Restoration of the Salton Sea

Volume 1: Evaluation of the Alternatives

Appendix 1L: Fishery Sustainability – Dissolved Oxygen

FISHERY SUSTAINABILITY – DISSOLVED OXYGEN

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A preliminary risk assessment model was developed for the Salton Sea to determine the potential for occurrence of low dissolved oxygen, with respect to fish survivability. The model is based on a model developed by Miranda (2001). It is a very simple model that looks at evening dissolved oxygen levels, and subtracts and sediment respiration during the non-photosynthetic night time hours. The output results are the probability of dissolved oxygen falling below a pre-defined limit by dawn for areas of the sea of a given depth. This limit can be set to any numeric value of dissolved oxygen desired.

Data for this study were obtained from several sources. Dissolved oxygen and temperature values were based on USBR data collected during the summer of 1999. Sediment (SR) and water respiration (WR) were obtained from a preliminary report issued by C. Amrhein and M.A. Anderson. Other WR values were collected by Davine Lieberman and Andrew Montano, in June 2005, from several sites on the sea. Comparative values were also obtained from 5 day BOD tests, conducted by other agencies, and converted to $mg{\cdot}L^{-1}{\cdot}hr^{-1}$. These latter values however, were not used as they were significantly higher than the maximum values we employed (1.22 vs. 3.375 $mgL^{-1}hr^{-1}$ for WR). Overall SR and WR data available for running the model were vary sparse, as such results may or may not be representative of the entire system. They do provide a good starting point for comparing the alternatives, however.

SR rates were calculated following the methodology described in C. Amrhein and M.A. Anderson's report to the USBR and will not be discussed further. Water respiration rates were collected in late afternoon. Triplicate composite water samples were taken from the surface to immediately off the bottom, using a weighted swimming pool hose at all stations. Water was emptied from the hose into a bucket and initial DO was recorded with a portable DO meter (WTW, model Oxi340i). Dark BOD bottles were filled to the top, capped with dark stoppers, submerged in a cooler filled with lake water, and initial time was recorded to indicate start of incubation. Additional water was added to the cooler as needed to keep BOD bottles at lake water temperature while all bottles were filled at each station. All BOD bottles were then transferred from the cooler to bottle racks and deployed until dawn directly in the lake. Final DO, temperature, and time were recorded at dawn for each BOD bottle. Sea temperature at time was approximately 29 °C.

Bathymetric data were provided by the Bureau of Reclamation, Paul Weghorst. Our analyses range does cover all elevations that would be expected under normal operating criteria for each of the alternatives. For each alternative this encompassed approximately 1-2 m (4-6 ft) of elevation change. Anything out side that range, i.e., deeper water, was lumped into one classification. As data will show, the justification for this is changes in the probabilities of low D.O. occurring have reached an asymptote in the curve and further depth intervals provide essentially no more resolution. Within the operating range we provided an analysis at 0.5 ft intervals across the entire range. At each interval lake surface area and volume was obtained from the expected operating curve for the sea.

Since we did not have data that might show differences between the proposed alternatives, we made the same assumptions for WR and SR for each of the alternatives. There may be differences that develop with each of the alternatives in terms of productivity and sea behavior, for instance increase in stratification. Unless circumstances could be identified to indicate extreme differences in productivity, these model results should at least provide a good comparison of the alternatives, all else being equal.

Modeling

This research focus was based on the Miranda et al. (2001) risk assessment model for an oxbow lake on the lower Mississippi River. SAS code for the original model was provided by L.E. Miranda, Mississippi Cooperative Fish and Wildlife Unit, Mississippi State University, and adapted for this study. The basic model employed by Miranda et al. (2001) linked bathmetry of the lake with a probabilistic risk assessment, using a respiration model to predict the potential for development of adverse low dissolved oxygen conditions. The model predicts the spatial acreage of the reservoir that might be impacted by low DO given the data available. We incorporate reservoir stage to determine potential surface area affected given different sea levels. The model is not designed to predict which areas of the sea are likely to be affected, just on average how much of it could be expected to be impacted.

To predict the amount of surface area potentially affected by low DO in the morning (when most extreme minimum values can be expected), we used DO at sunset the previous evening and conservatively estimated rate of change in DO over time. $\Delta DO/\Delta t = DO_t - (SR \cdot Z^{-1} + WR + DE \cdot Z^{-1})$ from Miranda (2001). For this Model Δt, the time step was set to one minute; Z was the water depth calculated from the area capacity curve; SR the sediment respiration rate ($g \cdot m^{-2} \cdot min^{-1}$);

WR the water respiration rate ($g^{\cdot}m^{-3\cdot}min^{-1}$); and DE the diffusive exchange ($g^{\cdot}m^{-2\cdot}min^{-1}$). WR and SR data were calculated from field data (see previous section), and fall within the range of values noted for eutrophic freshwater systems. DE was calculated following Borcker and Peng (1982). In the calculation of DE the molecular diffusion coefficient and thickness of the air water boundary layer, used in calculating DE, were set at $2.2^{\cdot}10^{-5}cm^{2}s^{-1}$ and at 0.03cm respectively following Miranda et al. (2001). As noted this value of DE is very conservative as it does not account for diel changes in temperature, or changes to the boundary layer from wind induced turbulence, which is the significant source of re-aeration events at the sea. We were not concerned with removing wind from the model as we are trying to represent what happens to the sea under calm conditions, when conditions are presumed to be at their worst.

We also made the assumption that the reservoir was uniform with respect to DO, WR, SR and temperature, and is well mixed at all times for simplicity. It is recognized this is rarely the case and would be expected to impact results. Our model thus provides a best case scenario. Stratification does result in more depressed levels of low DO. Summer months, June, July, August and September, were selected for the simulations period, as these months represent the most critical times for water quality. DO and temperature for the period June 23, to end of September 1999 were used. Only data from between 1 and 3 m in depth were used for the analyses. Deeper waters were almost always very low in DO, and would have resulted in more extreme cases of low DO occurring. For this study we assume depths deeper than 3m are always depleted in oxygen, and therefore unavailable as fish habitat, we are calculating risk only for the top 3-4m of the water column.

We further did not classify different areas of the sea, but combined all data for each parameter to obtain an expected range of values, that could reasonably be expected to be encountered. If sample sites selected were biased in any fashion, i.e., unreasonably low DO relative to other sites, or significantly different in productivity, or respiration values from a sea wide average, these could be expected to skew the results. Spatial heterogeneity and variability were averaged out via Monte-Carlo simulation. We also made model runs to demonstrate what changes in average levels of dissolved oxygen and respiration rates might be expected to do.

The Monte-Carlo based probabilistic risk assessment was conducted using values chosen from triangular statistical distributions of each parameter. The triangular distribution is a conservative characterization of a truncated normal or log-normal distribution (Miranda et al. 2001). To construct the distribution we used the minimum, maximum, and modal or mean values for each parameter. The small amount of data available, suggest this would probably be the most appropriate distribution to use. The selection of mean or mode depended on the normality of the data. Approximately normally distributed data could be represented by the mean, whereas the mode is more appropriate to skewed data. Miss-estimates, however, of the true mean value can be very dramatic, and affect the outcome of the results significantly when small datasets are available, such as the case here. Length of night was calculated as a uniform distribution using the range of values observed during the described study period. For each parameter sets of 5,000 values were randomly selected from the distributions for inputs to the respiration equation, which was then solved at discrete depth intervals from 0 to 3.9 m. Miranda et al. (2001) employed 10,000 values for each parameter in their model; however, due to available computer processing power we were unable to do this in a satisfactory amount of time. Instead several values were selected from 100 to 5000 and numerous simulations run. It appeared after 5,000 runs of each parameter the model had sufficiently converged, i.e. run to run variability was negligible (less than one percent).

Data used for the initial starting conditions in this study are as follows. Sediment respiration range from a minimum of 0.021 $mg \cdot m^{-2} \cdot hr^{-1}$ to a maximum 0.584 with a modal value of 0.217. For WR, the minimum was 0.12 $mg \cdot m^{-3} \cdot hr^{-1}$, the maximum was 1.2 and the mode was 0.35 $mg \cdot m^{-3} \cdot hr^{-1}$. DO at dusk ranges from 0.09 to 17.88 with a mode of 3.88 mg/L. Temperature ranges from 27.03 to 32.25 with a mode of $28.54^{0}C$. Night length ranged from 9.9 to 11.3 hours.

We selected dissolved oxygen values of 2 mg/L and 4 mg/L as critical values for the model runs. 2 mg/L represents a lethal level of dissolved oxygen for many species, whereas 4mg/L represents the threshold for stress for some species. Several of the species in the Salton Sea such as tilapia can survive down to 2 mg/L or below for a period of time. The proportion of values less than these defined limits was interpreted as the probability of DO becoming unsuitable for a sea area of a given depth.

