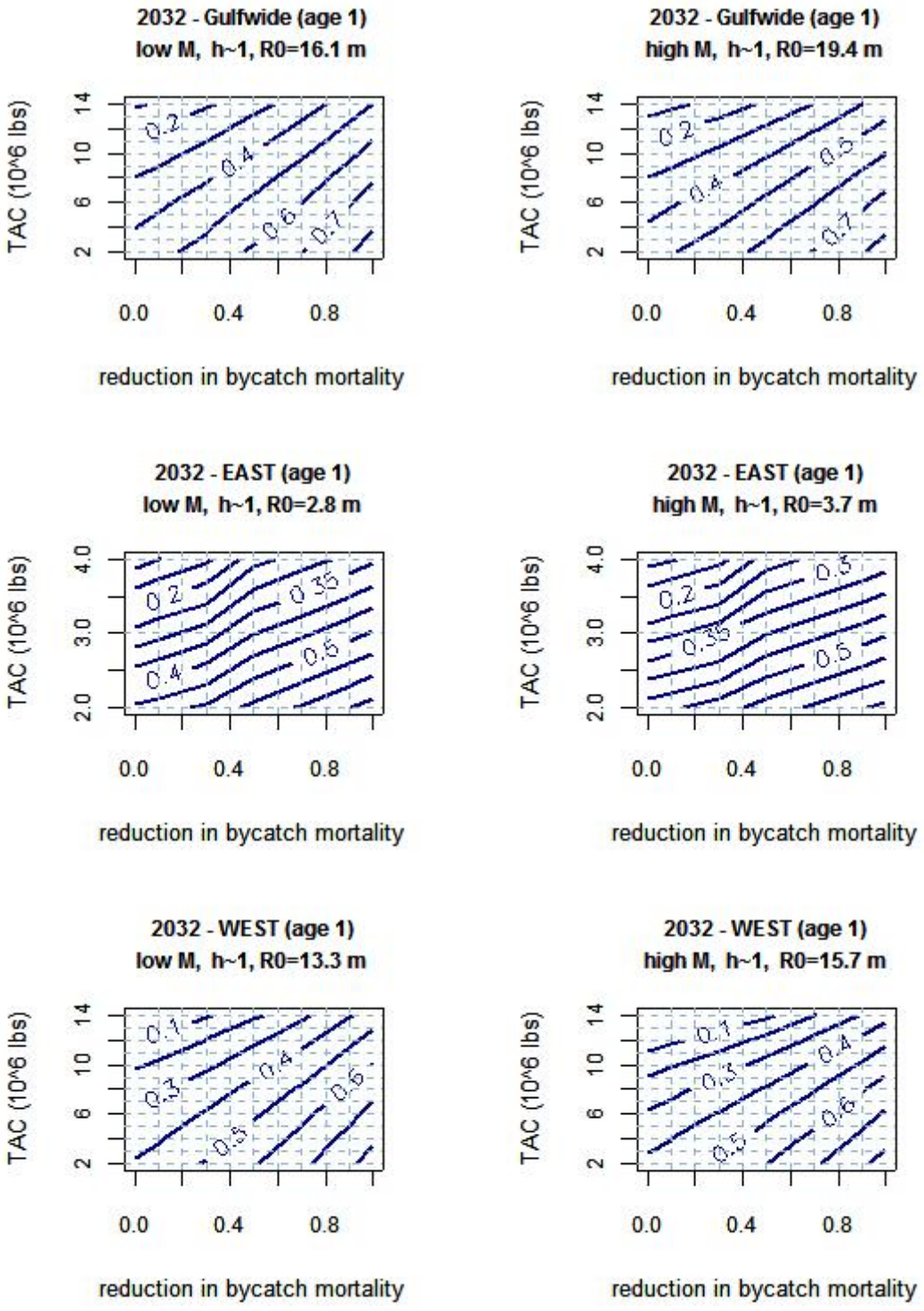

Figure 5. Predicted SPR isopleths in the year 2032 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were estimated. The age of recruitment was assumed to be 1.

