No. 142, Original

In the

Supreme Court of the United States

STATE OF FLORIDA,

Plaintiff,

v.

STATE OF GEORGIA,

Defendant.

Before the Special Master

Hon. Ralph I. Lancaster

PRE-FILED DIRECT TESTIMONY OF FLORIDA WITNESS MARCIA GREENBLATT, PH.D, P.E.

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October 14, 2016

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INTRODUCTION

1. My name is Marcia Greenblatt. I have a Ph.D. in water resources engineering, and have worked in the field of environmental consulting, with a focus on water modeling, for over 18 years. I have done work for federal and state agencies, and have taught university courses in hydrodynamics, hydrology, and numerical modeling. In my field, I often work with biologists and ecologists to investigate and understand issues related to aquatic environments. I perform modeling of relevant water issues – such as water temperature or salinity – and the biologists and ecologists use my modeling work to understand how modeled changes in the environment may harm plants and animals.

2. In this case, I performed modeling of Apalachicola Bay. The Bay is an estuary, where ocean saltwater and river freshwater mix. Apalachicola River is the dominant factor controlling how salty the Bay is (or the Bay's level of salinity) – the more freshwater flow from the River, the more diluted the salty ocean water becomes and the lower the salinity in the Bay. Over the past decades, Apalachicola Bay has experienced less freshwater inflow and higher salinity.

3. In this case, I have modeled how reductions in inflow result in higher salinity, and the biologist experts in this case (Dr. Glibert, Dr. White, and Dr. Kimbro) have used my results to understand impacts on the biology of the Bay**.** In my testimony, I explain my findings on the effects of changes in Apalachicola River flow on the salinity patterns in the Apalachicola Bay, including salinity at oyster bar locations. Salinity is a key variable in the Bay for the survival of oysters, as explained in the testimony of Dr. Kimbro. It also affects other important species such as phytoplankton and submersed aquatic vegetation, as explained in the testimony of Dr. Glibert.

4. The changes in salinity patterns are particularly pronounced in the lower salinity areas near the River, such as East Bay. As my work shows, Georgia's water consumption has a total impact of up to 8 parts per thousand (ppt) (with salinity in the Bay ranging between 0 ppt in fresh water, and approximately 35 ppt in Gulf of Mexico and ocean water), with the largest impacts in East Bay. Without Georgia consumption, the amount of oyster bar acres within the optimal salinity range for oysters (which is between 12 and 25 ppt) would more than double the current conditions.

5. There is no doubt that Georgia's consumption has an impact on salinity, and that recent salinities have very likely been higher than salinities in earlier decades. With a remedy capping Georgia consumption, there will be meaningful improvements in salinity (and other parameters such as nutrients) that bring the Bay closer to salinities historically experienced in the Bay that would be beneficial to the biology, as explained in Dr. Glibert's and Dr. Kimbro's testimony.

6. Specifically, my testimony covers the following topics:

a. First, my testimony will discuss historical changes in Apalachicola River flow, and the effects of flow on salinity in Apalachicola Bay generally. Dr. Hornberger has found that flows have declined in the Apalachicola River. As shown in Table 1, the number of low flow events (how often and for how long flow falls below 6,000 cubic feet per second (cfs)) has increased significantly since the 1920s. This finding of increased low flows is consistent with a similar analysis of the flow gage data that I performed. This observed flow data, which is a record of actual Apalachicola River flows, and records of measured salinity in Apalachicola Bay form the basis of my further evaluations.

b. In the modeling I performed, I rely on the findings of Dr. Hornberger and Dr. Flewelling, who have found that lower streamflow is a result of Georgia's increasing consumption. The data show, consistent with basic laws of physics, that reduced inflows result in increased salinity.

c. Second, I evaluate changes in patterns in salinity for various scenarios in which streamflow is changed from the observed flow data by either reducing or increasing Georgia's consumption. These scenarios were developed by Dr. Hornberger and are explained in his direct testimony. These scenarios are: (1) "no Georgia withdrawal," representing a scenario with no consumptive use by Georgia; (2) a "remedy" scenario, with limited Georgia consumption; and (3) a "future" scenario, with projected increased Georgia water use.

d. To model what salinity in the Bay would look like under these scenarios, I use a site-specific hydrodynamic and salinity model, which is fully described in the expert report I prepared for this proceeding (FX-787). A hydrodynamic model is a computer model that uses a series of established equations to simulate physical processes. The model uses a variety of input data, such as flow, wind, and tides, and inputs this information into the equations to calculate (among other things) the resulting salinity. The model allowed me to input the different flow scenarios to evaluate and compare the effects of the various water consumption scenarios on salinity in the Bay. As a general matter, salinity decreases when more flow enters the Bay (i.e., under the remedy and no withdrawal scenarios), and increases as less flow comes in (i.e., under the future scenario).

e. In my testimony, I also evaluate the potential impact of sea level on salinity in the Apalachicola Bay using site-specific measured data of sea level (the distance between the sea floor and the water surface) and salinity. Sea level is not static, but naturally varies both up and down. The Apalachicola Bay data shows that the monthly average sea level varied by about 10-15 centimeters, both higher and lower; and overall monthly average sea level varied by approximately 25 centimeters in the Bay. However, salinity does not follow a pattern with sea level; salinity does not increase when sea level is higher or decrease when sea level is lower. In other words, there are months and years that have a low average salinity but a high average sea level, and vice versa. Given that there is no clear relationship in the data, they do not show that sea level rise projected over the next decades will affect salinity in the Bay.

f. Additionally, sedimentation is connected to sea level rise. Sedimentation is the deposition of sand and silt and other material suspended in the water on the bottom of the Bay. As Dr. Douglass explains in more detail in his report, sea level rise would cause changes in sedimentation that will likely offset any potential change in the size of the inlets to the Bay, and the total flow of salt water into the Bay would remain roughly the same, even with sea level rise.

PROFESSIONAL BACKGROUND

7. I am a water resources engineer with over 18 years of experience in environmental consulting, specializing in hydrodynamic, water quality, and sediment investigations. I have designed and performed several modeling studies, applying both simple and complex numerical models, to predict hydrodynamic flows (that is, how water moves around

in a particular water body, such as a bay or river), sediment erosion, transport and deposition, and water quality. I have designed field studies to support modeling studies, evaluated and analyzed field data, and compiled data for model development. I have served as technical reviewer on multiple modeling studies. I have performed modeling studies for federal agencies, multiple state agencies, and private entities.

8. I received a Ph.D. in water resources engineering from University of California, Berkeley. I have taught university courses in fluid mechanics, numerical methods in water resources engineering, and hydrology. I am a licensed professional engineer in the Commonwealth of Massachusetts.

OPINIONS

I. OVERVIEW

A. Overview of the Apalachicola Bay System

9. Freshwater inflow, or the volume of water that flows into Apalachicola Bay, is the dominant factor controlling overall salinity in Apalachicola Bay. Other factors, including tidal exchange (the inflow of salt water from and outflow of fresh or salt water into the Gulf of Mexico); wind; and bathymetry (the shape and depths of the Bay floor) primarily affect the spatial patterns of salinity throughout Apalachicola Bay. In other words, with reduced freshwater inflow, the salinity in the Bay would increasingly and over a larger area reach salinities that are closer to the higher salinity of the Gulf of Mexico.

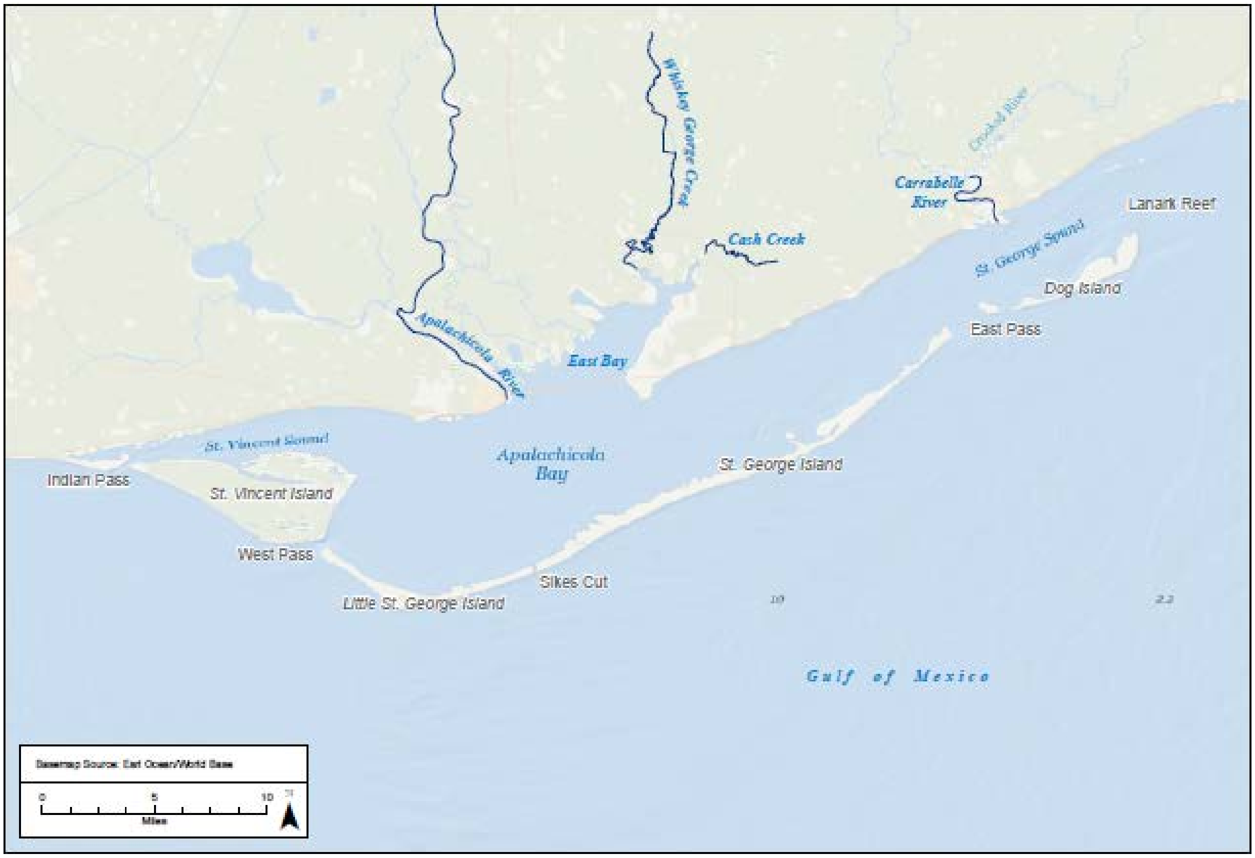

Figure 1 – Map of Apalachicola Bay region and sources of freshwater inflow. This is a true and accurate copy of Figure I in my report (FX-787). I created this map based on maps publically available from the Esri Ocean/World Base database, a source regularly relied upon by experts in my field and which I relied upon in forming my opinions in this case.

10. Freshwater inflows to Apalachicola Bay come primarily from the Apalachicola River. Discharge from the River flows into the Bay along both the main channel of the River as well as within a delta distributary system consisting of a network of small, interconnected waterways that enter the East Bay region of Apalachicola Bay east of the main River channel (*see* Figure 1).

11. While additional freshwater contributions to East Bay come from the Tate's Hell Swamp watershed, it only contributes a minor fraction of inflow. Tate's Hell is a forest on the north and northeastern end of East Bay. The watersheds associated with the creeks from this

forest, Whiskey George and Cash Creeks, encompass less than 1 percent of the Apalachicola-Chattahoochee-Flint (ACF) watershed area. It is common for watershed area to be used as an approximation of contributing flow when flow measurements are not available, and such a low percentage of watershed area indicates a very minor contributing flow. The Carrabelle River (including the New and the Crooked Rivers) provides an additional source of freshwater to the Bay system, discharging into the east end of St. George Sound. This watershed encompasses approximately 2 percent of the ACF watershed area, and also a small contribution to freshwater into the Bay.

12. Residence time is a way to describe the average time it takes for a drop of fresh water (or anything suspended in the water, such as a chemical molecule or a microscopic phytoplankton cell) to move out of the Bay once it has come in through the River or other freshwater source. Residence time is a measure of salinity conditions in Apalachicola Bay, with higher salinity observed when residence time is higher. If there is less fresh water coming into the Bay, there is less mixing and "flushing" of water out of the Bay. Using my model, I estimate residence time to be generally five to ten days for Apalachicola Bay, with residence times greater than 20 days for some low flow conditions. Residence time in East Bay ranges from three to six days for low flow conditions, and decreases to less than one day for higher flow conditions.

B. Salinity in Apalachicola Bay

13. I found that observed salinity in the Bay is strongly tied to the volume of freshwater that enters the Bay; during low flow periods, higher salinities are observed, and conversely, during high flow periods, lower salinities are observed. The relationship between flow and salinity is easily seen in plots I prepared of salinity versus flow at various locations within Apalachicola Bay where salinity data has been collected since the 1990s (*see* Figure 2). Although there is spread in the data (which is expected given the complex flow and salinity

dynamics in Apalachicola Bay), the highest salinity was observed at all four locations when flows at the USGS Chattahoochee stream gage were below approximately 10,000 cubic feet per second. At all locations, lower salinity was observed with increasing freshwater inflow.

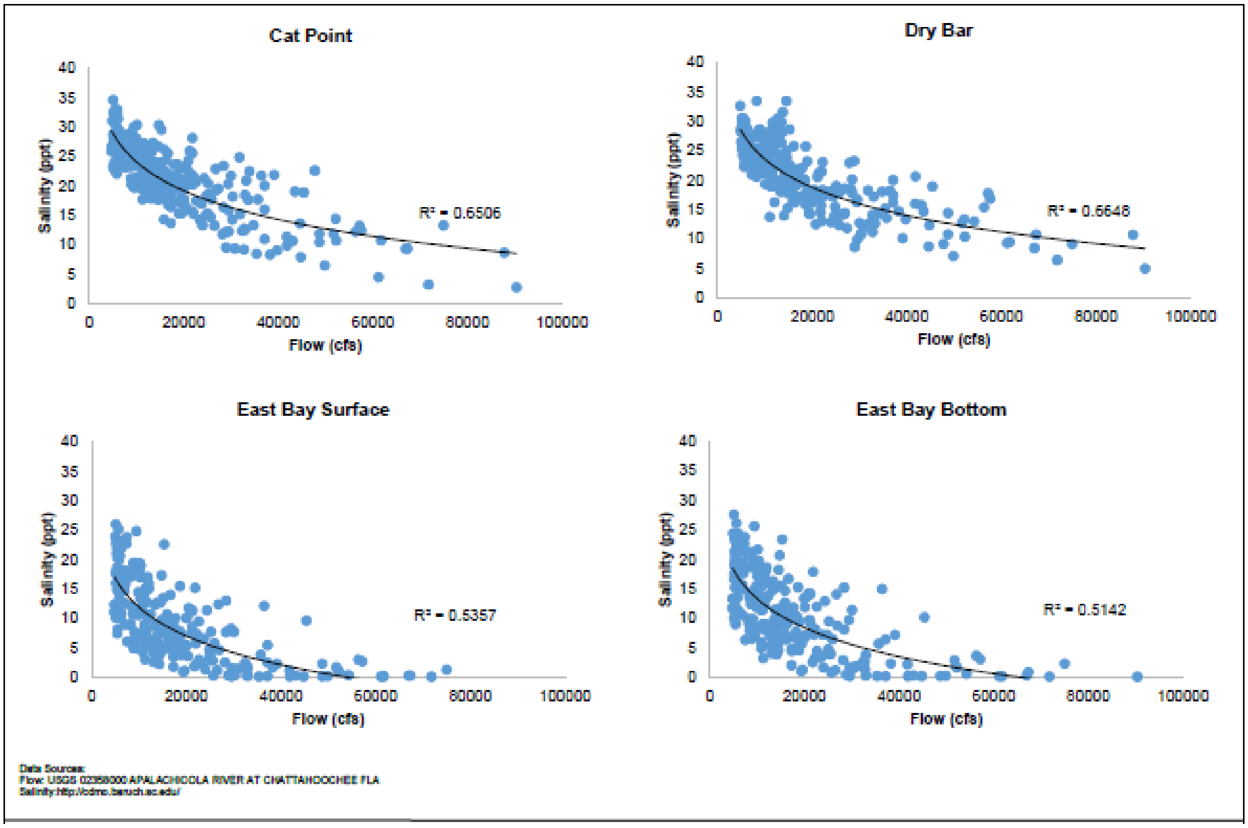

Figure 2 – Plot of observed salinity and flow data (at the Chattahoochee gage), showing strong correlation between flow and salinity at all four locations where salinity is continuously measured. This is a true and accurate copy of a figure I created and presented in my expert report (FX-787, Fig. 1-5). The flow data was taken from the official USGS gage measurements (JX-128) and the salinity data was taken from official ANERR salinity measurements (JX-136). These are the types of data typically relied upon in my field and which I relied upon in forming my opinions in this case.