Results and Discussion

Since the bathymetry of the Salton Sea is shape of a shallow dish, surface area to volume ratios are relatively uniform with increasing water depth (Figure 1a, 1b). This has ramifications for the modeling output as it indicates there is no optimal stage level to manage for in terms of DO risk. In lakes were substantial changes in morphometry occur with depth, such as a bowl shaped lake or a even more complex shape where stage changes may result in significant changes in surface area/volume ratios it is fairly easy to identify what the optimal stage level might be under a given set of conditions. For the purposes of the modeling scenario presented, there are no differences between the Sea as it exists now, and any of the alternatives, except for extreme cases where average depths of the alternative may be extremely shallow. The parameters used in the model are from existing data obtained from the current status of the Sea. The only output differences from the model would be number of acres affected, simply because the water bodies under the different alternatives are of different size. We have no information to indicate there are differences in productivity that would favor the one over the other.

The probability of dissolved oxygen dropping below the thresholds of 4.0 and 2.0 mg/L respectively, decreases with increasing sea depth. However, an asymptote is quickly reached beyond which increase in depth did not result in further changes in dissolved oxygen (Figure 2). For the scenarios given here areas of the sea greater than 3.0m in depth essentially behave the same. Given the starting scenarios we employed, we can, on average, expect that on any given night about 58% of the Salton Sea as it exists today would be affected by dissolved oxygen levels lower than 4.0 mg/L. The effect of varying sea levels would have little impact on the percentage of the sea that is impacted by low DO, as the increases from one depth to another are proportional to the increasing surface area of the sea (assuming all respiration parameters remain constant).

Figures 3-11 show allocation of surface acreage of the sea to the different modeled depth intervals. For each alternative the potential area impacted by DO <4mgL and DO < 2mg/L are also presented. Table 1 represents the sum of these impacted areas a as proportion of each alternative, at a given elevation that could be expected to drop below 4 mg/L on any given summer night. With the exception of alternative 3ab it can be seen that the potential for low dissolved oxygen varies little across the alternatives. All are within about one percent of each other and probably not statistically different, with the exception of alternative three which shows a much higher proportion the sea being affected by low DO. Alternative 3 happens to be the shallowest of the alternatives, which explains why it is most susceptible to low DO.

Our selection of the initial conditions for the model can have a dramatic impact on the final model outcome, and can be used to explore how changes in respiration and dissolved oxygen levels potentially impact the outcome. We had very little data to work for sediment and respiration values. One extreme value on either end of the data has the ability to change the model outcome. The biggest impact comes from our selection of what DO should be in the evening hours. This model assumes a mixed water column; however, the Salton Sea commonly exhibits strong stratification with respect to DO. Based on the 1999 data we used, it appears that during most of the summer months, water much below about 3m in depth is nearly always close to anoxia. If we had employed these values in our model the probability of a low DO occurrence is always greater than 90%. As it is, we restricted our data to the top 3m of the water column, where there does appear to be at least some diel change in DO. We also elected to spread our data out over June, July, August, and September, which gave a broader range of DO values. For example if we had used only August and September data we find the maximum DO observed was 10.88. If this value is put in the model while retaining the same modal values it results in the proportion of low DO occurrence increasing significantly (Figure 12). As another example the modal and minimum values for both water and sediment respiration were kept the same, but the maximum values were reduced by 25% (Figure 13). When this happens there is a reduction of the probability of low DO occurrence. Though changes in these values do affect the model outcomes, they still allow a valid comparison between the alternative. If predictions can be made about differences in WR and SR between the alternatives, these could then be modeled to develop a more precise estimate of expectations of low DO occurring.

It must be remembered that although we might expect on any given night for roughly 58-60 percent of the sea to drop below the threshold of 4 mg/L, we have not provided any information on the distribution of low DO. If the occurrences are at a patch size small enough relative to fish movement they may be able to avoid these areas.

Figure 1.—Depth specific probability distributions of DO dropping below 4.0 and 2.0 mg/L overnight.

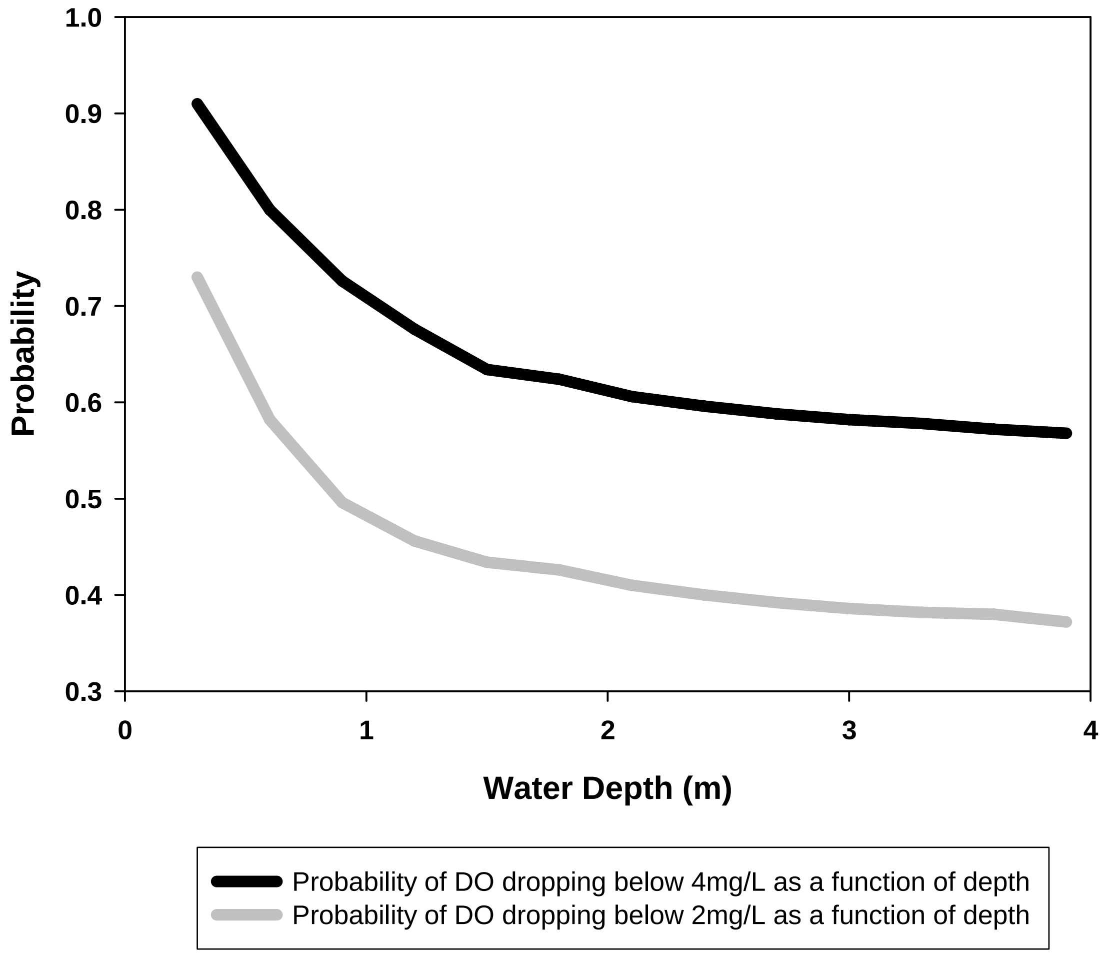

Figure 2a.—Sea elevation versus surface area for areas within the scope of this study. Color bands represent the surface area of the reservoir for each 1 ft (0.3m) change in depth. b. Zoomed in to show area elevation relations for areas less than 12 ft deep.