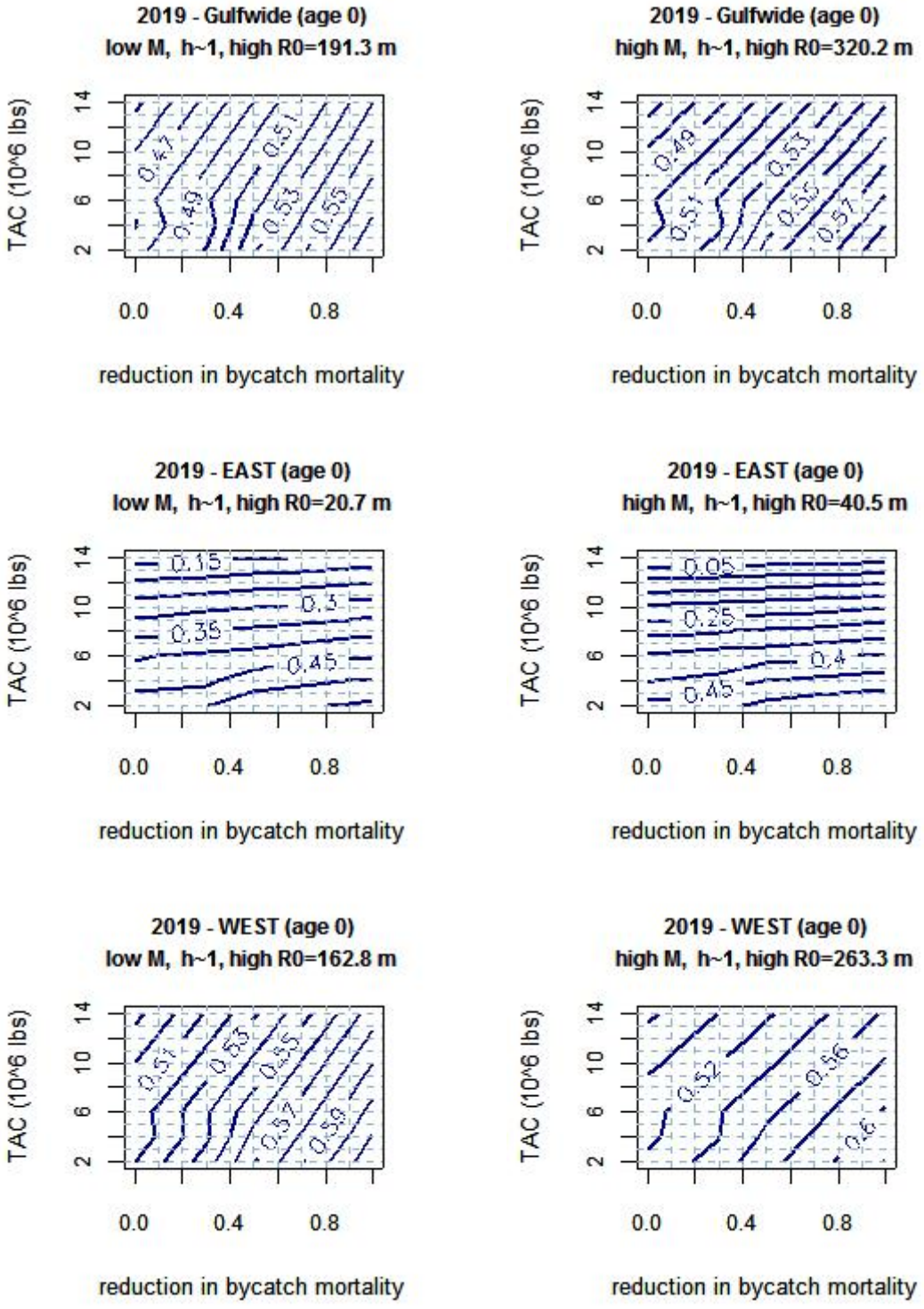

Figure 6. Predicted SPR isopleths in the year 2019 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were fixed (see Table 1). The age of recruitment was assumed to be 0.