II. HISTORICAL PATTERNS IN APALACHICOLA RIVER FLOW

14. Dr. Hornberger performed an analysis to characterize alterations to the hydrology in the ACF watershed (Hornberger Expert Report, Sec. IV (FX-785)). Dr. Hornberger found that flows have declined in the Apalachicola River since 1970, and that low flow conditions are more

prevalent especially in recent decades. The average number of days of low flow conditions has increased over time (Table 1). Between 1922 and 1970, the average number of days with flow below a low flow of 6,000 cfs in a year was approximately 5.2; between 1970 and 2013, the average number of days below 6,000 cfs in a year was approximately 30; and between 2003 and 2013, the average number of days with flow below 6,000 cfs was approximately 71. Similar changes are seen for other low flow thresholds (Hornberger Expert Report, Sec. IV (FX-785)).

Threshold Q (cfs)	1921-1970	1970-2013	1992-2013	2003-2013
6,000	5.2	29.8	50.6	71
5,500	2.6	19.0	32.7	54.0
5,400	1.9	16.3	28.0	47.2
5,300	1.5	13.1	22.2	37.8
5,200	1.0	11.4	19.3	33.7
5,100	0.2	6.0	9.2	14.8
5,000	0	3.0	3.8	4.5

Table 1 - Average number of days with flow below indicated flow (Threshold Q) at the Chattahoochee gage. This is a true and accurate copy of Table 4 from the Hornberger Expert Report (FX-785). This is the type of data typically relied upon in my field.

15. I personally performed a similar analysis of historic record at the Chattahoochee flow gage, and found a consistent result: low flows in the Apalachicola River have become more frequent and of a longer duration in recent years (*see* Attachment 2 (Extracts from Greenblatt Expert Report, FX-787), Table 1-1).

16. The expert opinions of Drs. Flewelling and Hornberger, as set forth in their testimony and reports (Flewelling Expert Report (FX-786); Hornberger Expert Report (FX-785)), show that Georgia's consumptive water use in the ACF watershed directly affects the volume of freshwater inflow into Apalachicola Bay. As they explain, increased consumptive use in Georgia results in less water in the Apalachicola River and less freshwater that enters

Apalachicola Bay. As I explain above using the flow and salinity correlations, less inflow generally results in higher salinity in the Bay.

III. APALACHICOLA BAY SALINITY MODELING

A. Explanation of the Apalachicola Bay Hydrodynamic and Salinity Model

17. Apalachicola Bay is a complex tidal system, with flows, circulation, and salinity distribution influenced by freshwater inflow, tidal exchange, wind, and bay geometry. A numerical model is required to examine and simulate spatial and temporal salinity patterns and to compare alternative (e.g., historical or future) conditions. As I explain in my introduction, a numerical hydrodynamic model is a computer model that uses equations to calculate (among other things) salinity, using inputs such as flow. Since a model allows me to change the flow input, it allows me to compare results of various flow scenarios.

18. INTERA, an engineering consulting firm, developed a numerical hydrodynamic and salinity model of Apalachicola Bay for the Northwest Florida Water Management District to assess, among other things, the impact of changes in freshwater discharge to Apalachicola Bay. (INTERA 2014 (JX-107)). INTERA used the Regional Oceanic Modeling System (ROMS), a widely used modeling platform selected following a comprehensive comparison of several modeling platforms (INTERA 2013 (JX-102)).

19. I evaluated this numerical hydrodynamic and salinity model and concluded it was developed using the best available site-specific data to establish initial and boundary conditions. Initial conditions are values based on data such as water level and bathymetry (the shape and depth of the Bay floor) that are used to set up the model to represent the starting conditions for the model simulations. Boundary conditions are values based on data such as river inflows, tides, and winds that are put into the model to represent changing conditions over the model simulation. Changes in boundary conditions cause changes in simulated salinity.

20. I also determined that the model used the best available data to calibrate and validate the model. Calibration is the process in which the model is run, and then the simulated parameter (in this case salinity) is compared against the observed salinity. The model is adjusted to optimize the fit between the simulated and observed salinity. Then, in the validation step of the process, the model is run for a different set of conditions and the simulated salinity is compared to the different set of observed data to confirm model set up (without further adjustments).

21. The selection of data for model setup requires a review of data from a range of sources and professional judgment to select the most suitable data. The INTERA model was calibrated to a large set of measured data collected at 37 locations in Apalachicola Bay and tested for sensitivity to the input parameters. A sensitivity analysis is a process where model parameters such as bathymetry or wind are adjusted to assess their impact on the match between simulated and observed salinity. The model simulations were generally well-matched to observed data, indicating the model was well calibrated. Following my independent review of the model and the results, I determined that this model was suitable to support my evaluations of the impact of Georgia's consumptive use on salinity in Apalachicola Bay.

22. To use the model for an evaluation of salinity patterns in Apalachicola Bay, the model was updated to be able to simulate the recent six-year period from 2007 to 2012. This period includes four years with below average freshwater inflow, one with closer to average freshwater inflow, and one with high freshwater inflow. The model grid extent (or the geographic area covered by the model) was modified slightly from the original version to decrease model run times. Specifically, the outer boundary of the model (in the Gulf) was moved several miles closer to the Bay to reduce the total area the model simulated, which

reduced computer run time. The model boundary was still sufficiently far from the tidal inlets, or passes, to allow for proper simulation of tidal exchange, and this change did not affect the validity of the results.

23. The selection of grid size and extent includes a review of available data, evaluation of model results, and professional judgment. I determined based on my independent review that the grid size in the final model that I used was appropriate to simulate salinities in the Bay. The simulated results from the updated model were compared to observed data, both visually and statistically, and were found to be in good agreement, consistent with the original model.

B. Application of the Apalachicola Bay Salinity Model Using the Flow Scenarios

24. I used the INTERA numerical model to compare salinity in the Bay for observed flow conditions (as measured at the USGS Sumatra stream gage) with three alternative flow conditions, provided by Dr. Hornberger and explained in his testimony: (1) a "no withdrawals" scenario, in which there is no consumptive use by Georgia; (2) a very conservative "remedy" scenario that represents decreased consumptive use by Georgia resulting in increased freshwater inflows; and (3) a "future" scenario that represents lower freshwater inflows resulting from projected increased consumptive use by Georgia.

25. The model simulations showed, in general, that salinity in the Bay decreased under the alternative conditions where freshwater inflows were higher than current conditions (i.e., the no withdrawals and the remedy scenario). A true and accurate copy of the full output of all my model results is provided as FX-469. True and accurate copies of salinity graphs, tables, and maps that I created and which present the outputs of my model in graphical form, as produced with my report (FX-787) are provided as Attachment 2.

26. To assist in putting these salinity results in perspective, I note that freshwater (i.e., River water) has a salinity of 0 ppt, and salt water from the Gulf of Mexico has a salinity of about 35 ppt. During the driest years in recent history, annual average salinity has been over 25 ppt at the main oyster bars (Dry Bar and Cat Point, *see* Figure 3), and monthly averages can be higher. Other experts discuss the biological effects of increased salinity. For instance, based on Dr. Kimbro's work, the optimal range of salinity for oysters in the Bay is between 12 and 25 ppt; as Dr. Kimbro explains in his testimony, at higher salinities oyster predation becomes severe. Model results are presented relative to this range.

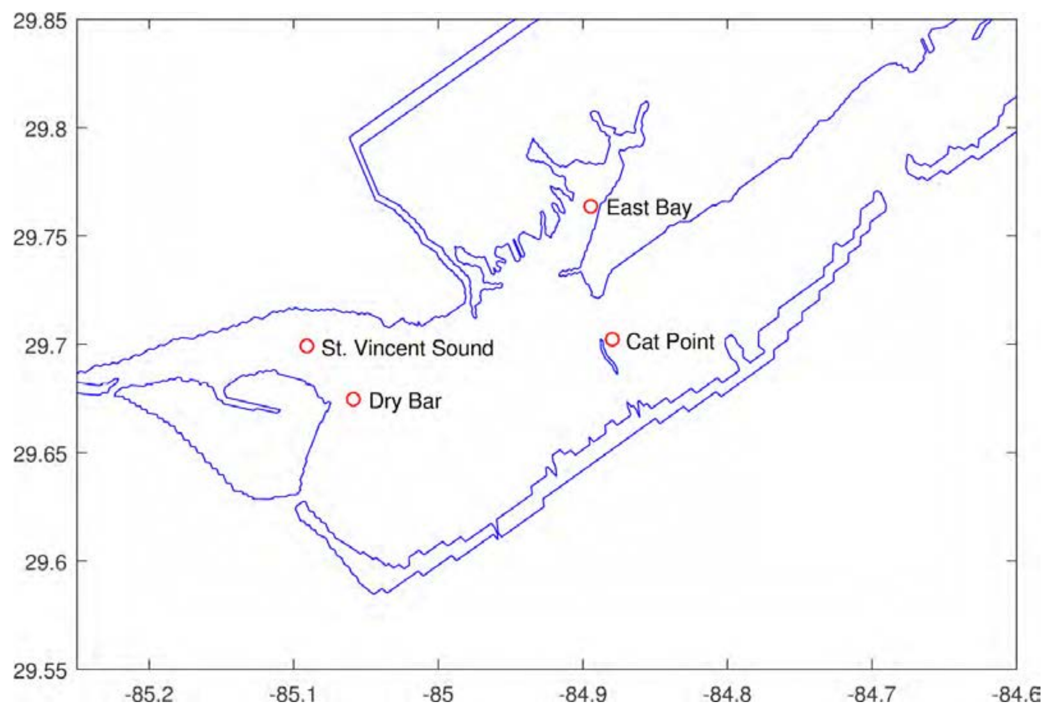

Figure 3 – Location of selected simulated observation points, including Cat Point and Dry Bar. This is a true and accurate copy of a figure I created from my model, as presented in my expert report (FX-787, Fig. 3-9).

C. Modeling Results

27. *No Withdrawal Scenario:* I used this scenario to evaluate the full impact of Georgia consumption, which I believe is important to gain an understanding of the range and

magnitude of impacts on this system. I understand this type of analysis is an important evaluation for the biologist experts as well. To compare how this scenario would change salinity in the Bay, I developed a set of maps showing the salinity differences between scenarios for each month in the dry season. In comparing the no withdrawals scenario with the observed conditions, the model simulations showed that dry season monthly average salinity decreased in the absence of Georgia withdrawals and consumptive use, depending on the date and location, from less than 1 ppt to up to 8 ppt, with the highest salinity decrease near the mouth of Apalachicola River, in East Bay, and in St. Vincent Sound (*see* Figure 4; Attachment 2, Figures 3-3 to 3-8).

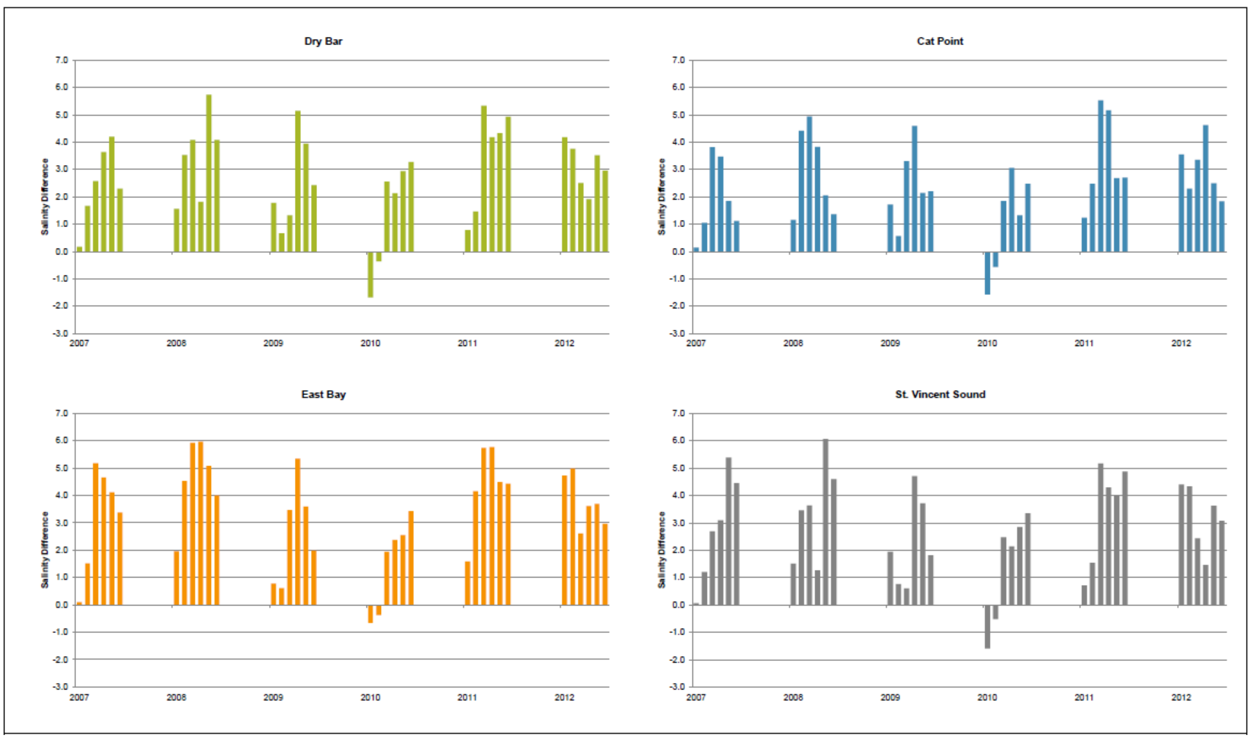

Figure 4 – This is a chart that compares my modeling results for the observed flow conditions and modeled "no withdrawal" conditions. This chart compares the average monthly differences in salinity for each dry season month in each year. For instance, in East Bay in 2008, the bars show that in the summer months, salinities without Georgia consumption could be up to 6 ppt lower, depending on the month. This chart is a true

and accurate copy of a figure I created, which is contained in my expert report (FX-787, Fig. 3-10).

28. I also analyzed the results of the model simulations to quantify the change in salinity over oyster bed locations. Specifically, I calculated the number of acres over the oyster beds where bottom salinity was within the range of 12 to 25 ppt, the range identified by Dr. Kimbro as an optimal range for oysters in the Bay. The number of acres over oyster beds within this optimal range was more than three times larger for some dry season months for the no withdrawals scenarios compared with the observed conditions. In four of the six years of the model simulation, the average acres over oyster bar areas with bottom salinity in the optimal range for the no withdrawals scenario was more than double the observed conditions. (Attachment 2, Table 3-2)

29. *Remedy and Future Scenarios*: Simulated salinity within Apalachicola Bay decreased, depending on date and location, from less than 1 ppt to up to 3 ppt with freshwater flow increases in the remedy scenario compared with observed conditions. (Attachment 2, Figures 3-11 to 3-16) Conversely, with decreased freshwater inflows that would result from a potential increased future Georgia consumptive use, salinities increased from less than 1 ppt up to 3 ppt compared with observed conditions. (Attachment 2, Figures 3-17 to 3-22) Comparison of the increased future consumptive use with the remedy scenario shows salinity differences of up to 4 ppt between potential futures for the Bay, one with and one without a cap on Georgia consumption. (Attachment 2, Figures 3-23 to 3-28) If a remedy were to result in more freshwater entering the Bay than the modeled scenario I used, salinities would decrease even further.

30. In summary, my modeling evaluation of existing conditions and alternative scenarios provides comparative examples of how salinities will be affected by different amounts

of future Georgia water use. Georgia consumption is causing increases in salinity in the Bay and declines in optimal salinity conditions over the oyster bars. As discussed in Dr. Glibert's and Dr. Kimbro's testimony, the remedy scenario will make an important difference in a variety of ways, including by reducing salinity as shown by my modeling.

IV. EVALUATION OF THE RELATIONSHIP BETWEEN SEA LEVEL AND SALINITY

31. To explore the potential effect of sea level rise on salinity and the relationship between sea level and salinity in Apalachicola Bay, I looked at a long term (about 50 years) record of water level data collected by NOAA in the Bay, as well as the salinity data collected at the continuous measuring stations at two of the oyster bars in Apalachicola Bay (Cat Point and Dry Bar).