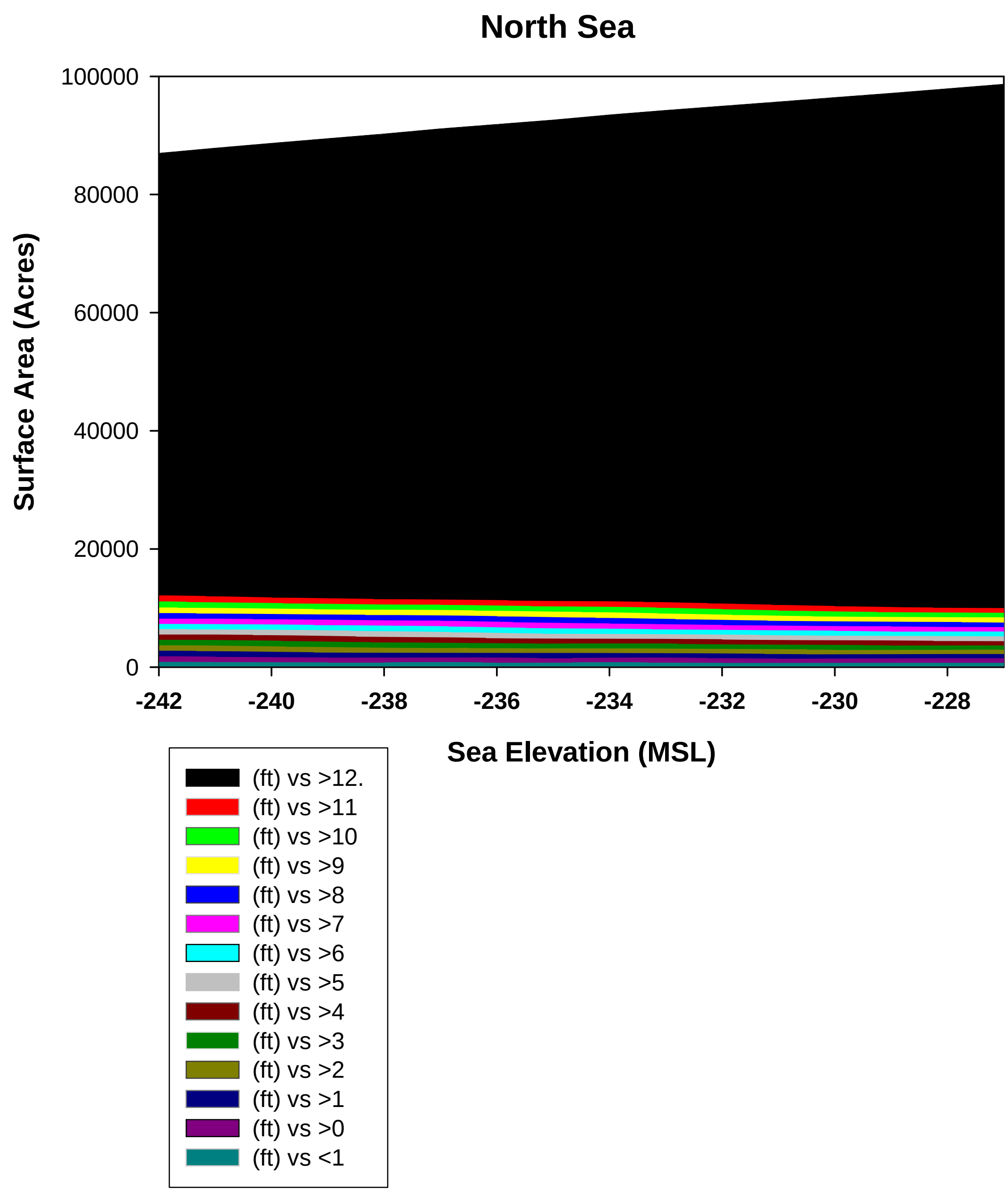

Figure 2b.

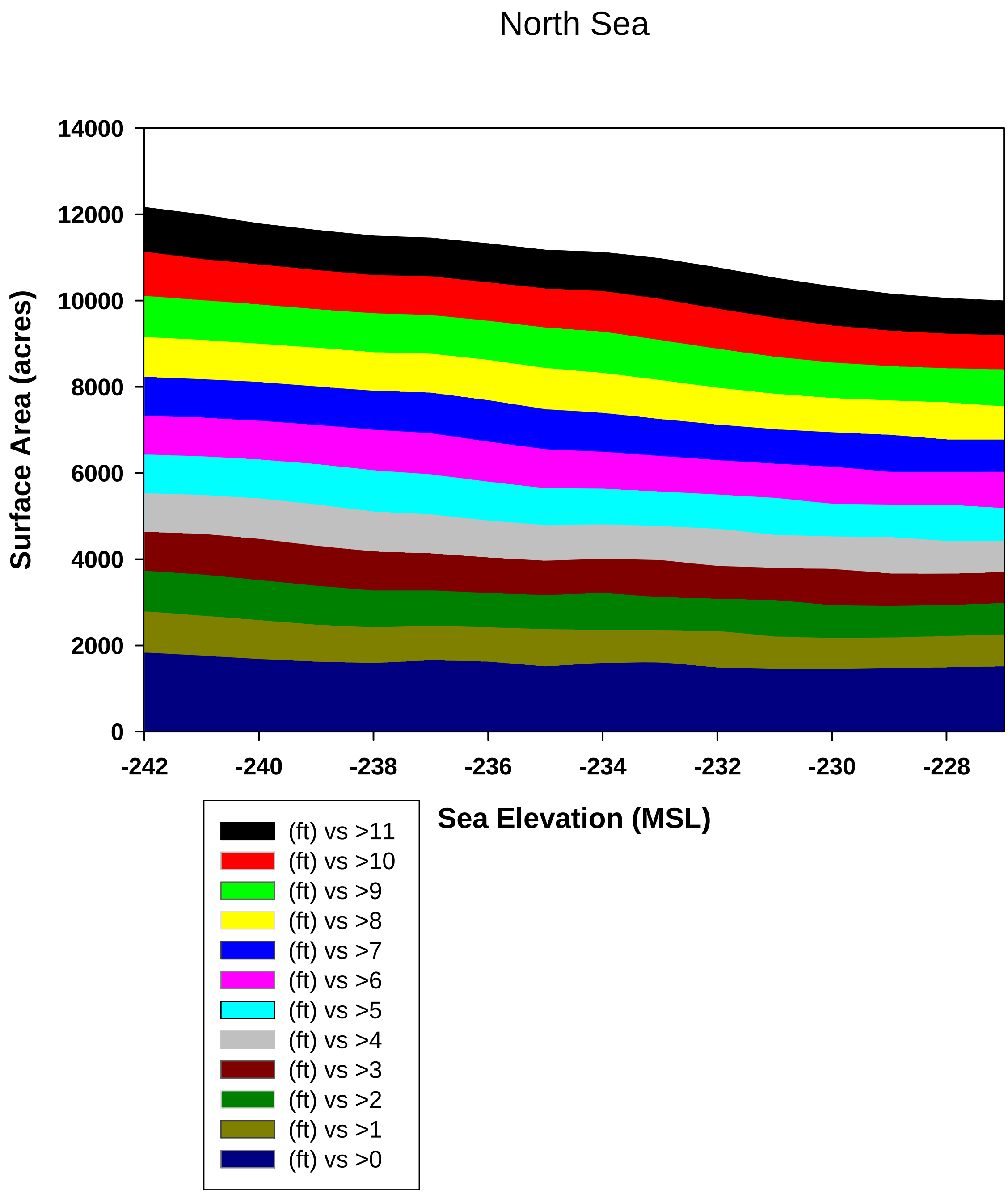
North Sea
14000
12000
10000
8000
6000
4000
2000
0
Surface Area (acres)
-242
-240
-238
-236
-234
-232
-230
-228
Sea Elevation (MSL)
(ft) vs >11
(ft) vs >10
(ft) vs >9
(ft) vs >8
(ft) vs >7
(ft) vs >6
(ft) vs >5
(ft) vs >4
(ft) vs >3
(ft) vs >2
(ft) vs >1
(ft) vs >0

Figure 3.—Total sea area under alternative 1A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