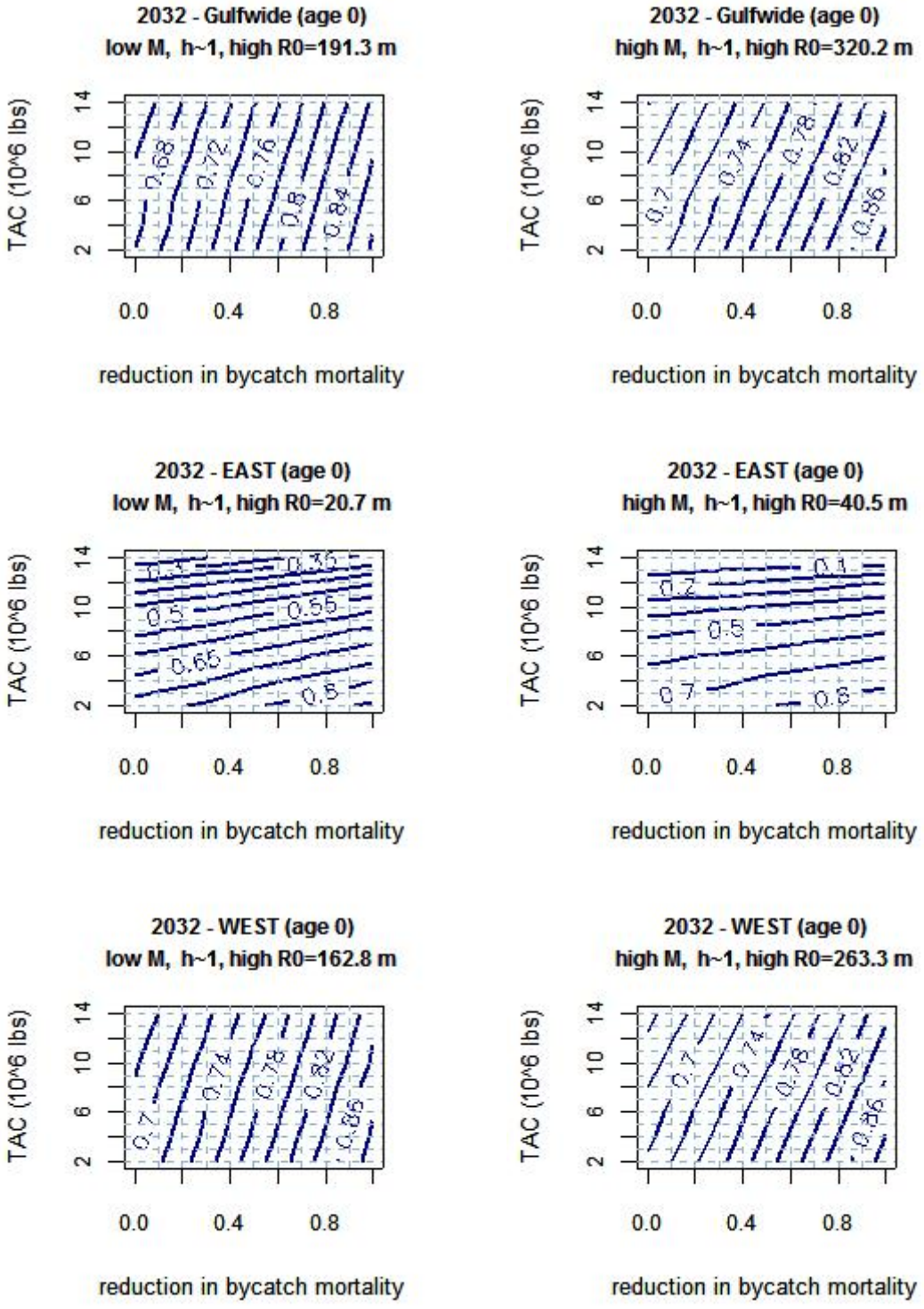

Figure 7. Predicted SPR isopleths in the year 2032 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were fixed (see Table 1). The age of recruitment was assumed to be 0.