32. Upon evaluating the observed water level data and salinity data, I concluded that there is no readily discernable relationship between annual average sea level and salinity in Apalachicola Bay (*see* Figure 5). Observed annual mean sea level varied by more than 10 centimeters from year to year with little change in observed salinity. For example, average annual salinities at Cat Point in two recent dry years (2007 and 2012) were similar (27.2 ppt and 26.6 ppt, respectively); however, annual mean sea level for the two years differed by 10.5 centimeters. (Attachment 2, Figure 4-5)

33. In an analysis of sea level variations over approximately 50 years of observed data in Apalachicola Bay, NOAA reports that monthly average sea level varies over a range of approximately 25 centimeters, and annual average sea level varies over a range of approximately 40 centimeters. The projected rise in sea level, based on NOAA's observed sea level trend of 1.96 mm/year, would be approximately 10 centimeters over 50 years. Given that there is no discernable relationship between salinity and sea level (Figure 5), and that this projected sea

level rise is within the variation observed in the sea level data, sea level rise will not have a discernable effect on salinity in Apalachicola Bay.

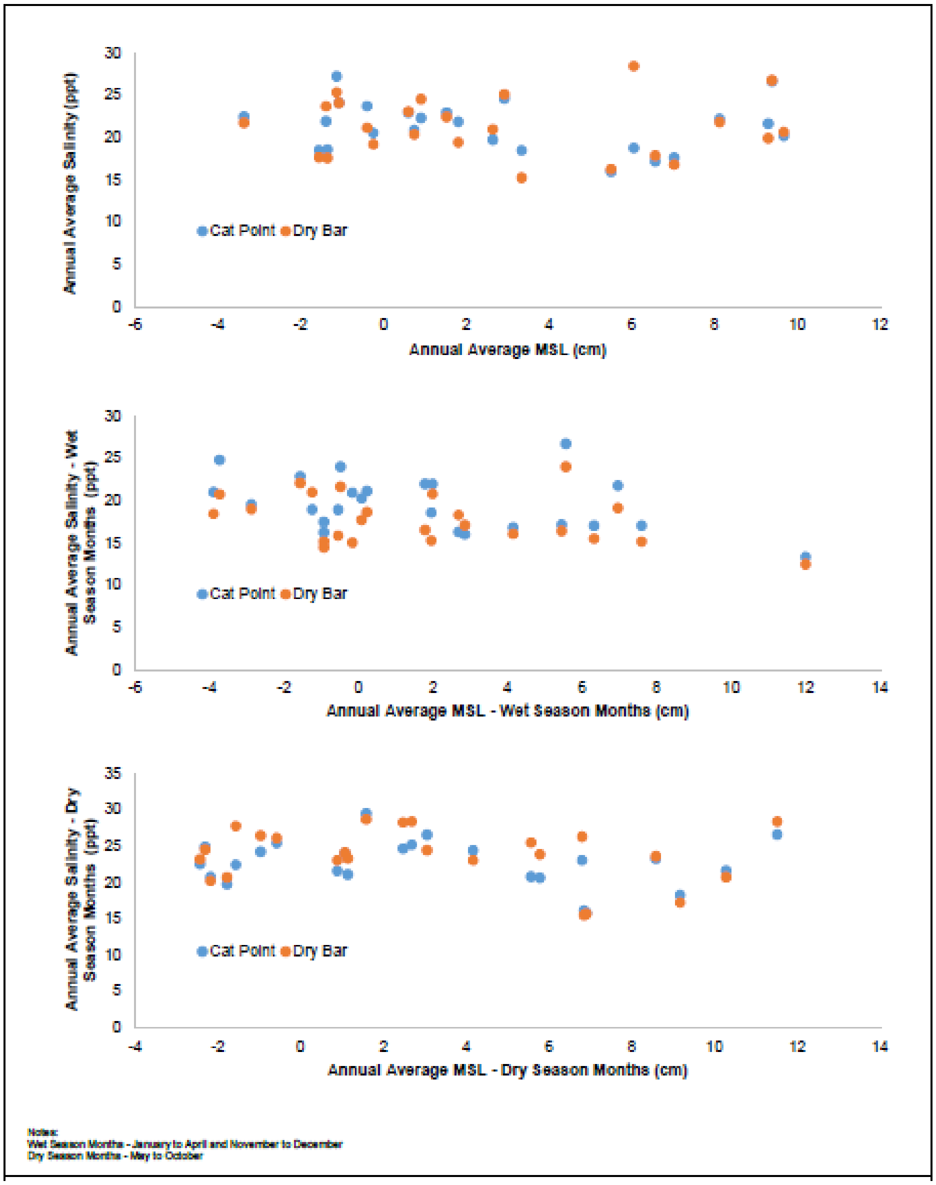

Figure 5 – Plots of observed annual average and seasonal salinity at two locations in the Bay and annual average and seasonal mean sea level. The plots show that while salinity levels vary, they are not higher at higher levels of mean sea level or vice versa. This figure is a true and accurate copy of the figure presented in my report, based on officially published NOAA and ANERR data (FX-787, Fig. 4-4). These are the types of data typically relied upon in my field and which I relied upon in forming my opinions in this case.

34. Finally, it is important to understand that the Bay system responds to changes in sea level. These system responses include changes in sedimentation and changes to inlet geometry. Increases in sea level will affect how the water flows through the inlets or passes from the sea into Apalachicola Bay, which in turn changes how sand and other sediments are deposited, both in the inlets and at other locations throughout the Bay. As Dr. Douglass explains in his report (FX-788), more sand will be deposited in tidal inlets when water levels rise, making the inlets shallower and counteracting the effect of sea level rise, since the amount of salt water that flows into the Bay will probably remain roughly the same.

V. RESPONSES TO DR. MCANALLY'S REPORT

35. As part of the preparation of this testimony, I reviewed the work of Georgia's salinity modeling expert, Dr. McAnally, as presented in his expert report. His work does not undermine any of my conclusions.

36. First, I reviewed his salinity modeling work and found that Dr. McAnally's work confirms my own. I found that his model and the INTERA model I used were set up with largely the same data, which further supports the validity of INTERA model data selection. Additionally, I confirmed that my modified model grid is similar to that used by Dr. McAnally in the development of the Georgia model. Last, Dr. McAnally provided an additional check of the validity of the modified model when he used my model inputs in his numerical model and produced similar results.

37. Dr. McAnally criticized my report and questioned the validity of my model because I did not report on uncertainty and sensitivity in the model. Model uncertainty refers to the degree to which the results of a mathematical model do not exactly represent or reproduce the behavior or characteristics of the natural system under investigation; all models have some uncertainty. However, the implementation of a meaningful uncertainty analysis would entail

placing uncertainty bounds on the multiple sources contributing to uncertainty and performing tens or hundreds of model runs to quantify how uncertainty in the model inputs affects the model outputs. Such a study is rarely performed in practice in my field.

38. Model sensitivity refers to the degree to which model results vary based on changes in specified model input parameters and data that are not precisely known. INTERA performed a sensitivity evaluation during the calibration of the original model, with results that were consistent with Dr. McAnally's sensitivity analysis. Because I generally looked at model results in a comparative manner, and held all input parameters (such as bathymetry and tides) other than inflow constant between scenarios, sensitivity of the model results to input parameters would not affect the relative difference between model results. The absence of a sensitivity or uncertainty analysis in my report does not invalidate my comparative results or weaken my confidence in my findings.

39. Second, Dr. McAnally performed statistical analyses in an effort to support his opinion that sea level affects salinity in the Bay. However, while his presentation of the results imply some mathematical relationship, he provides no analysis to demonstrate the strength of this relationship. Scientists make this determination of how strong a relationship is by calculating a correlation coefficient. A correlation coefficient is a statistical measure of relationship strength; the higher the correlation coefficient, the more strongly two sets of data are correlated. Dr. McAnally did not report a correlation coefficient for his statistical analysis of how sea level affects salinity.

40. More importantly, his analysis does not in any way determine cause and effect; although Dr. McAnally reports a mathematical relationship between sea level and salinity, he acknowledges that this relationship alone does not mean that sea level changes are the cause of

salinity changes. In contrast, he acknowledges that freshwater flow is the dominant factor affecting salinity, and he admits that flow as an input by itself (without sea level and wind as inputs) in his mathematical relationship can be "reasonably" used to predict salinity.

41. Finally, Dr. McAnally admits that his application of a numerical model to evaluate the effects of sea level rise on salinity does not include the complex response of the system to changes in sea level. Dr. McAnally acknowledges that these system responses, such as sedimentation and inlet depth changes, will occur, yet he did not fully or accurately include these in his sea level rise model scenario. His results, therefore, are highly uncertain and not a reliable representation of how sea level rise may impact salinity in the Bay.

CONCLUSION

42. In summary, it is my opinion that freshwater inflow is the dominant factor that influences salinity in Apalachicola Bay and that decreased freshwater inflow that results from Georgia's increased consumptive use (as indicated by Drs. Flewelling and Hornberger) results in increased salinity. Future increases in consumptive use will lead to greater increases in salinity, and future reductions will lead to decreases in salinity – and with those decreases, improvements to and potential recovery of the Bay ecosystem, as detailed in the testimony of Drs. Kimbro and Glibert. The effect of sea level on salinity in Apalachicola Bay is not clearly evident in the observed data, and the complex interaction between sea level rise, salinity, and sedimentation makes any modeling analysis of sea level rise highly uncertain.

ATTACHMENT 1 – LIST OF EXHIBITS CITED

- JX-102: This is a true and accurate copy of INTERA's 2013 official report to the Northwest Florida Water Management District, titled *Development of Model Selection Criteria and Model Recommendations for Assessing the Environmental Effects of Changes in Freshwater Discharge into Apalachicola Bay*, as produced to Georgia by Florida, describing the selection of INTERA's hydrodynamic model for the District. Modeling experts typically rely on such reports, and I relied upon it to inform my opinions.
- JX-107: This is a true and accurate copy of INTERA's 2014 official report to the Northwest Florida Water Management District, titled *Three-Dimensional Hydrodynamic Model Development, Calibration, and Verification of Circulation and Salinity in Apalachicola Bay, FL*, as produced to Georgia by Florida, describing the creation of INTERA's hydrodynamic model for the District. Modeling experts typically rely on such reports, and I relied upon it to inform my opinions.
- JX-128: This is a true and accurate copy of the gage data at Chattahoochee, FL, published by the United States Geological Survey (USGS). Such data is typically relied upon by experts in my field, and I relied upon it to inform my opinions.
- JX-136: This exhibit is an online database containing official Apalachicola National Estuarine Research Reserve (ANERR) water quality data, including salinity. I downloaded the data from the link provided, http://cdmo.baruch.sc.edu/ on January 11, 2016. Such data is typically relied upon by experts in my field, and I relied upon it to inform my opinions.
- FX-469: Described in text.

- FX-785: This is a true and accurate copy of Dr. George Hornberger's report as submitted by Florida to Georgia on February 29, 2016. Hydrodynamic modeling experts typically cooperate with and rely upon hydrologists, and I relied upon Dr. Hornberger's work to inform my opinions.
- FX-786: This is a true and accurate copy of Dr. Sam Flewelling's report as submitted by Florida to Georgia on February 29, 2016. Hydrodynamic modeling experts typically cooperate with and rely upon hydrologists, and I relied upon Dr. Flewelling's work to inform my opinions.
- FX-787: This is a true and accurate copy of the expert report that I prepared for this case, as submitted by Florida to Georgia on February 29, 2016.
- FX-788: This is a true and accurate copy of Dr. Scott Douglass's report as submitted by Florida to Georgia on February 29, 2016. Hydrodynamic modeling experts typically cooperate with and rely upon engineering and sedimentation experts, and I relied upon Dr. Douglass's work to inform my opinions.

ATTACHMENT 2 – EXTRACTS FROM DR. GREENBLATT EXPERT REPORT (FX-787)

Figures and tables are in the order cited in the testimony.

Table 1-1 Summary of Low Flows in the Apalachicola River

	1970-1985	1986-2015	1970-1991	1992-2015
Mean Daily Flow (cfs)	16,647	13,863	16,013	13,749
Number of Low-flow Events	2	58	11	49
Number of Years with Low-flow Events	1	19	4	16
Average Duration of Low-flow Events (days)	4	22	15	23

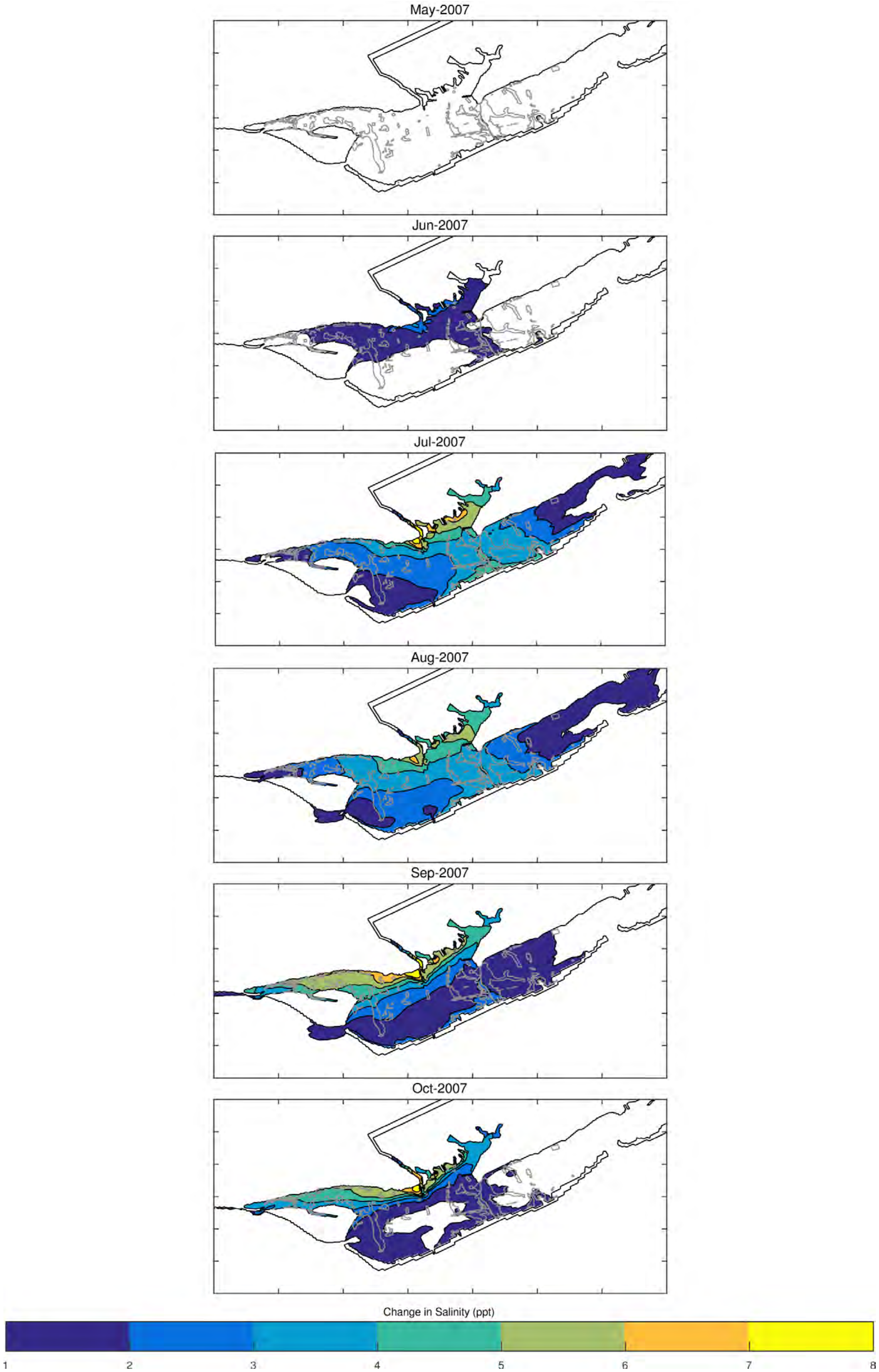

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Figure 3-3.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2007)