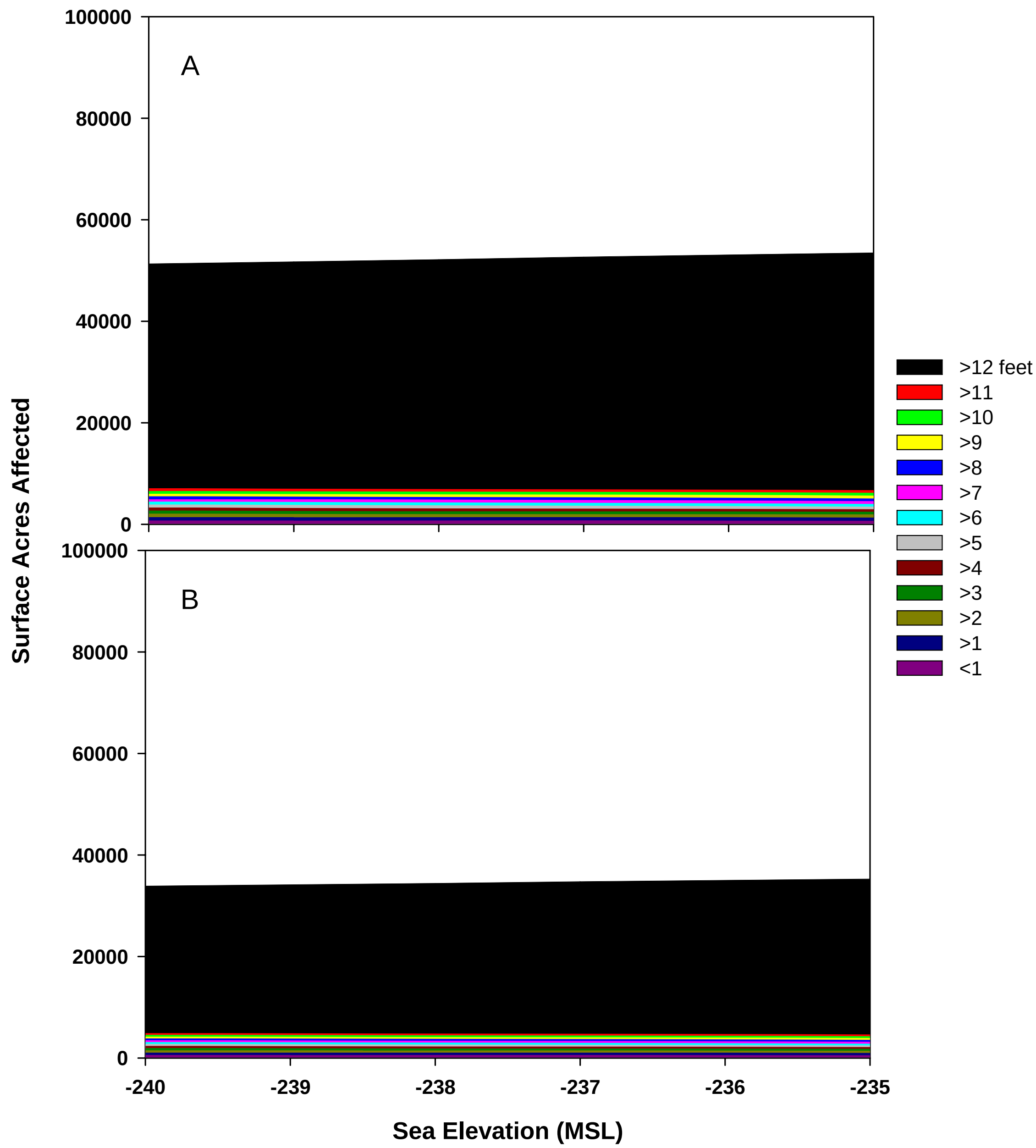

Figure 4.—Total sea area under alternative 2A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

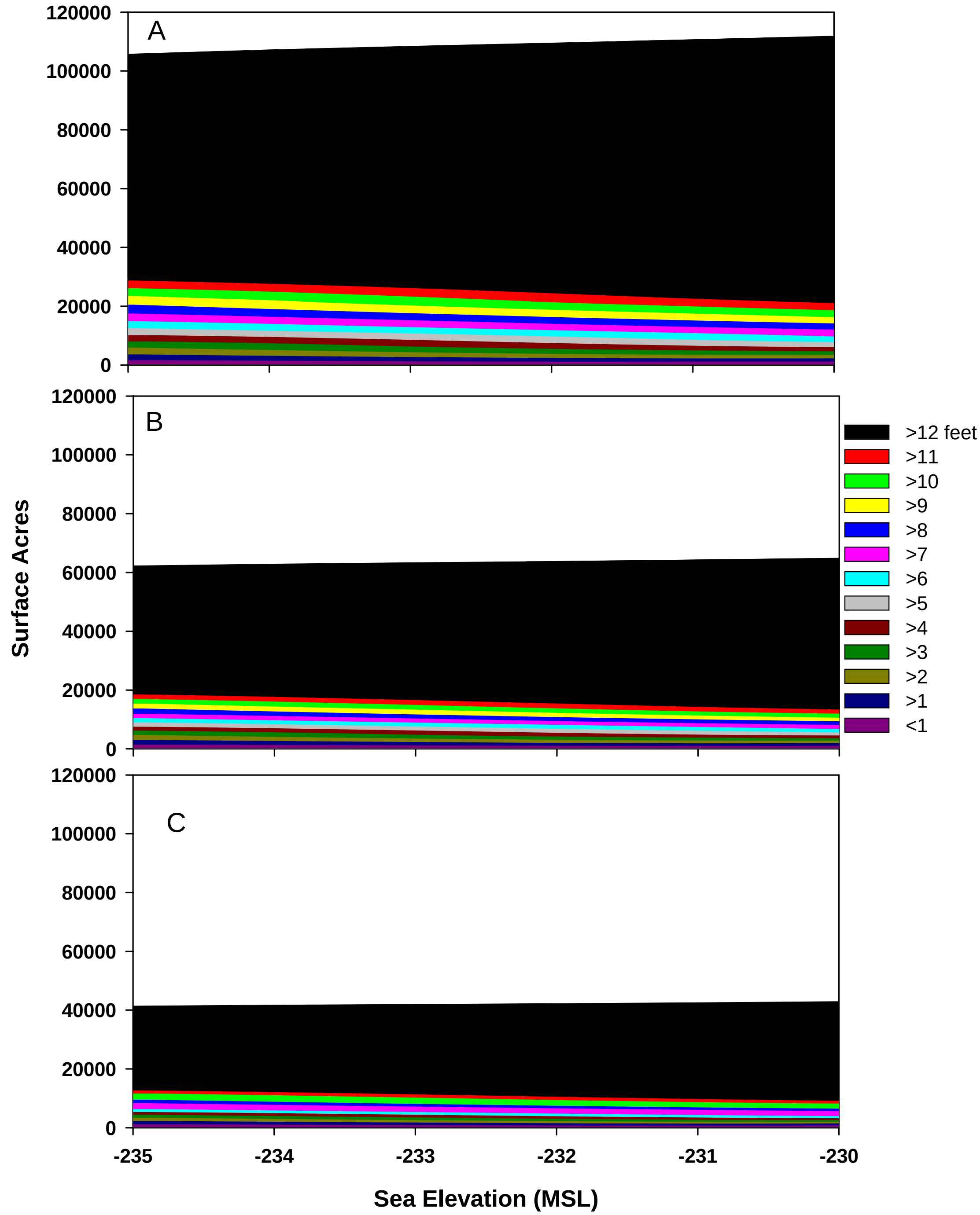

Figure 5a.—Total sea area under alternative 3A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L. Ring at -245.

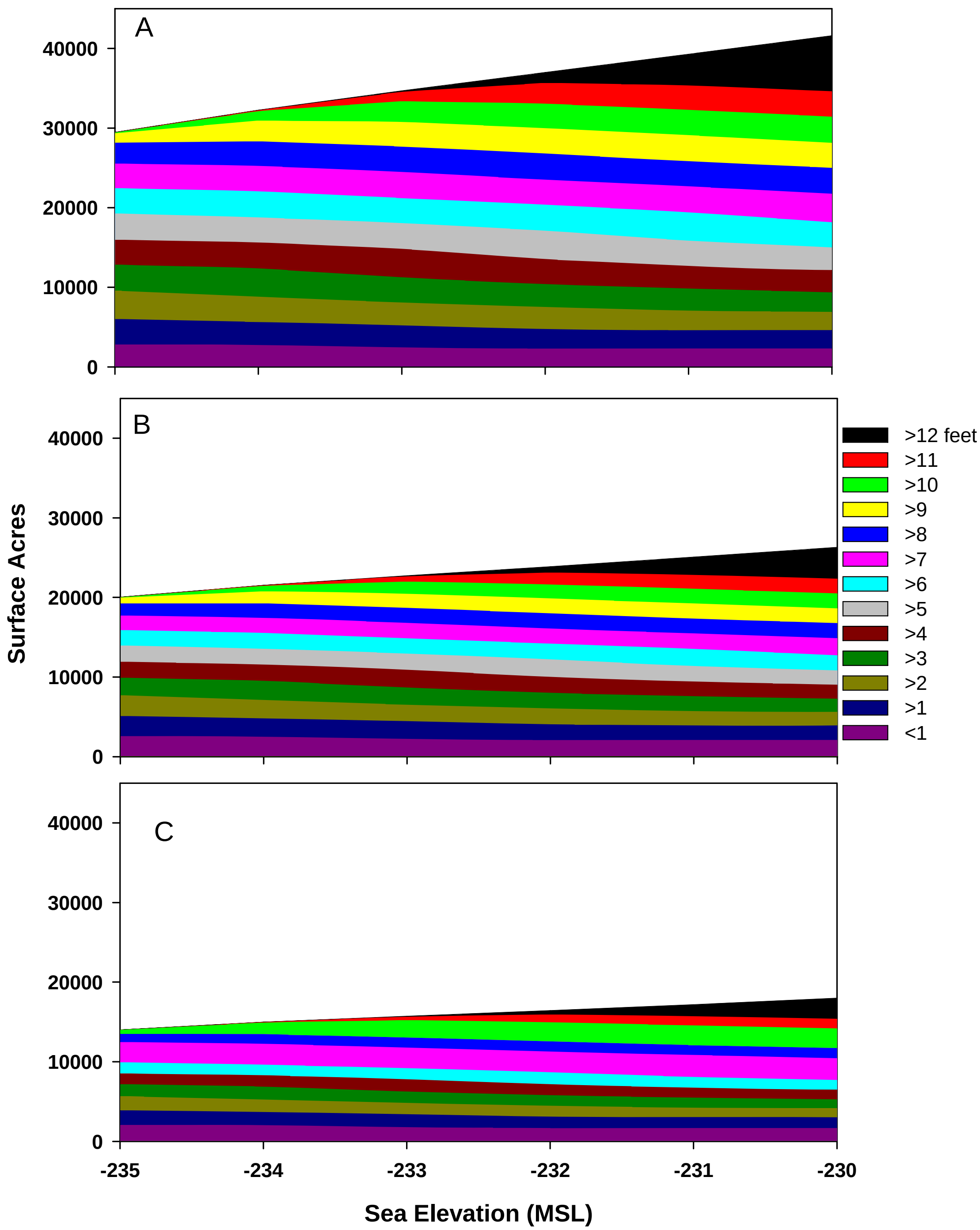

Figure 5b.—Total sea area under alternative 3A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L. Ring at –260.