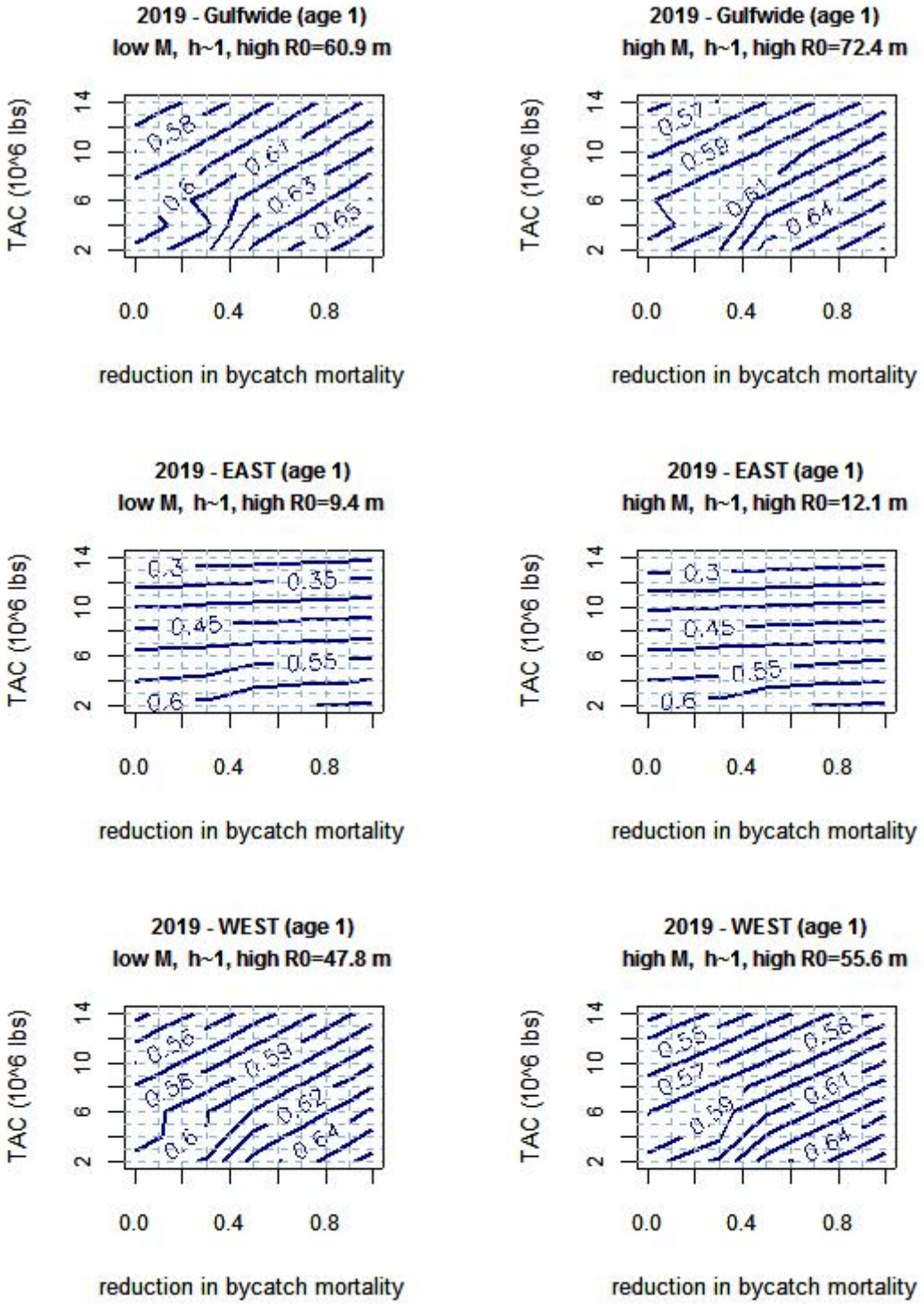

Figure 8. Predicted SPR isopleths in the year 2019 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were fixed (see Table 1). The age of recruitment was assumed to be 1.