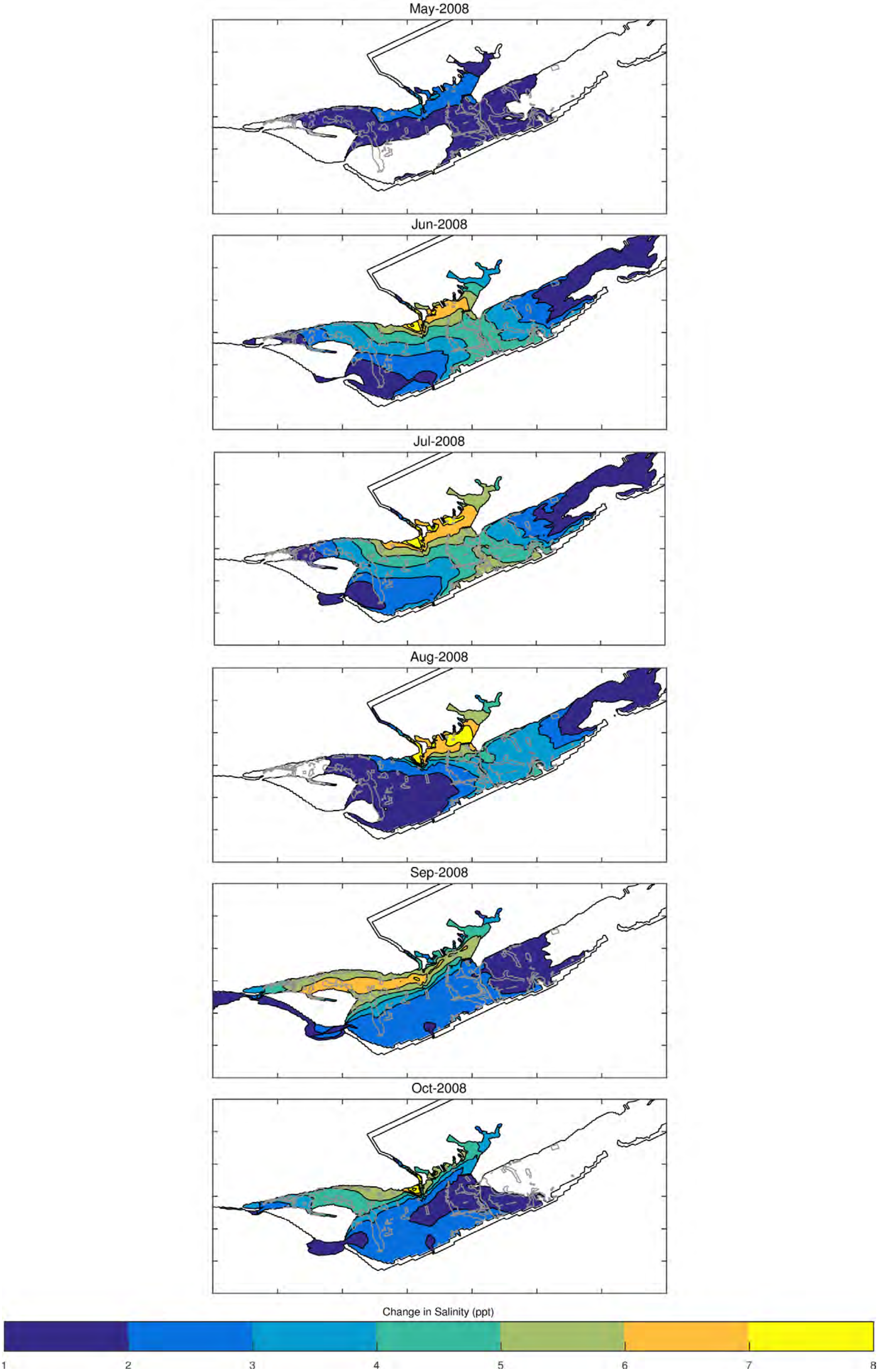

Figure 3-4.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2008)

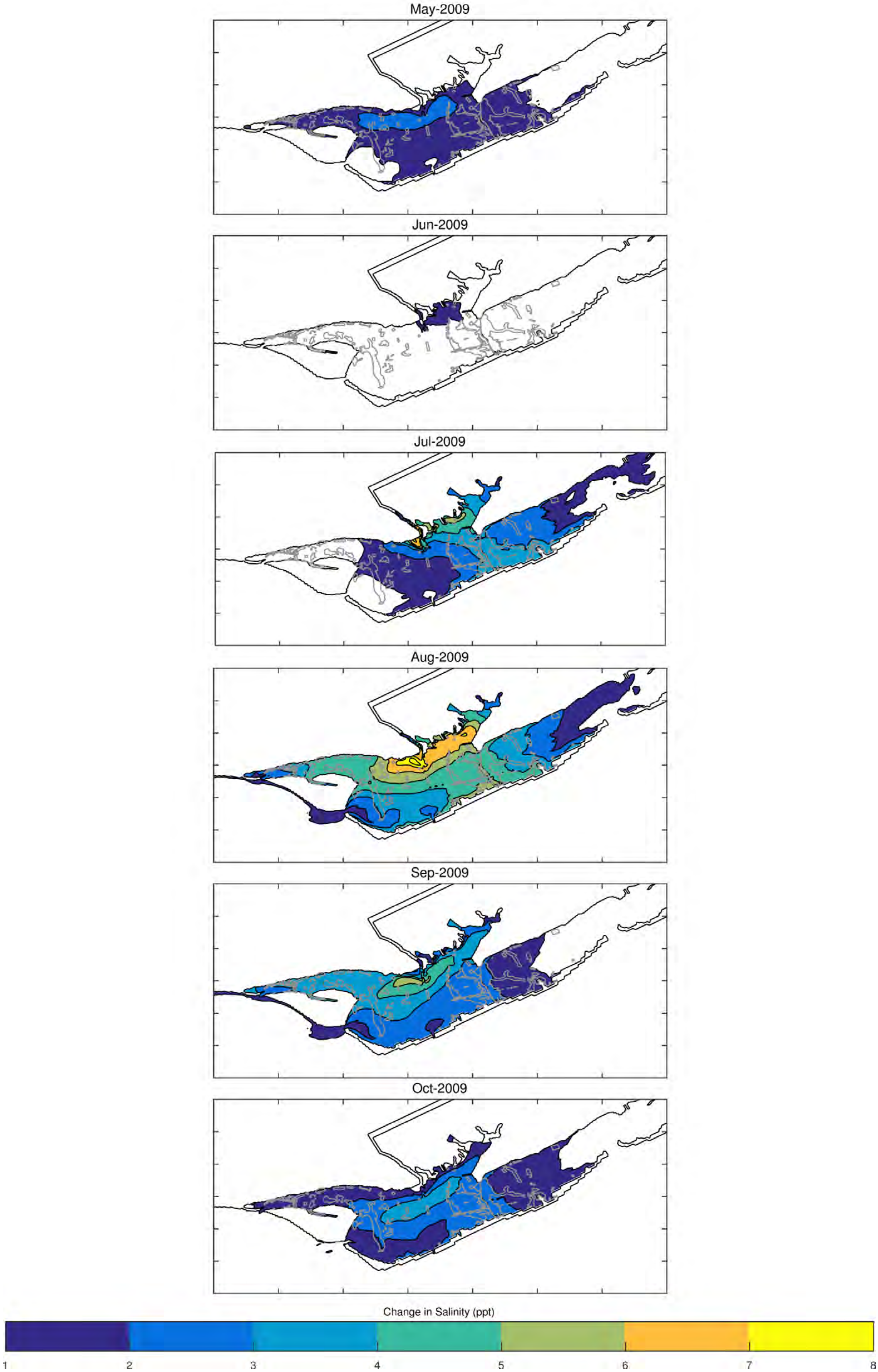

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Figure 3-5.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2009)

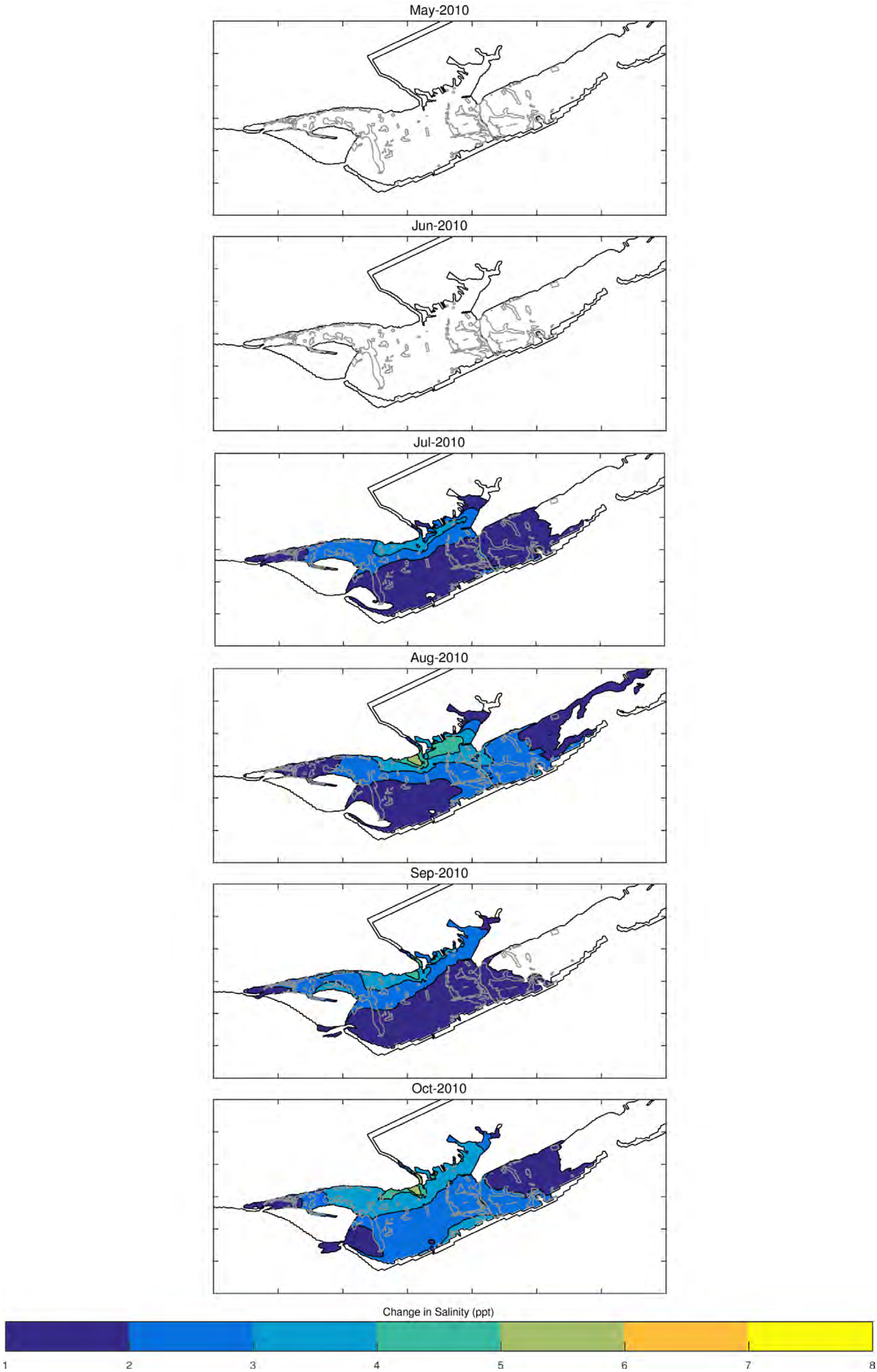

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Figure 3-6.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2010)

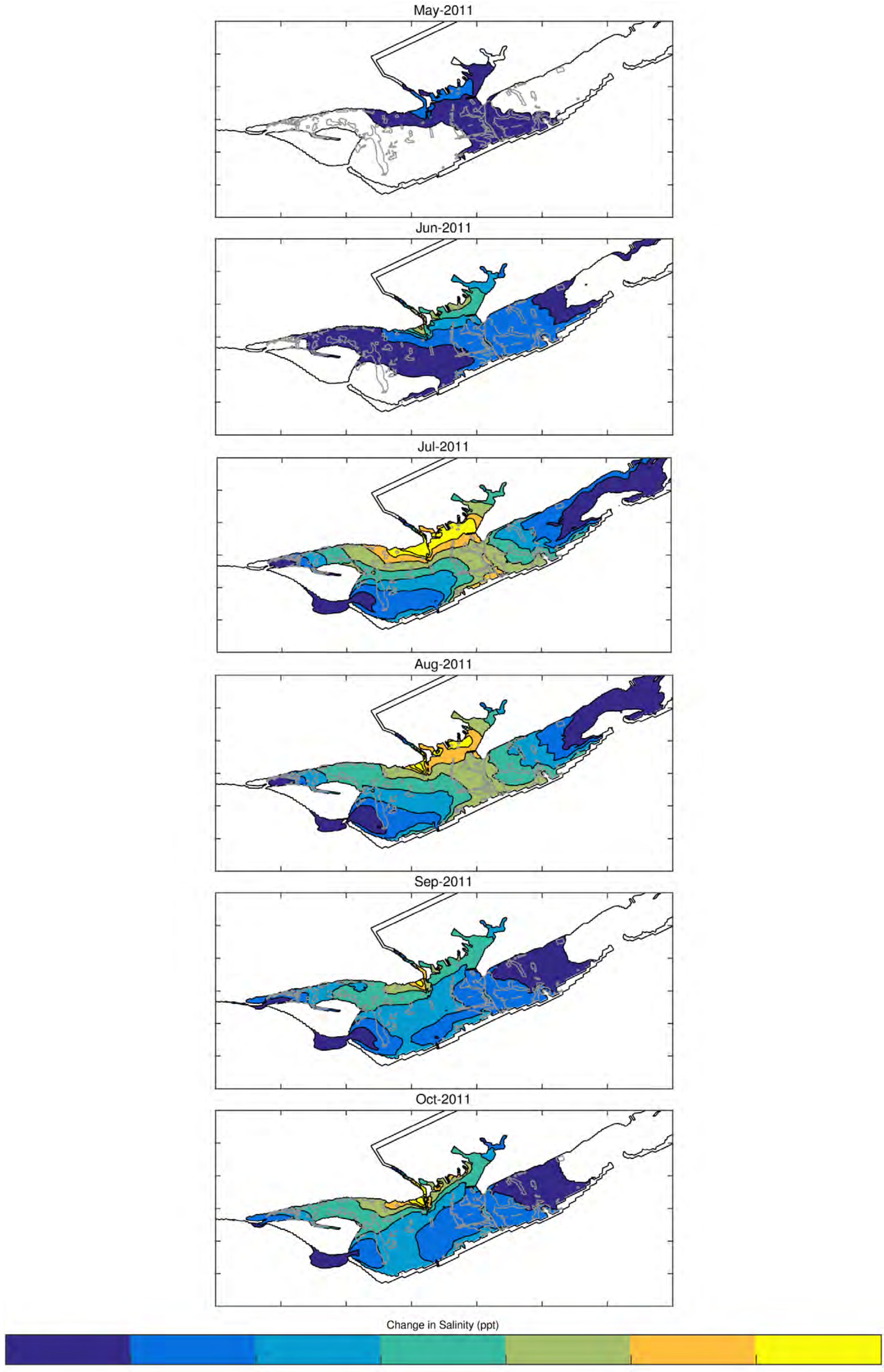

Figure 3-7.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2011)