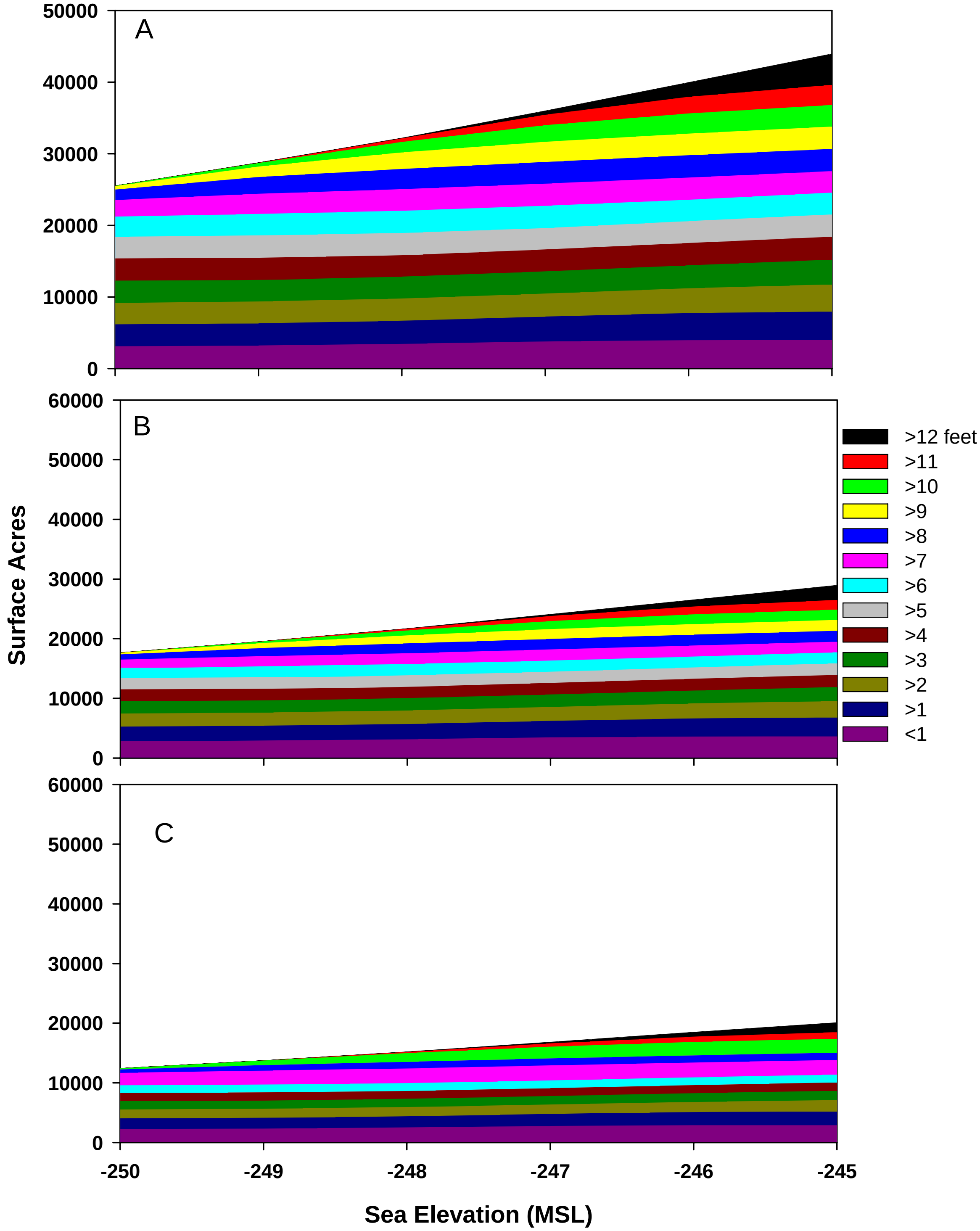

Figure 6.—Total sea area under alternative 4A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

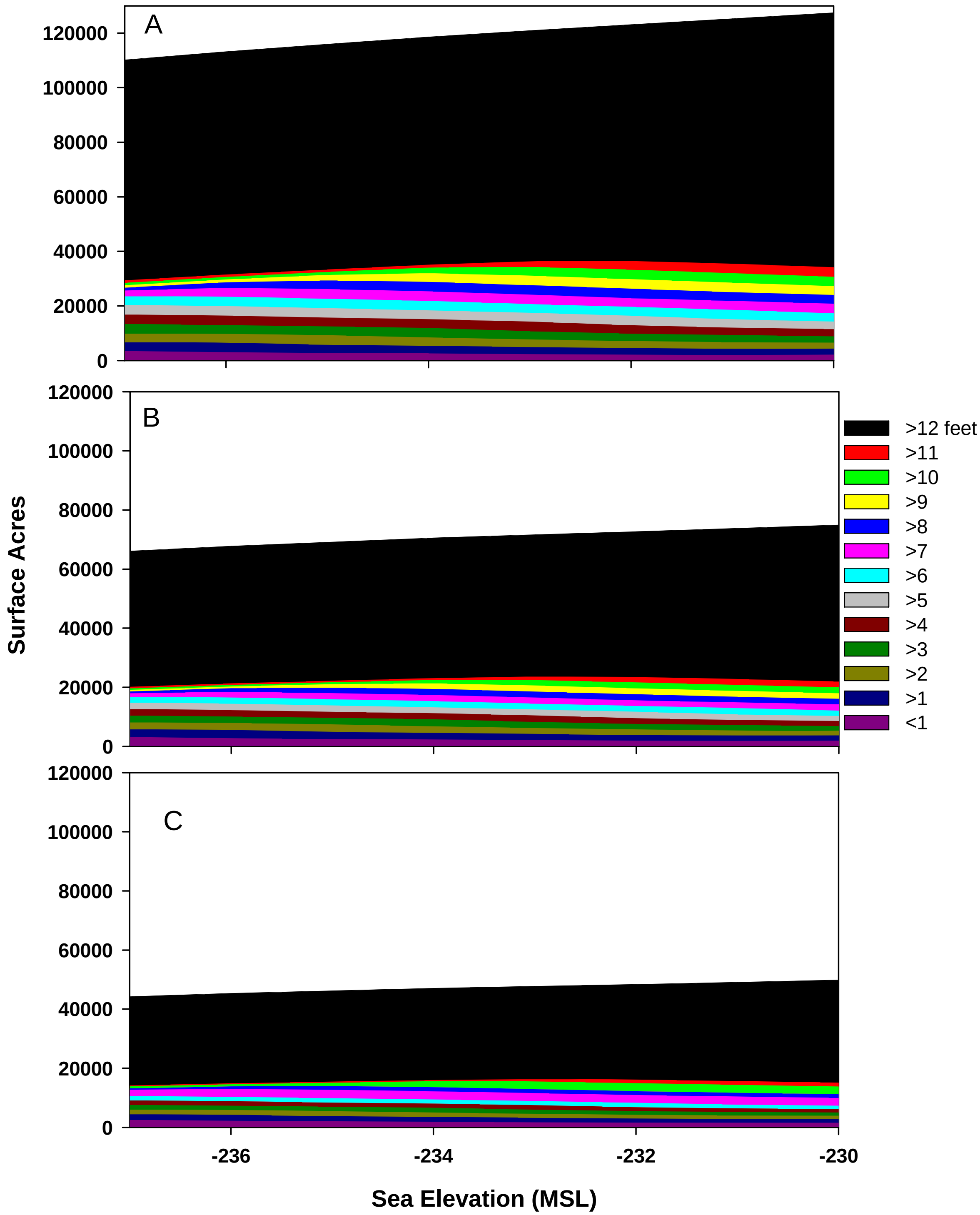

Figure 7.—Total sea area under alternative 5A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