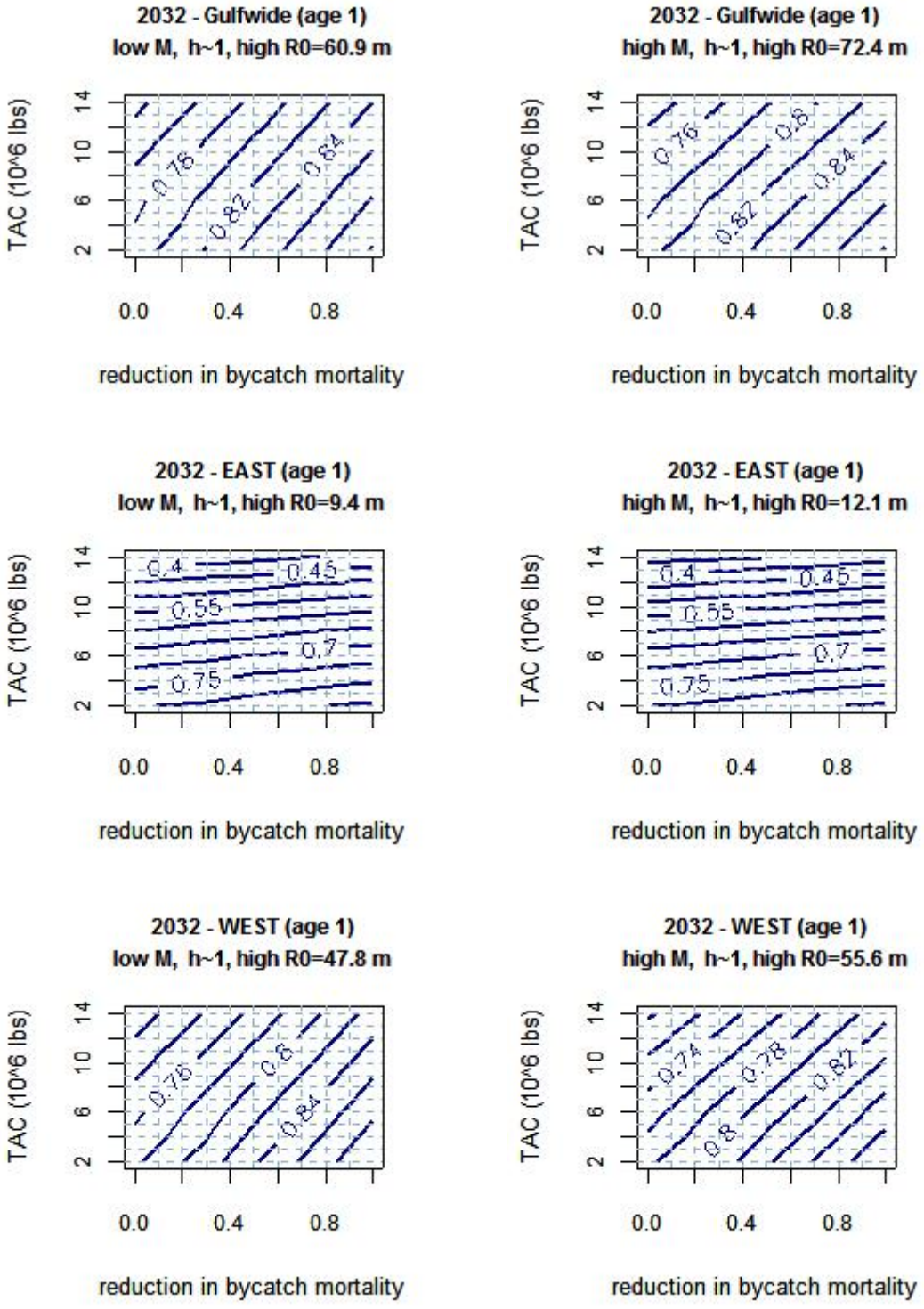

Figure 9. Predicted SPR isopleths in the year 2032 for Gulfwide (top), Eastern Gulf (middle) or Western Gulf (bottom). The left set of panels assumed the "low M" scenario [M_0=0.5, M_1=0.3, $M_{2\text{-}15+}$=0.1], while the right set of panels assumed the "high M" scenario [M_0=1.0, M_1=0.6, $M_{2\text{-}15+}$=0.1]. R0 and