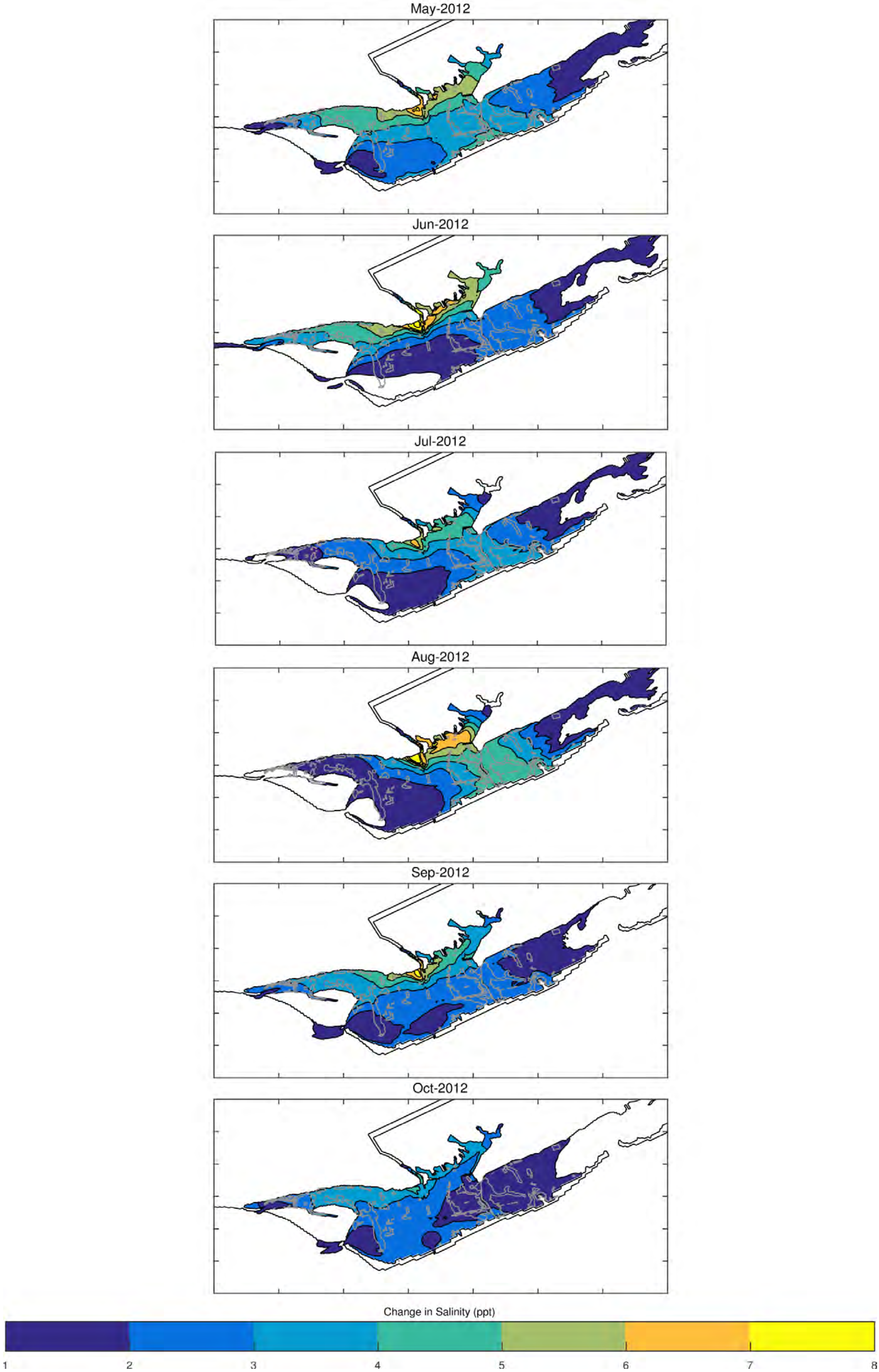

Figure 3-8.
Modeled Average Monthly Bottom Salinity Differences
Observed – No Withdrawals (2012)

Table 3.2 Acres of Oyster Bar Area with Bottom Salinity between 12 and 25 ppt – No Withdrawals versus Observed

	No Withdrawals	Observed	Difference
May 2007	1,656	1,579	5%
Jun 2007	1,342	492	173%
Jul 2007	3,057	991	209%
Aug 2007	3,938	2,835	39%
Sep 2007	2,283	1,184	93%
Oct 2007	1,107	339	227%
May 2008	2,163	1,904	14%
Jun 2008	4,103	2,744	50%
Jul 2008	3,815	2,253	69%
Aug 2008	2,103	577	264%
Sep 2008	2,007	1,182	70%
Oct 2008	1,307	464	181%
May 2009	2,865	2,905	-1%
Jun 2009	3,224	3,325	-3%
Jul 2009	1,892	994	90%
Aug 2009	4,141	2,865	45%
Sep 2009	2,382	2,075	15%
Oct 2009	3,737	3,992	-6%
May 2010	3,746	3,727	1%
Jun 2010	4,197	4,401	-5%
Jul 2010	3,452	2,760	25%
Aug 2010	3,577	2,850	25%
Sep 2010	2,427	1,582	53%
Oct 2010	2,635	1,290	104%
May 2011	2,894	2,210	31%
Jun 2011	2,059	969	112%
Jul 2011	4,074	1,979	106%
Aug 2011	4,105	1,812	127%
Sep 2011	2,335	934	150%
Oct 2011	1,965	442	344%
May 2012	3,956	1,926	105%
Jun 2012	1,674	666	151%
Jul 2012	3,849	2,843	35%
Aug 2012	3,118	1,651	89%
Sep 2012	2,527	951	166%
Oct 2012	2,704	1,539	76%

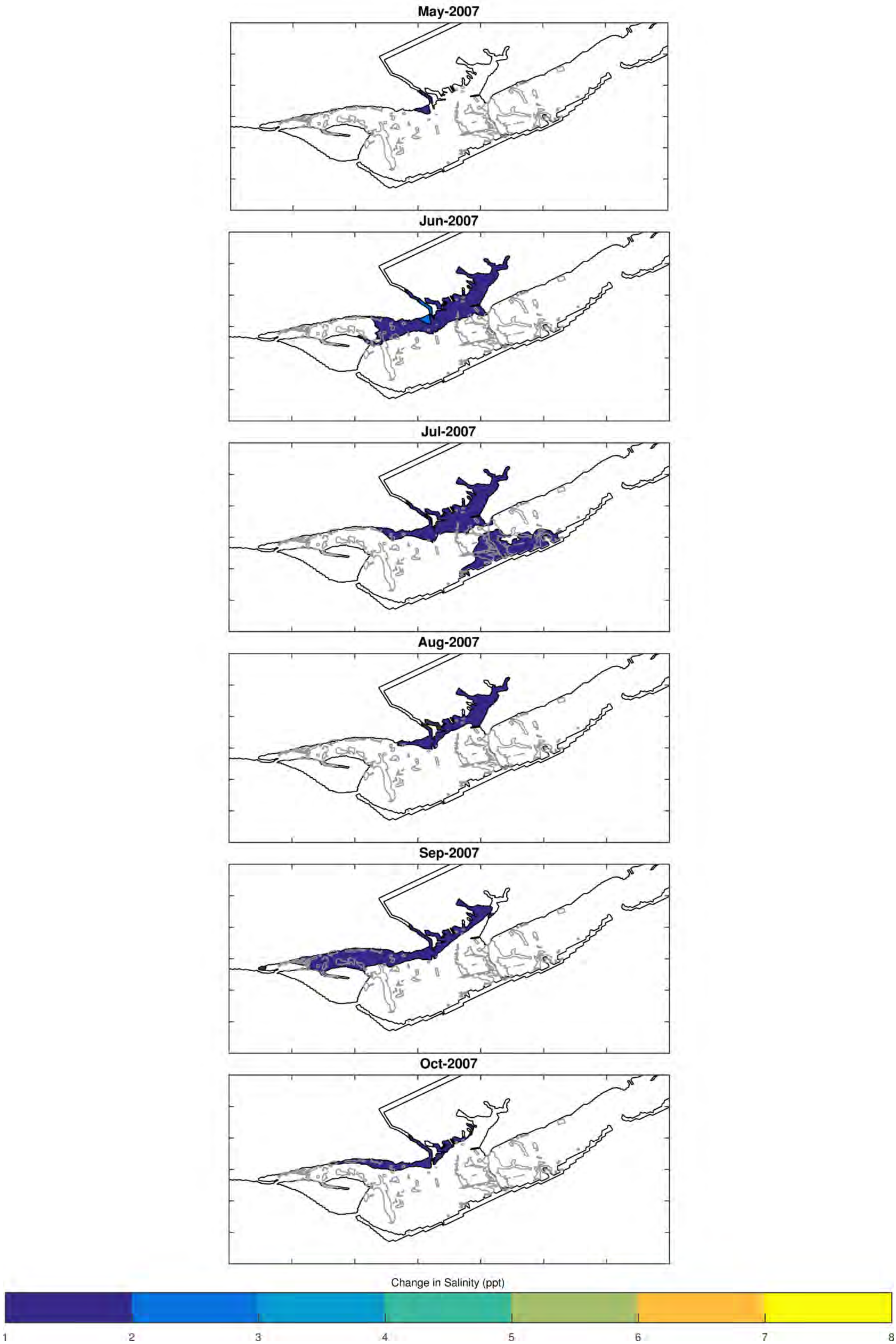

Figure 3-11.
Modeled Average Monthly Bottom Salinity Differences,
Observed - Remedy (2007)

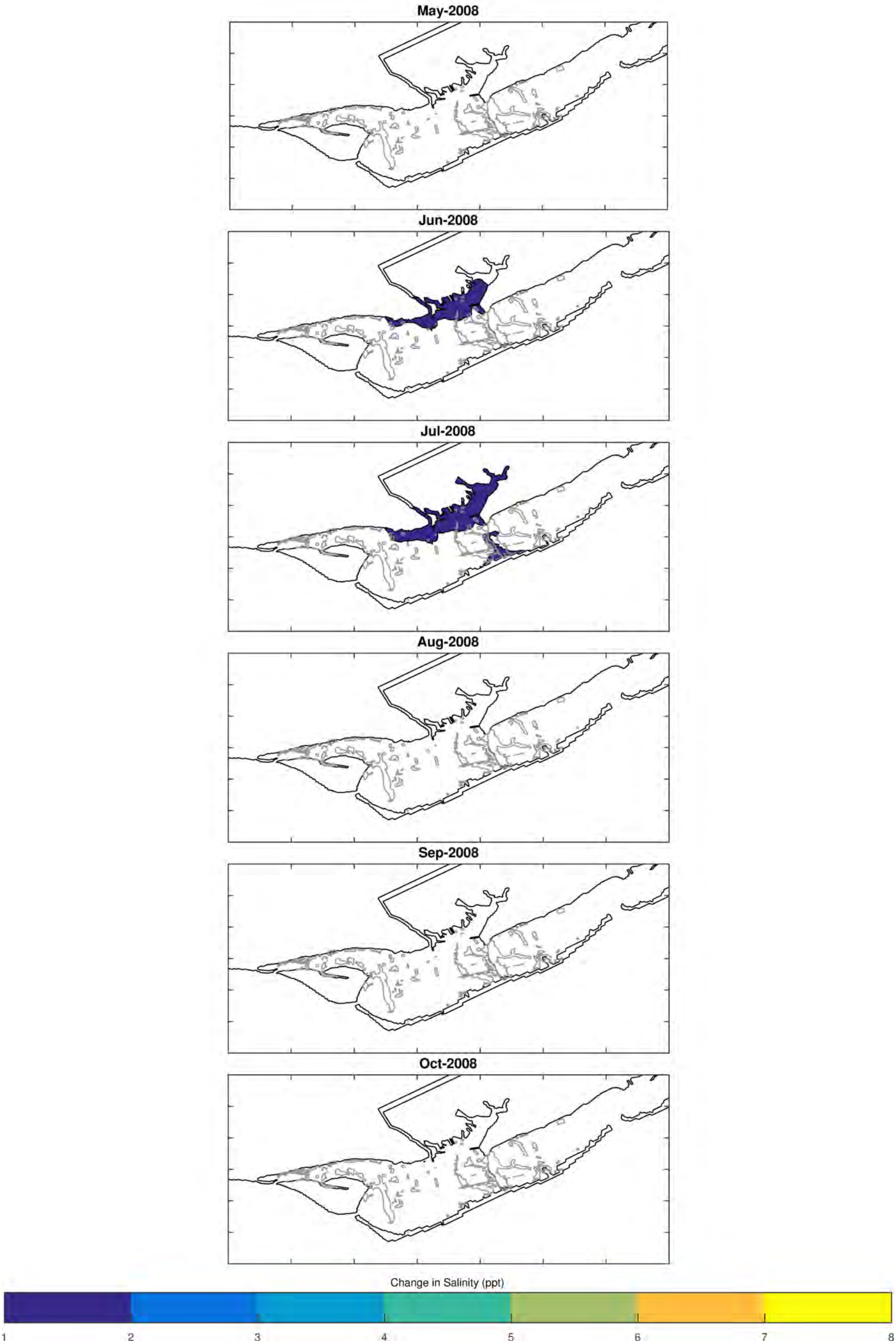

Figure 3-12.
Modeled Average Monthly Bottom Salinity Differences, Observed - Remedy (2008)

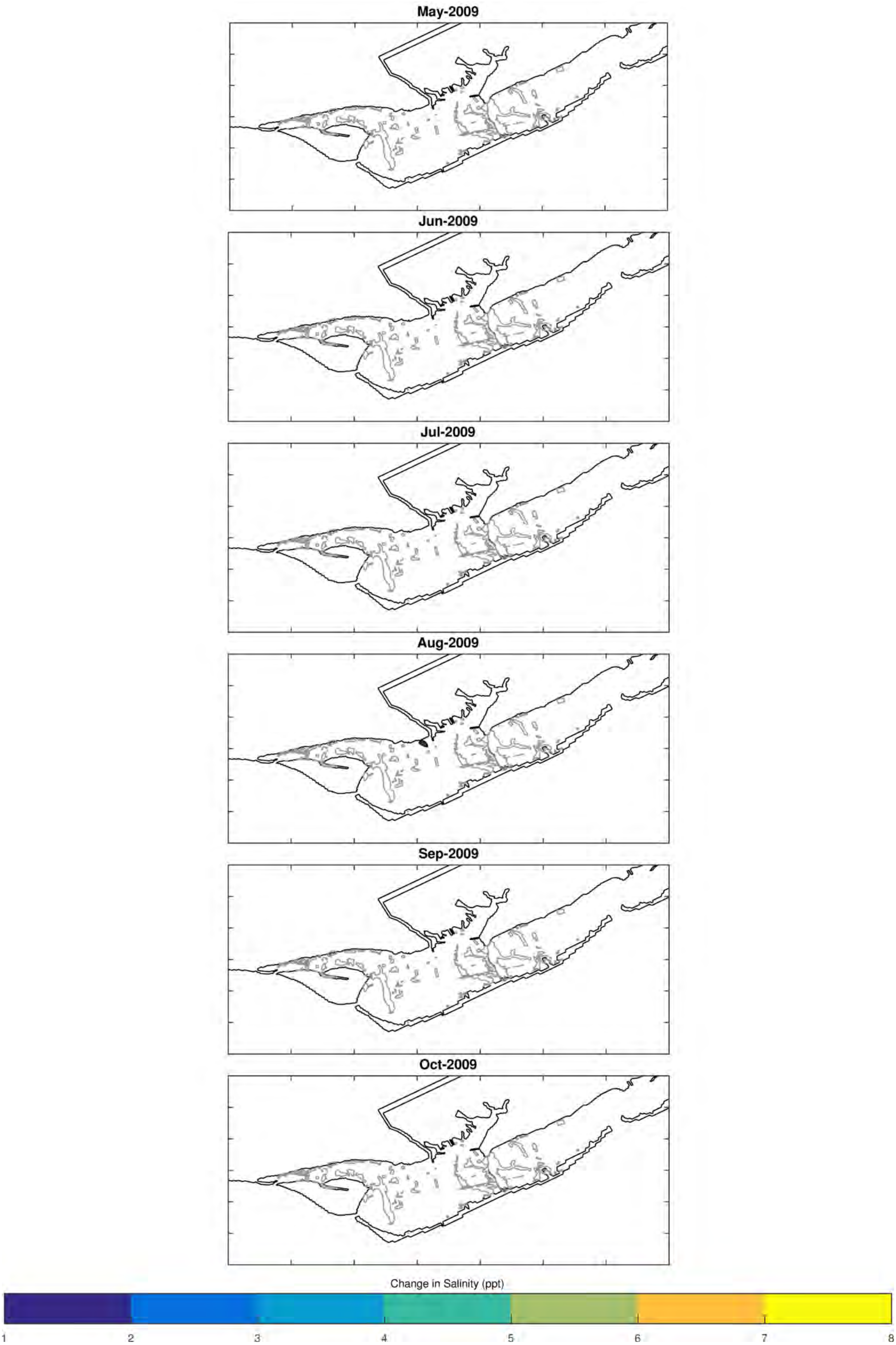

Figure 3-13.
Modeled Average Monthly Bottom Salinity Differences, Observed - Remedy (2009)