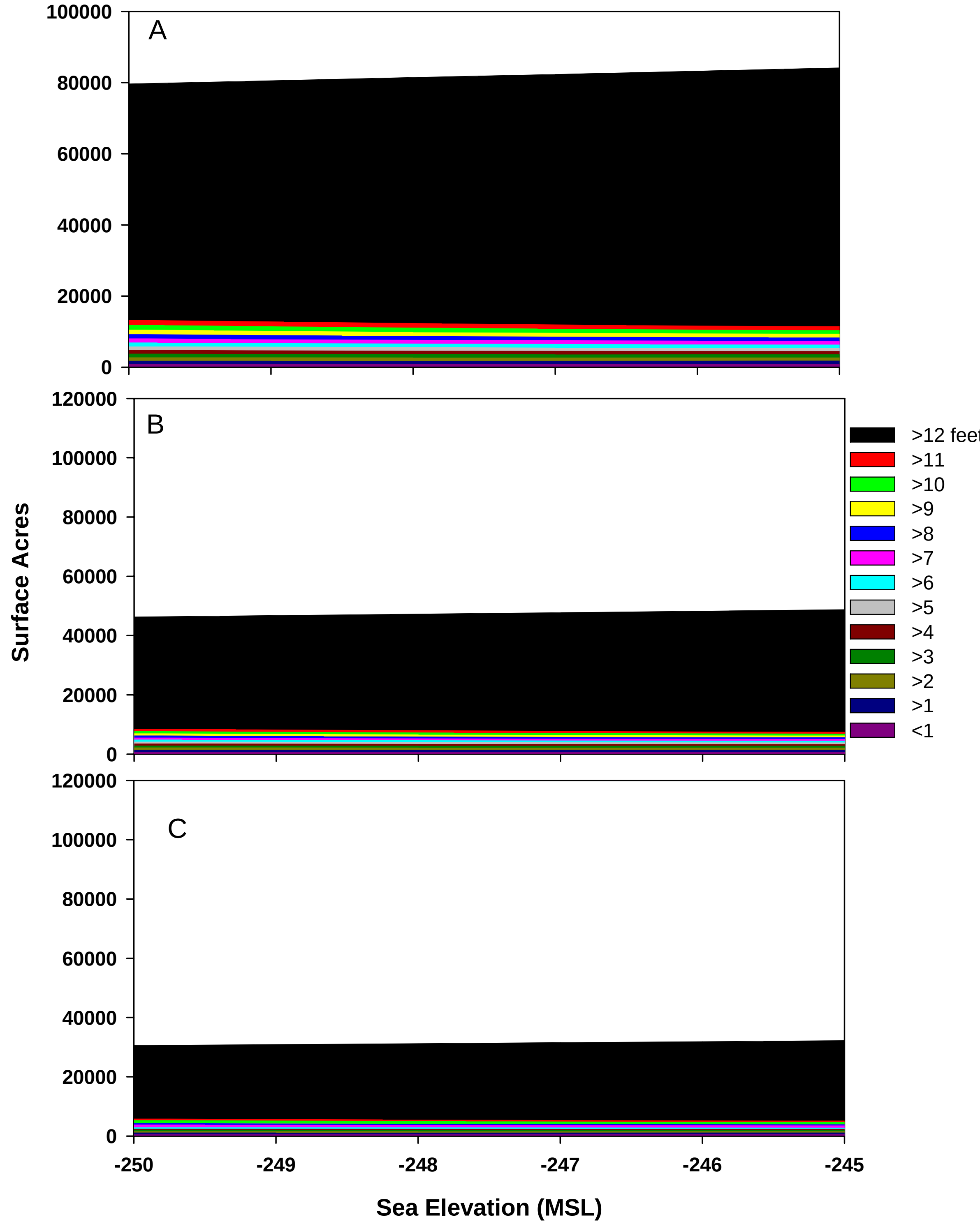

Figure 8.—Total sea area under alternative 6A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

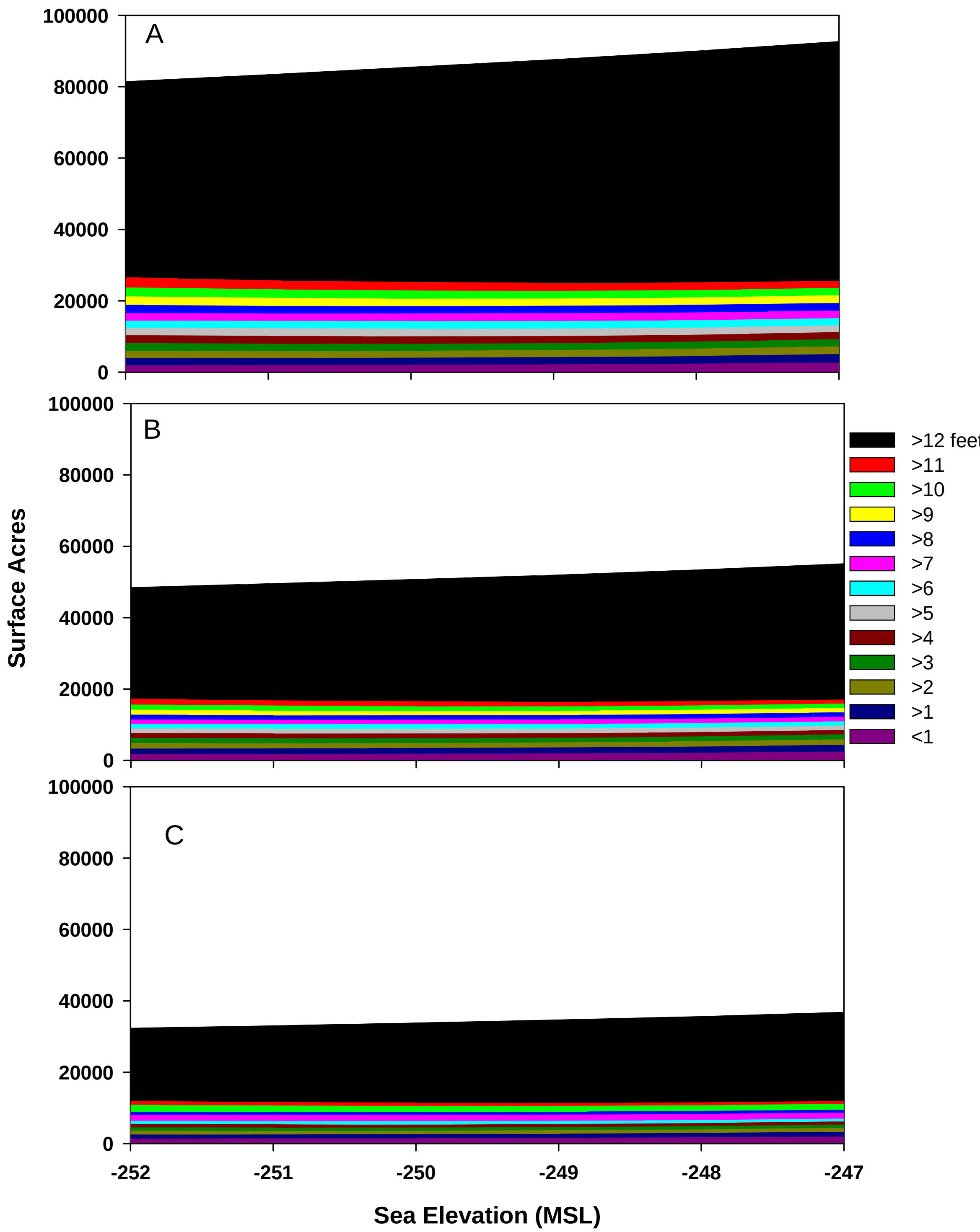

Figure 9.—Total sea area under alternative 7A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