steepness were fixed (see Table 1). The age of recruitment was assumed to be 1.

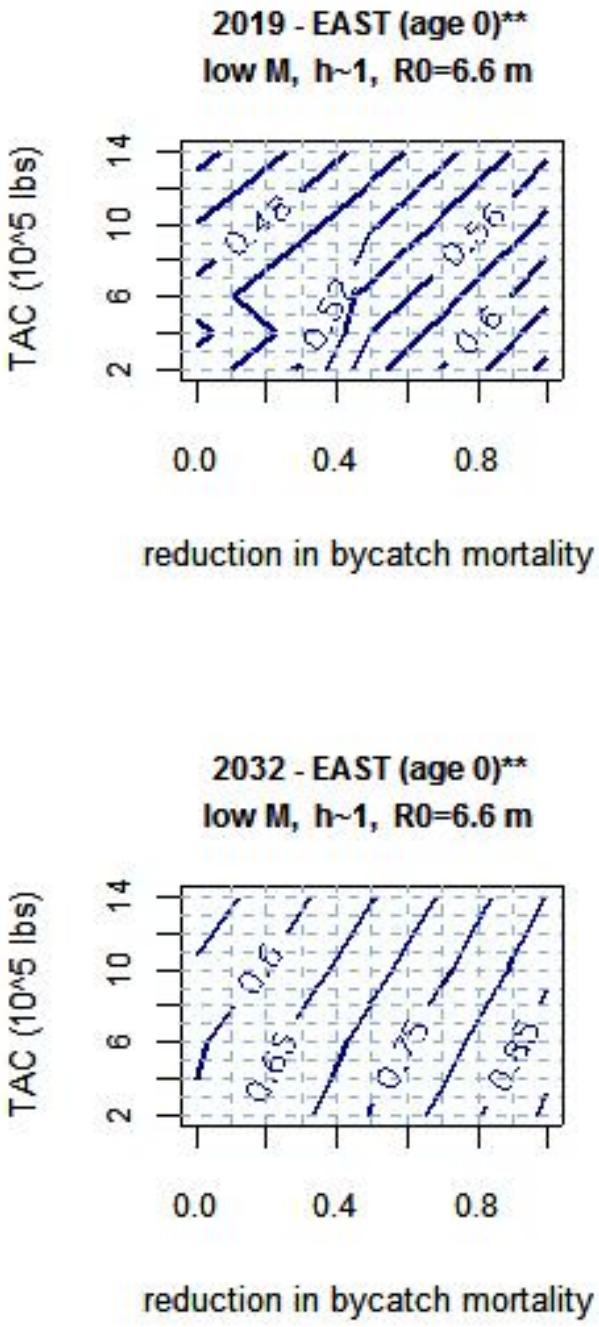

Figure 10. SPR isopleths for the Eastern gulf, with low natural mortality assumed and R0 as estimated by fitting a Beverton-Holt. Directed fishery TACs ranged from 0.2 to 1.4 million pounds instead of 2-14 million pounds as in all other model scenarios.