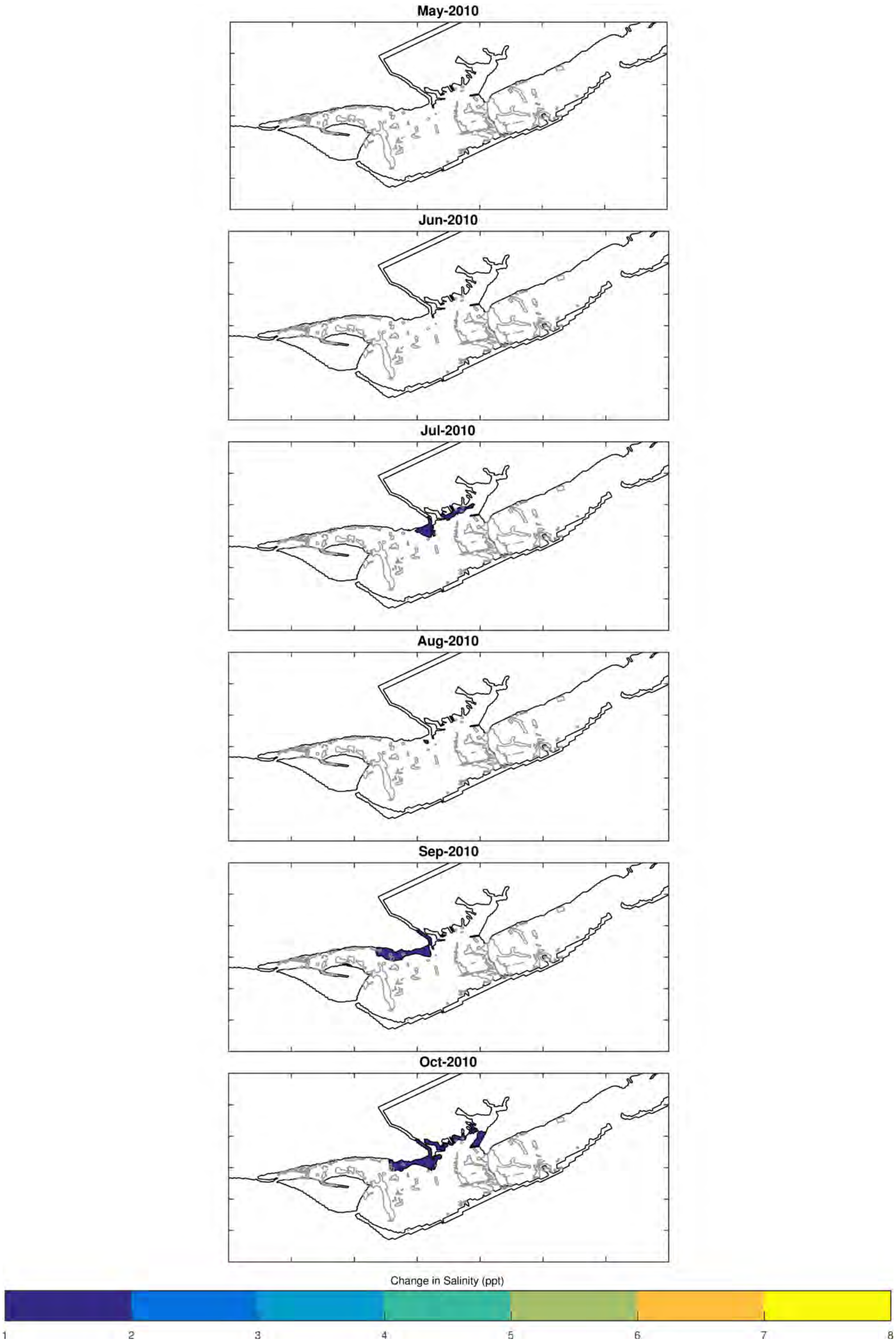

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Figure 3-14.
Modeled Average Monthly Bottom Salinity Differences, Observed - Remedy (2010)

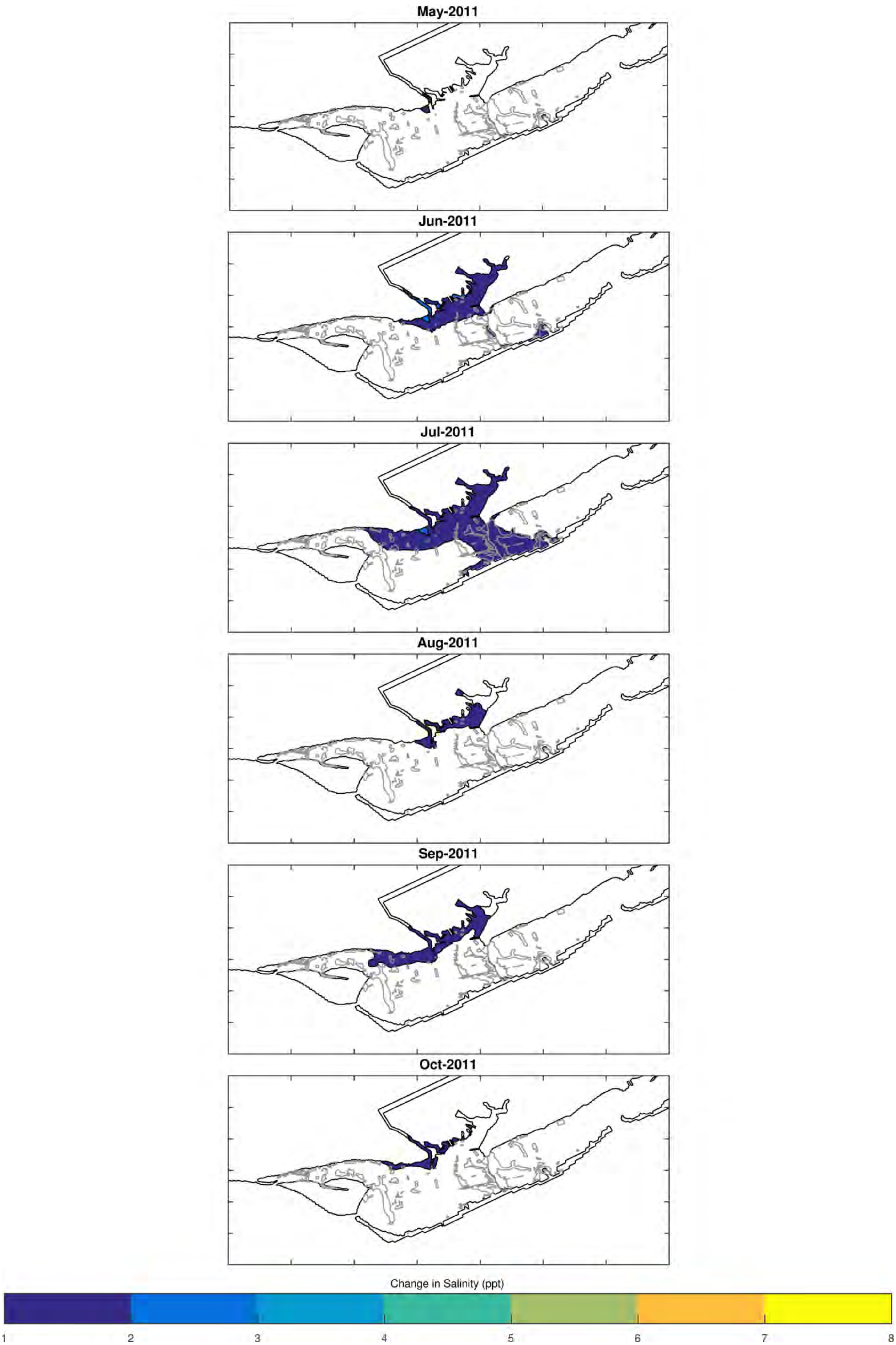

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Figure 3-15.
Modeled Average Monthly Bottom Salinity Differences, Observed - Remedy (2011)

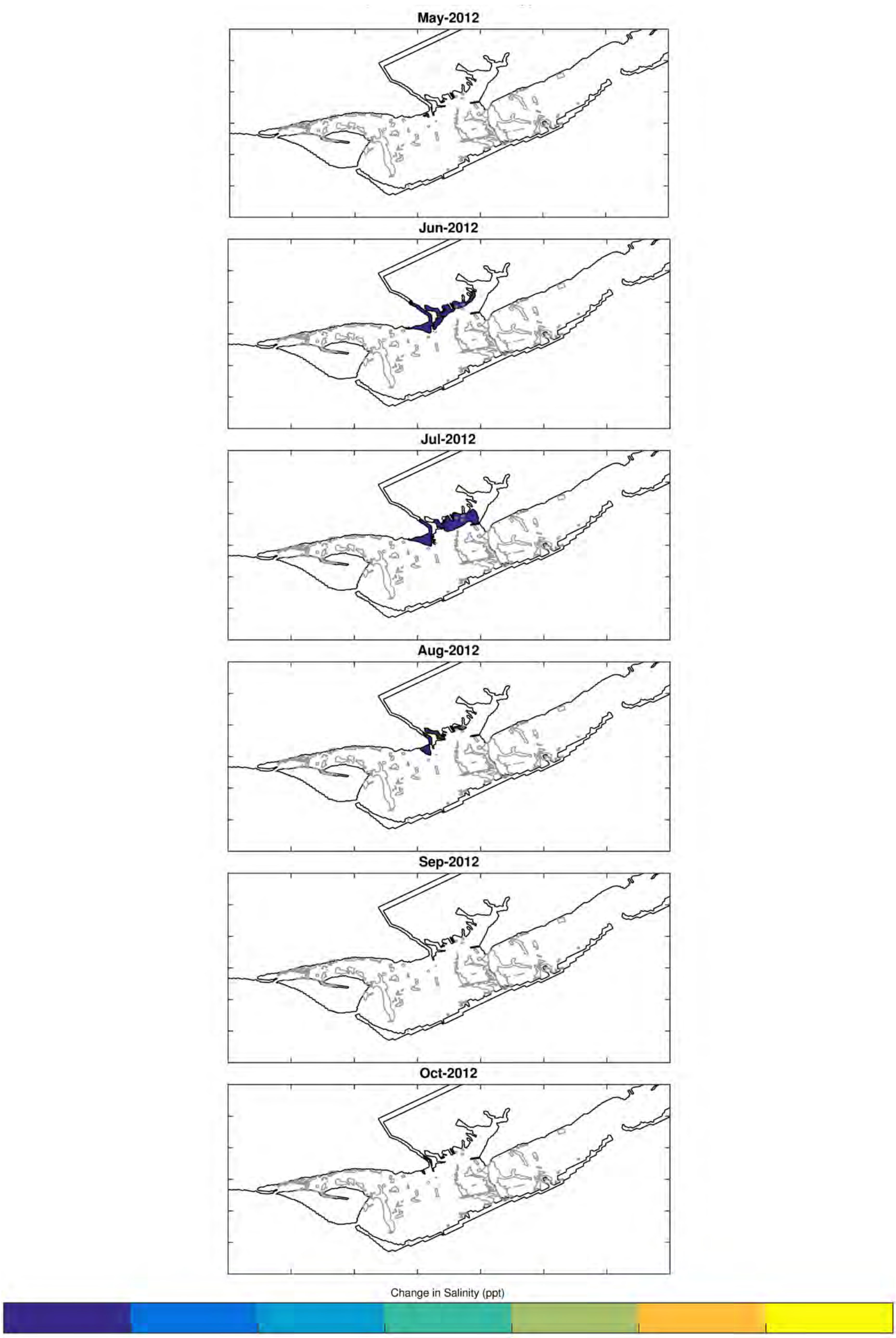

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Figure 3-16.
Modeled Average Monthly Bottom Salinity Differences, Observed - Remedy (2012)

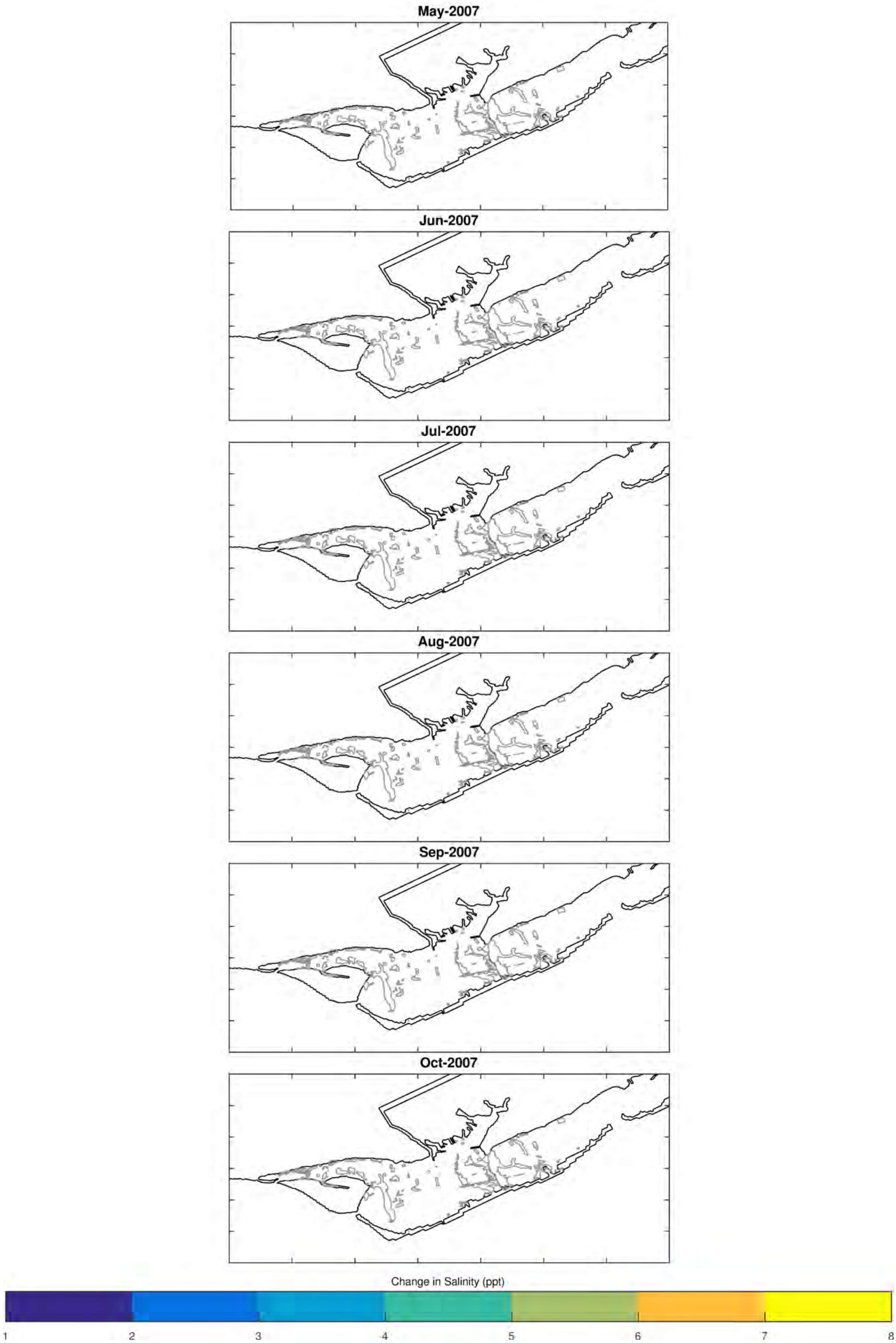

Figure 3-17.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Observed (2007)