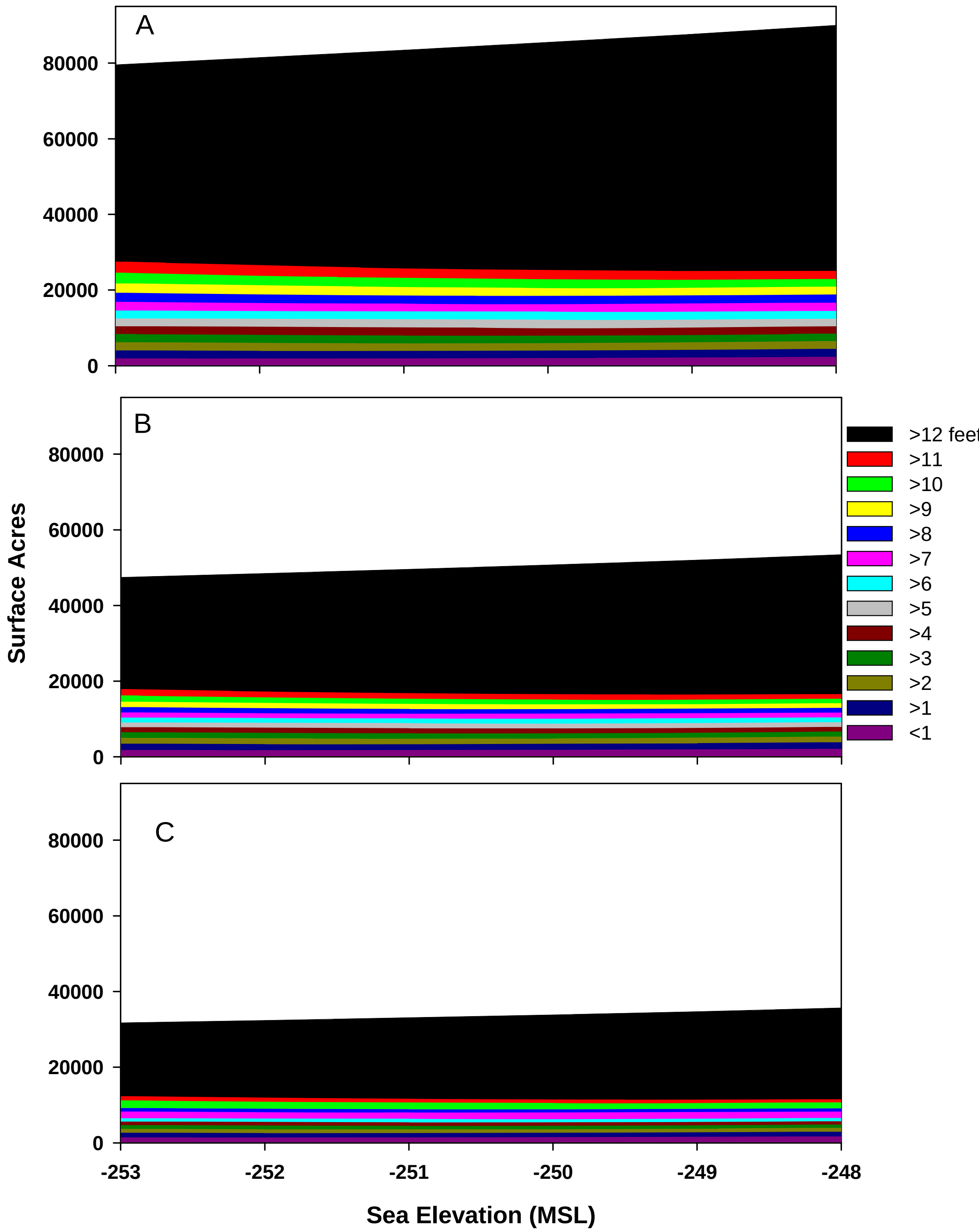

Figure 10.—Total sea area under alternative 8A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

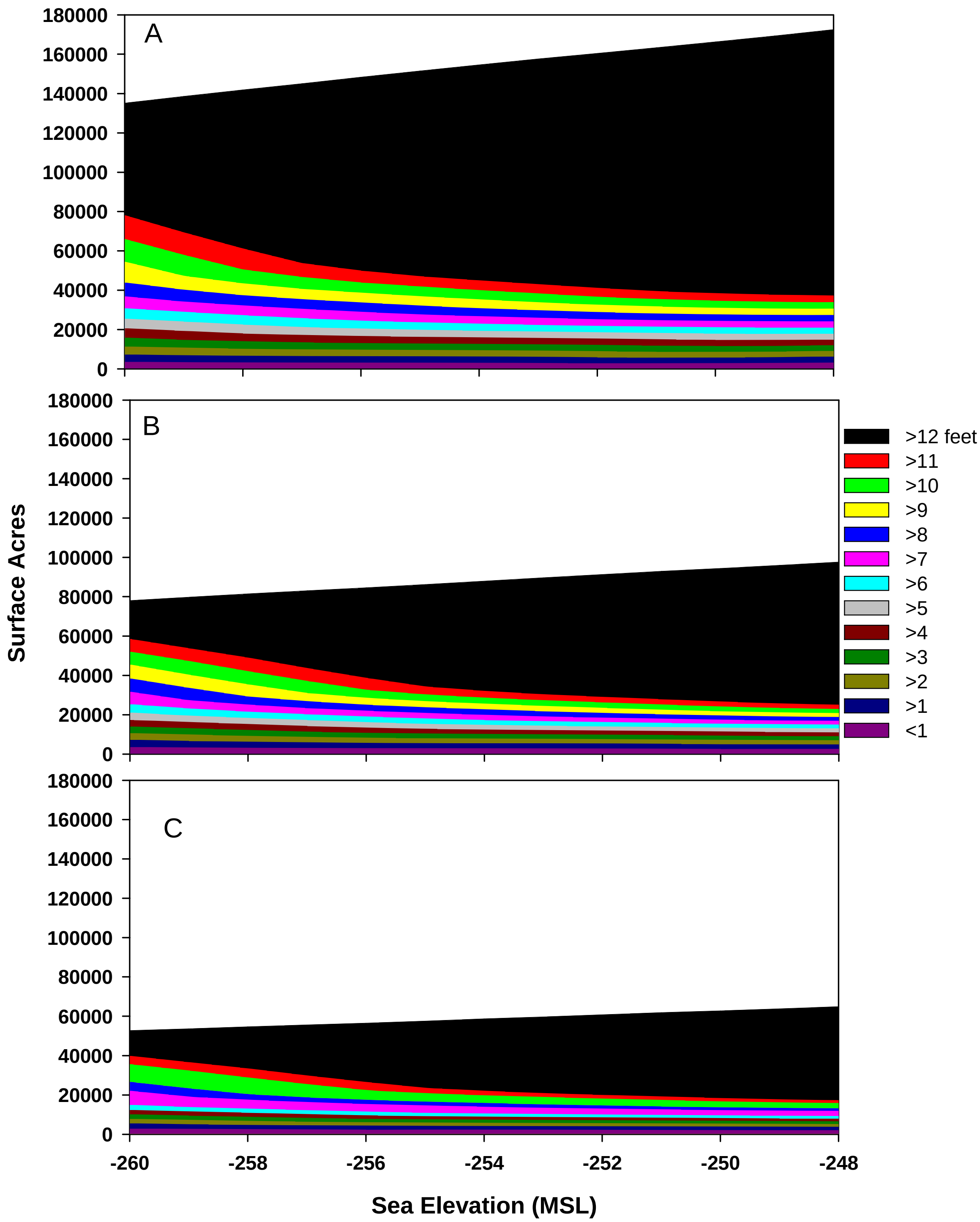

Figure 11.—Total sea area under alternative 9A and B, potentially affected by dissolved oxygen values A. Less than 4.0 mg/L, B. Less than 2.0 mg/L.

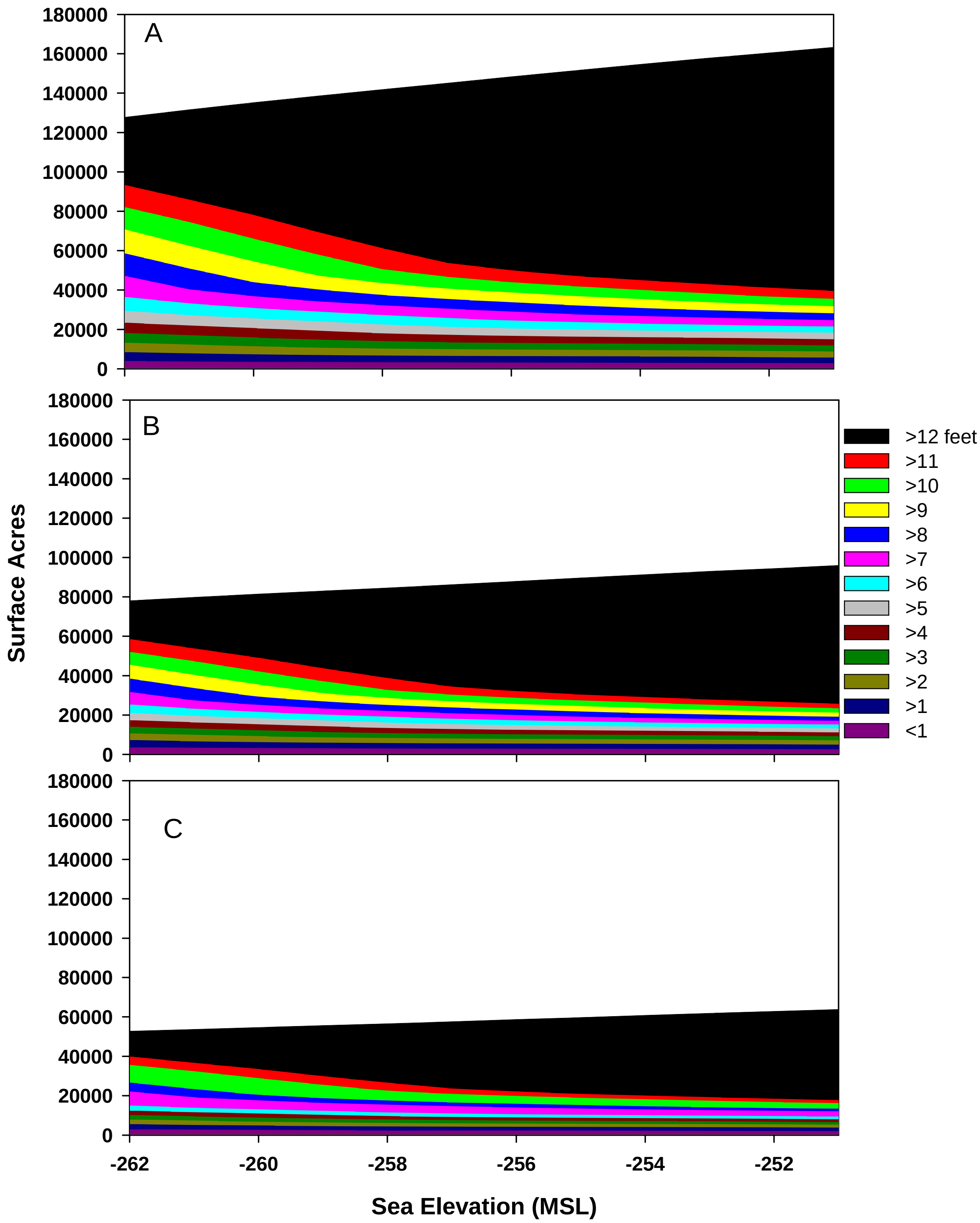

Figure 12.—Response to differing maximum and modal values of dissolved oxygen levels.

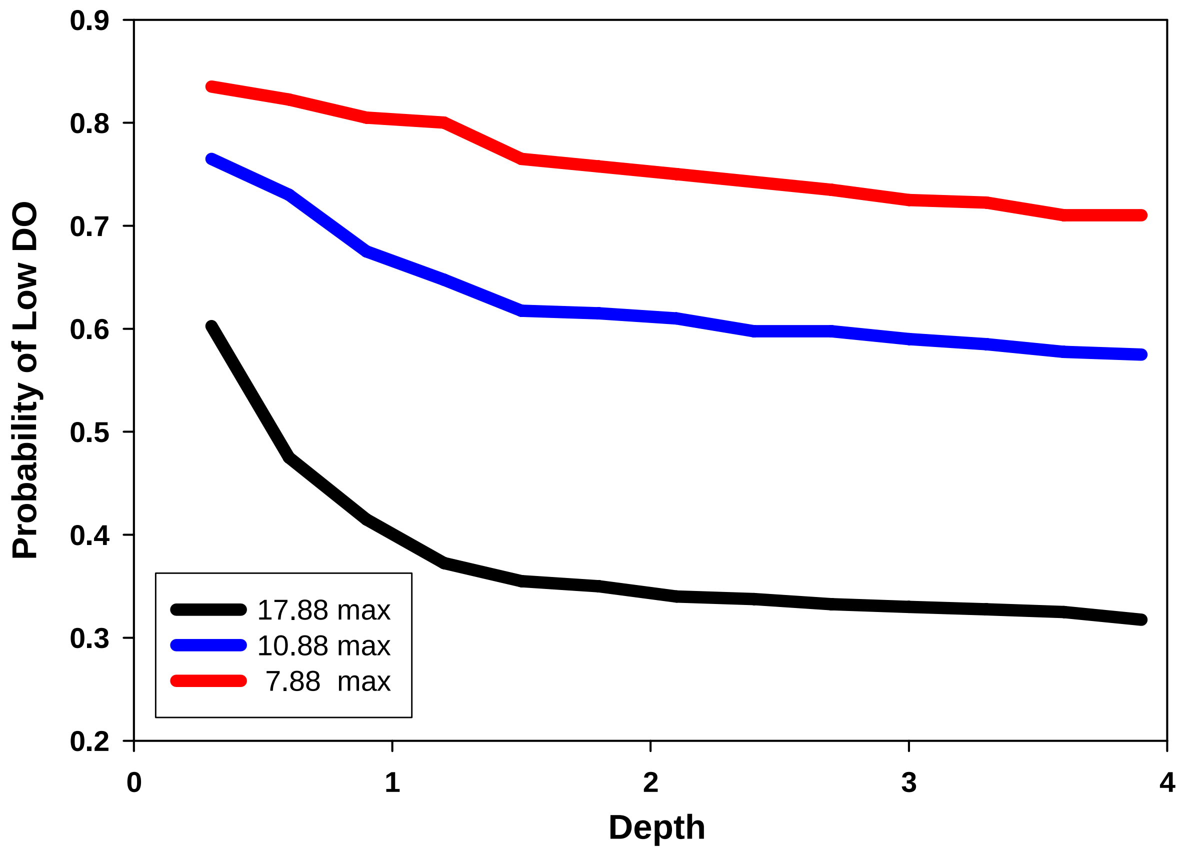

Figure 13.—Model response to changes in SR and WR values.

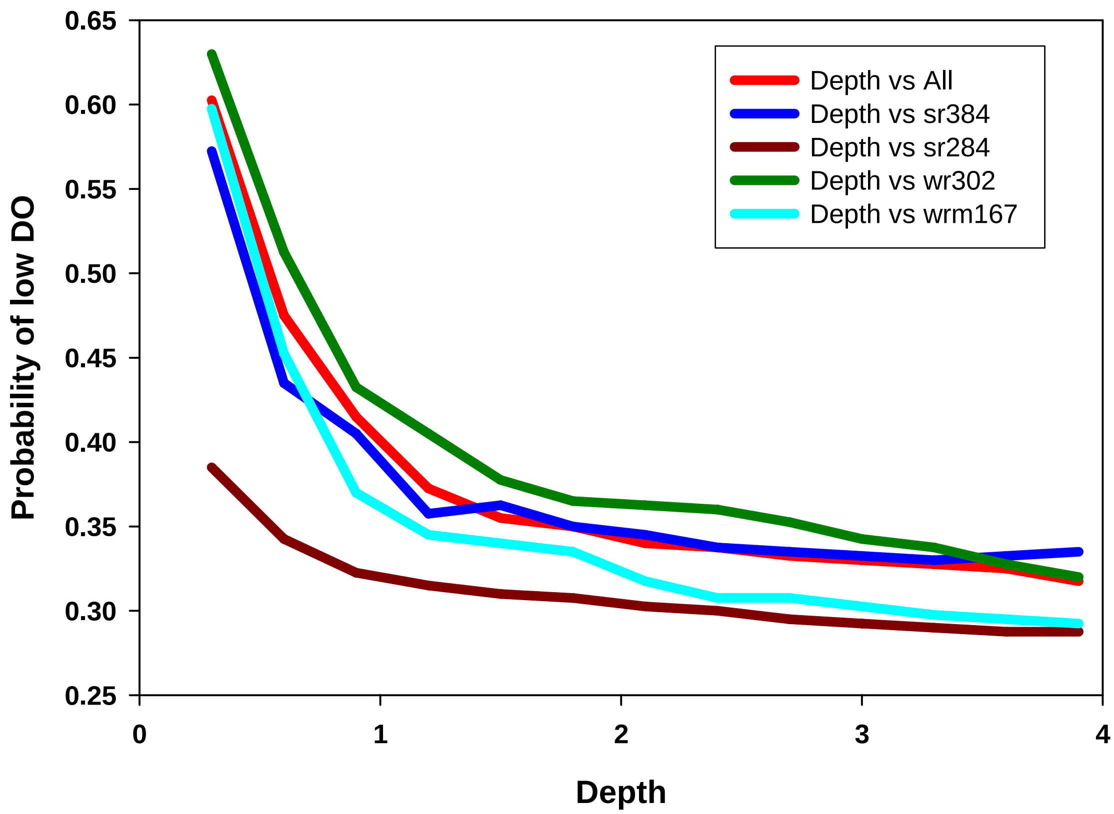

Table 1.—Expected proportion of the sea that can be expected to drop below 4 mg/L on any given summer night for each of the alternatives.

Elevation (MSL)	1ab	2ab	3ab	4ab	5ab	6ab	7ab	8ab	9ab
-262									0.61
-261									0.61
-260								0.58	0.60
-259								0.58	0.60
-258								0.57	0.60
-257								0.57	0.59
-256								0.57	0.59
-255								0.57	0.59
-254								0.57	0.59
-253							0.60	0.57	0.59
-252						0.59	0.59	0.57	0.59
-251						0.59	0.59	0.57	0.59
-250			0.69		0.58	0.59	0.59	0.57	
-249			0.68		0.58	0.59	0.59	0.57	
-248			0.67		0.58	0.59	0.59	0.57	
-247			0.67		0.58	0.60			
-246			0.66		0.58				
-245			0.66		0.58				
-244									
-243									
-242									
-241									
-240	0.58								
-239	0.58								
-238	0.58								
-237	0.58			0.60					
-236	0.58			0.60					
-235	0.58	0.59	0.68	0.60					
-234		0.59	0.67	0.59					
-233		0.58	0.66	0.59					
-232		0.58	0.65	0.59					
-231		0.58	0.64	0.59					
-230		0.58	0.63	0.59					