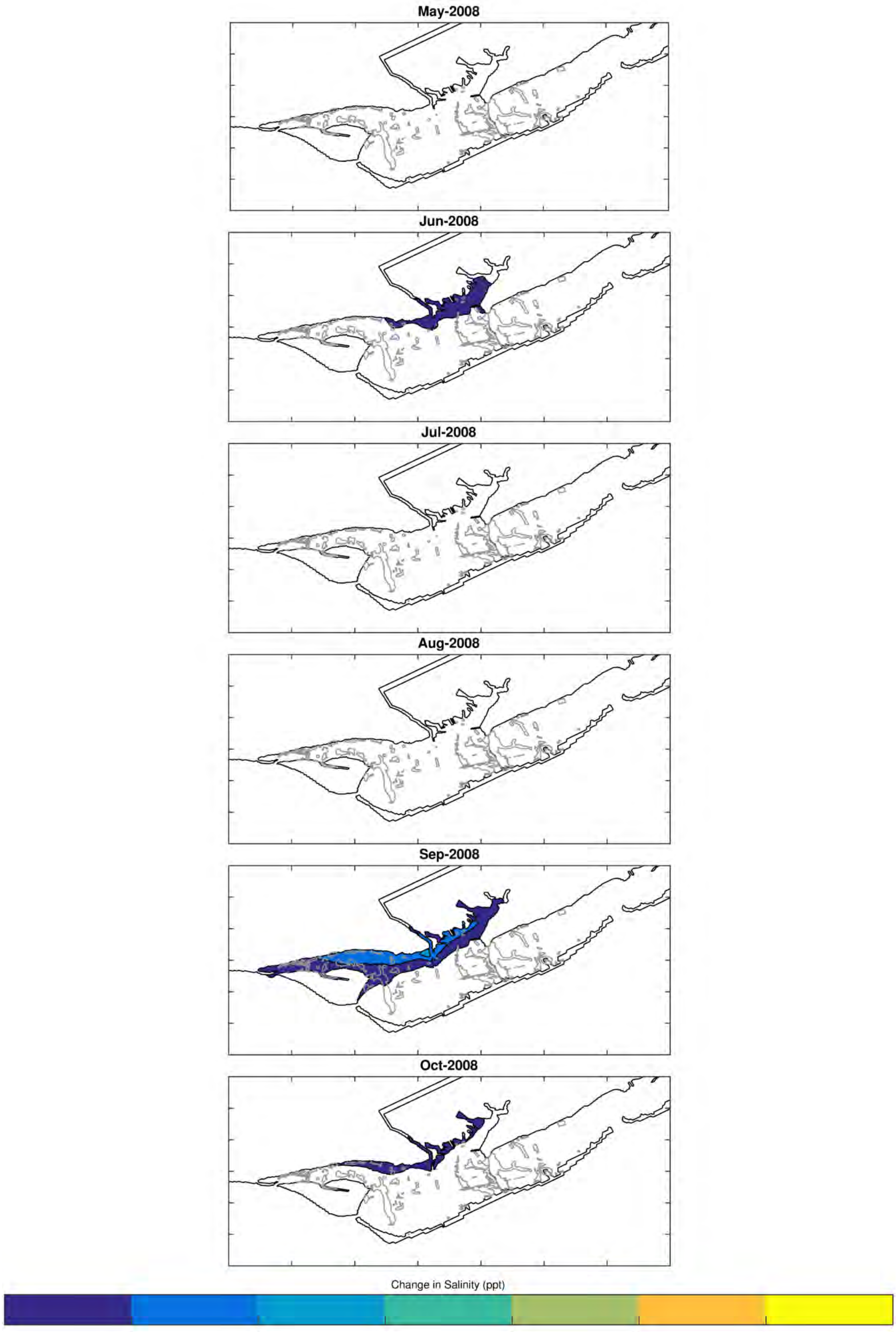

Figure 3-18.
Modeled Average Monthly Bottom Salinity Differences,
Increased Future Withdrawals - Observed (2008)

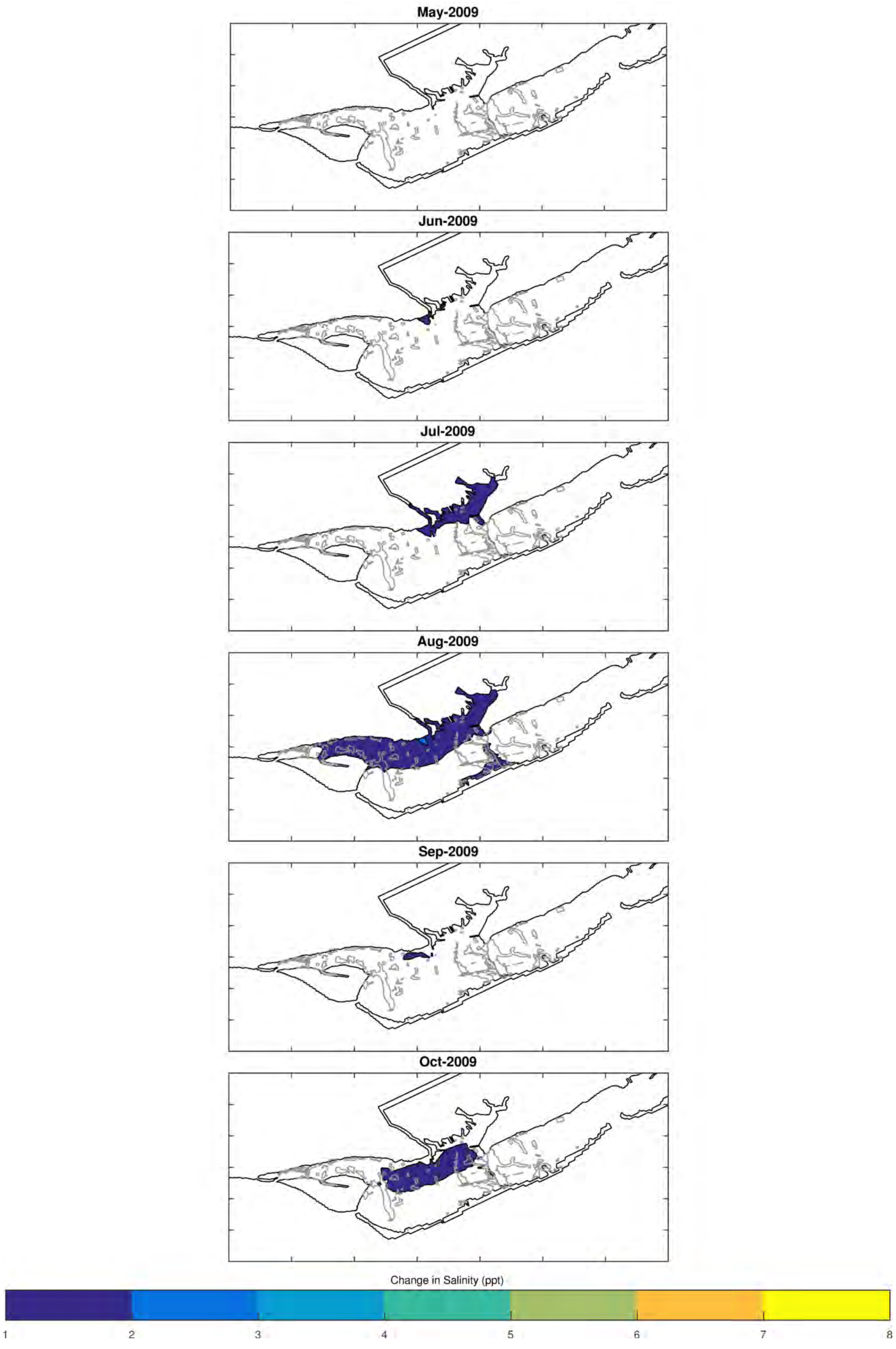

Figure 3-19.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Observed (2009)

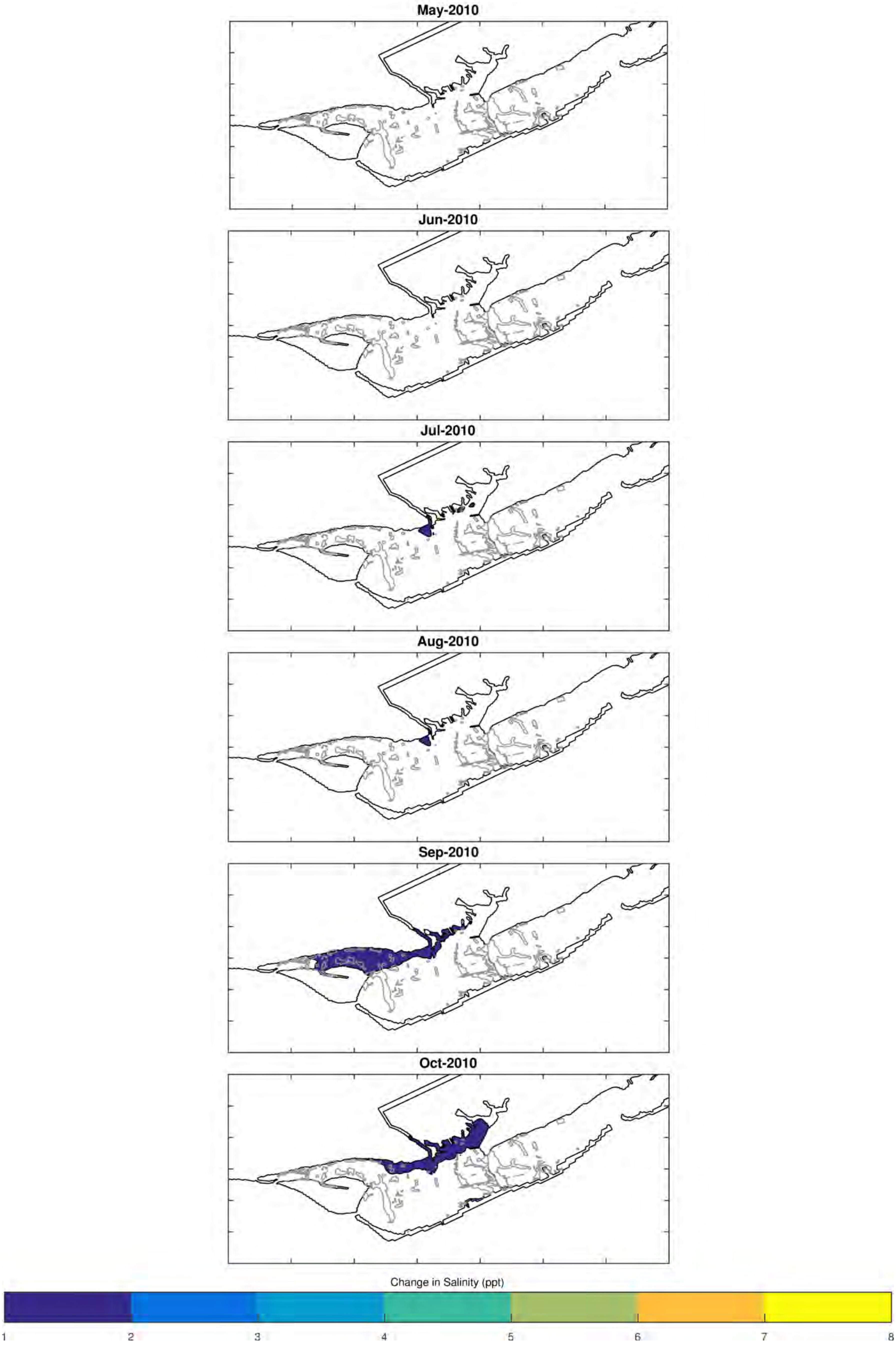

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Figure 3-20.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Observed (2010)

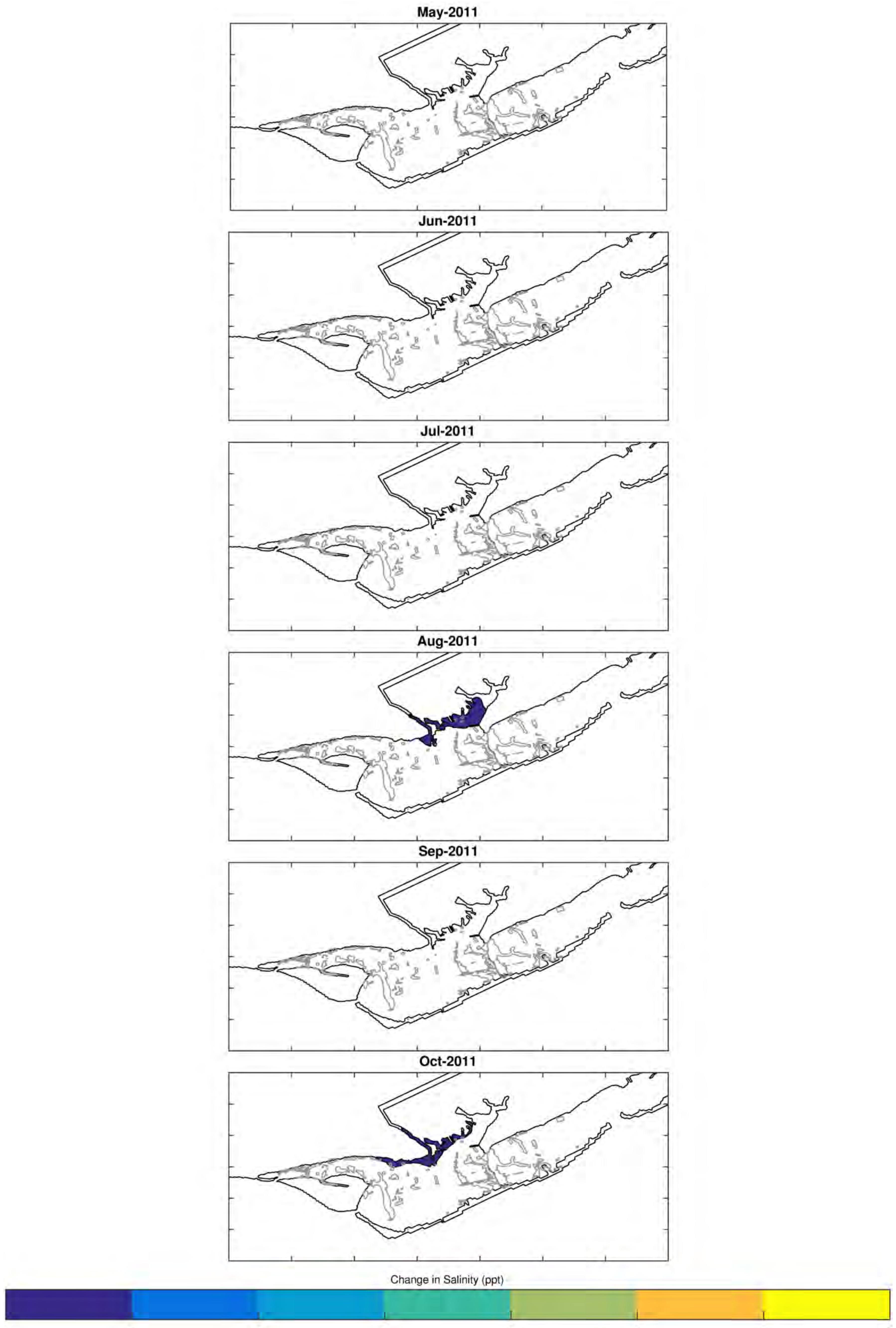

Figure 3-21.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Observed (2011)

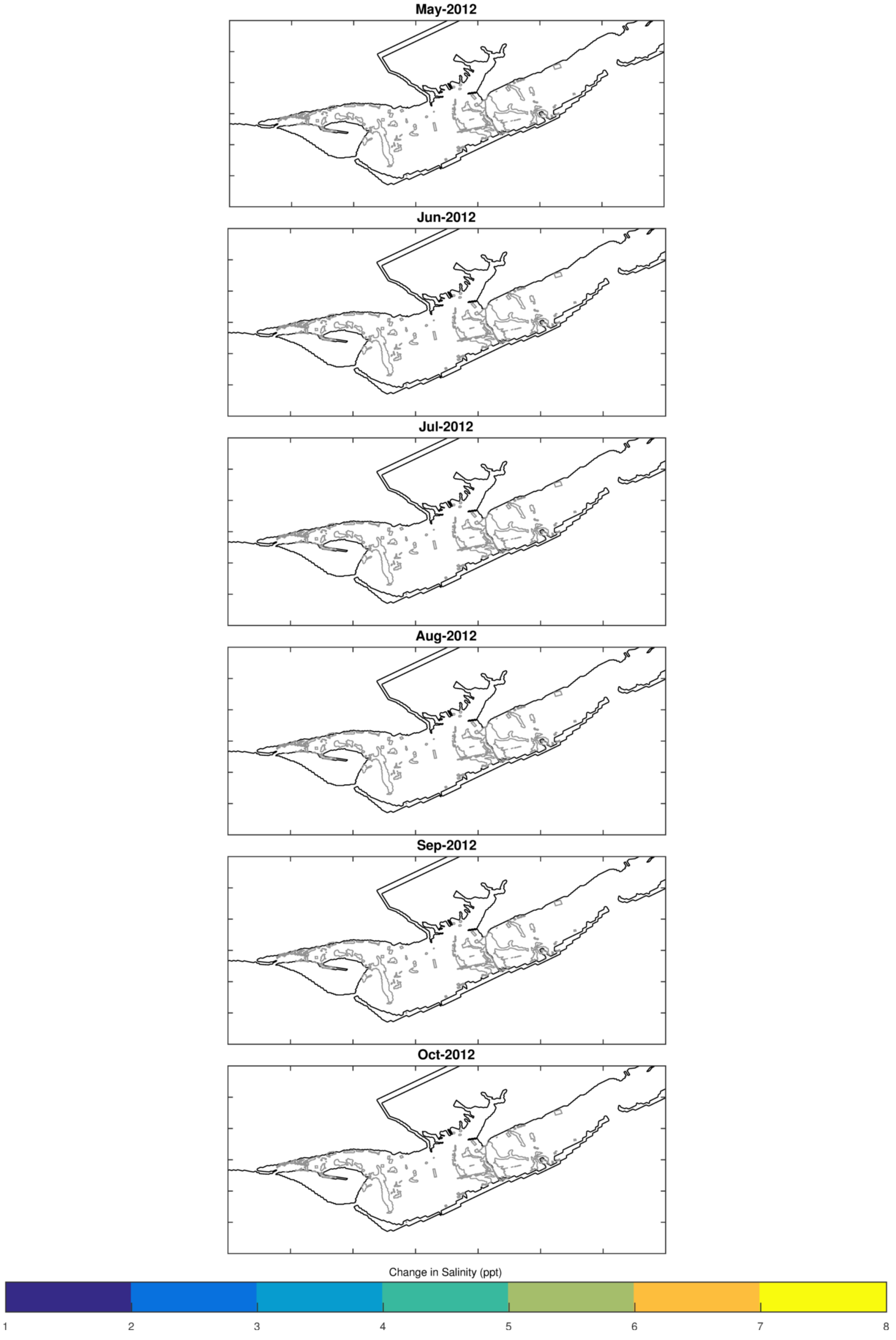

Figure 3-22.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Observed (2012)

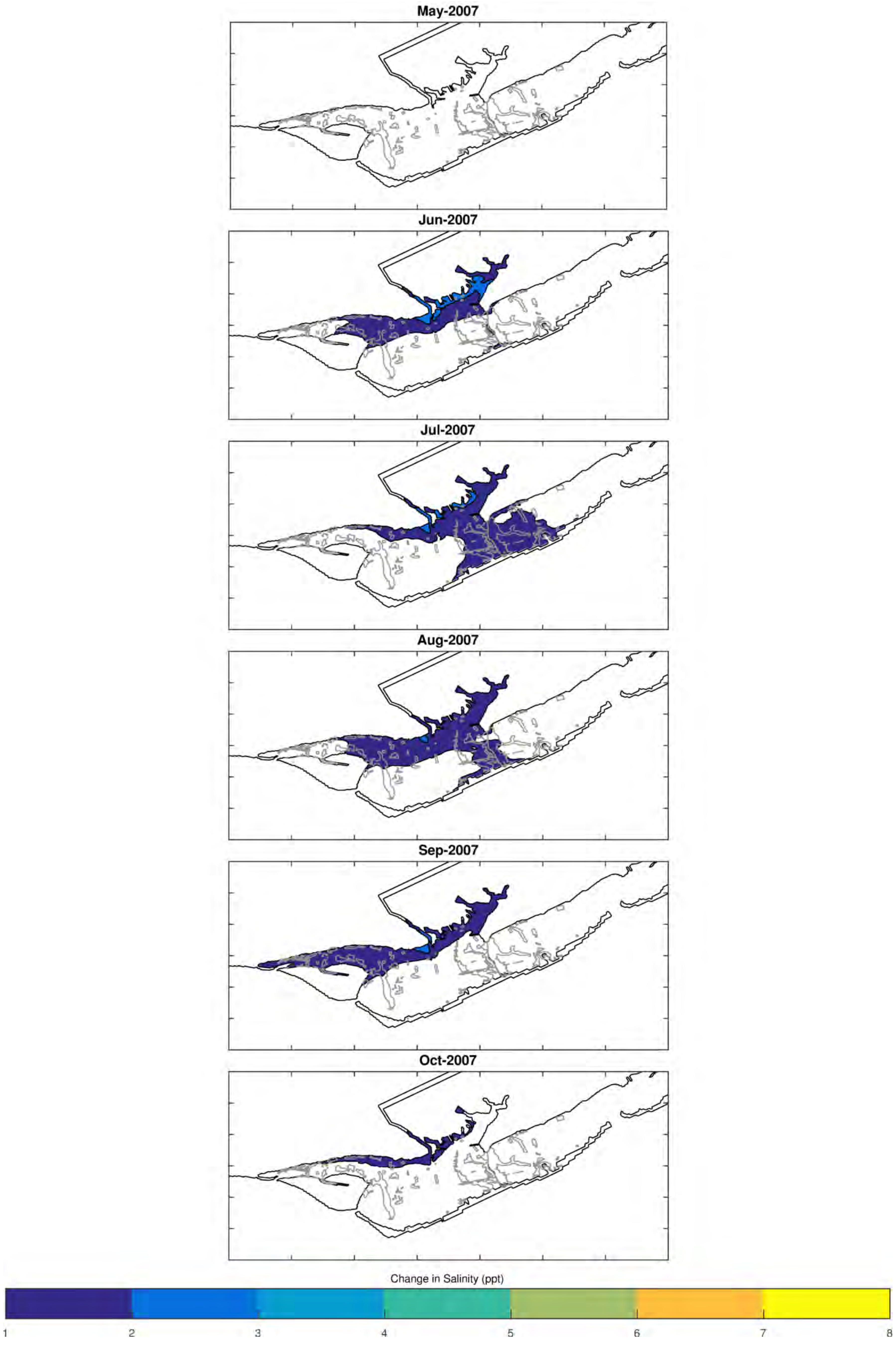

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Figure 3-23.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2007)

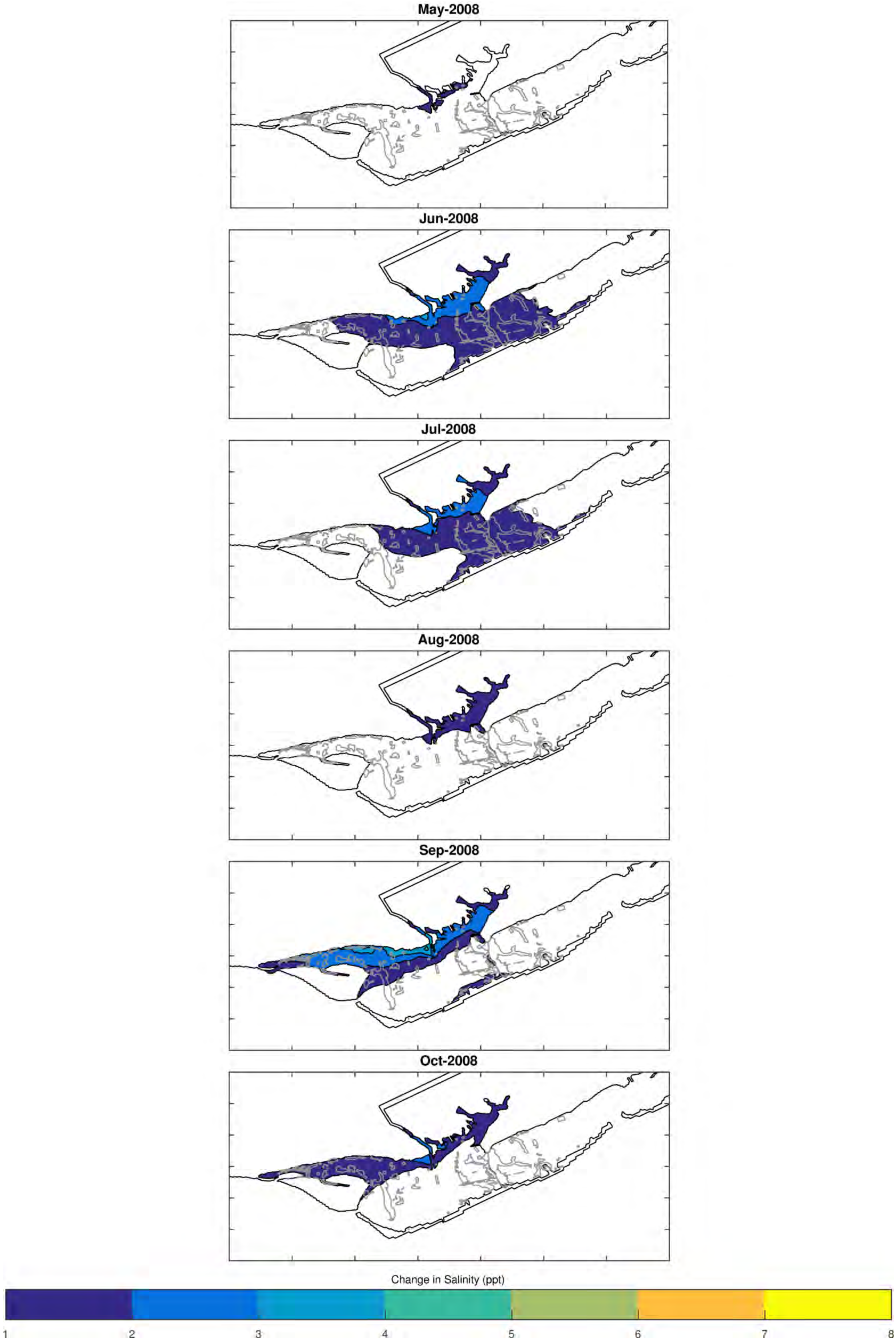

Figure 3-24.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2008)

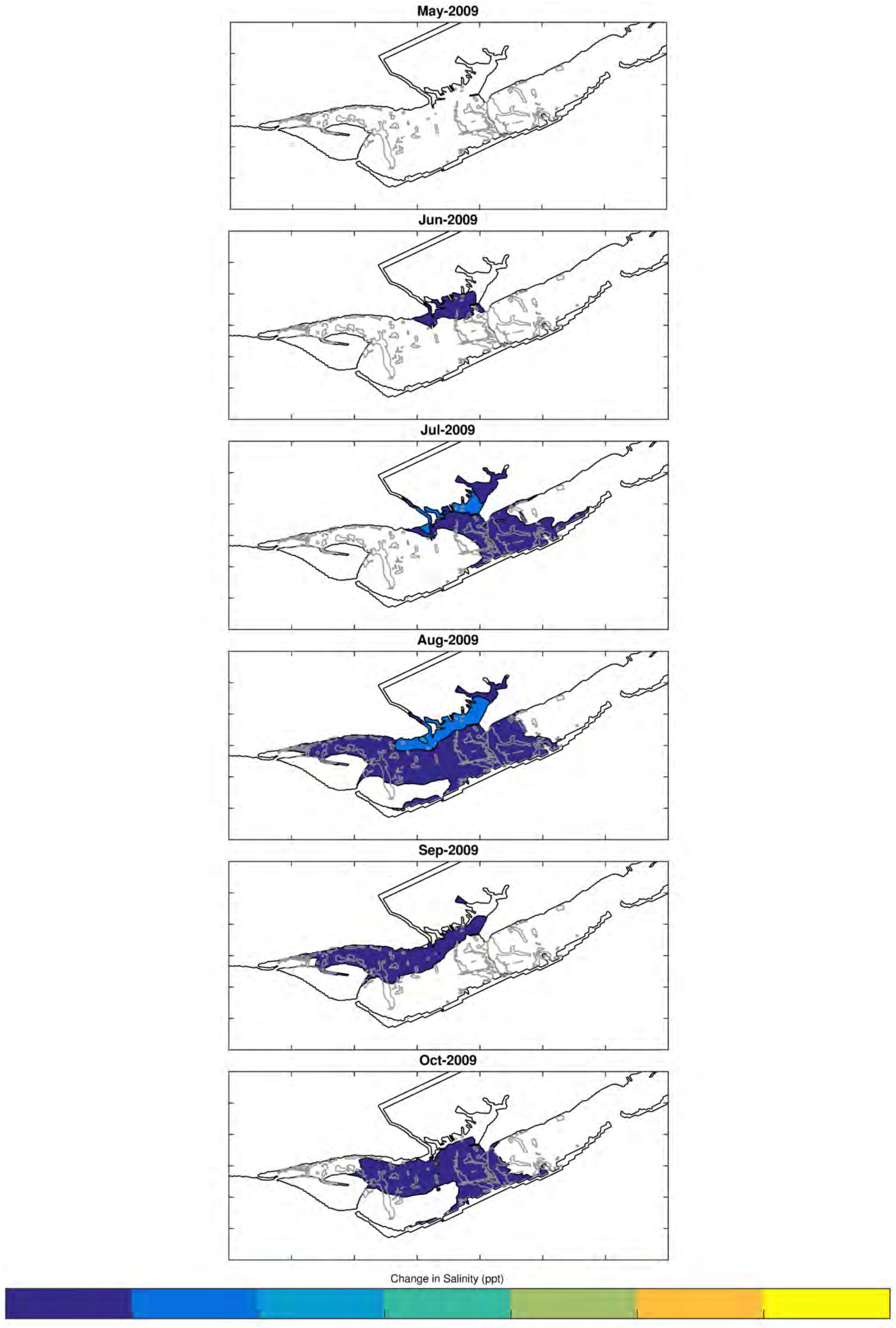

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Figure 3-25.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2009)

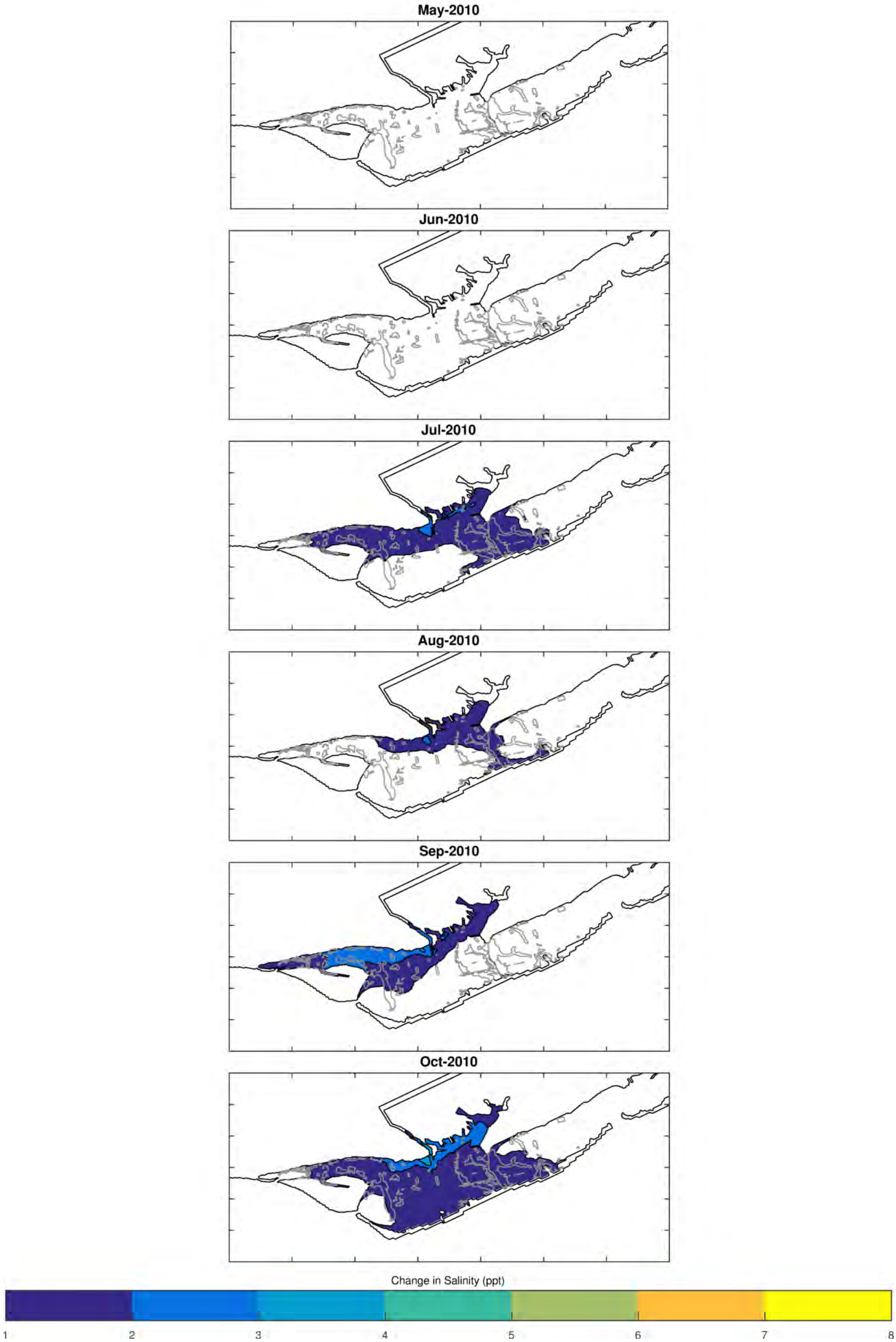

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Figure 3-26.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2010)

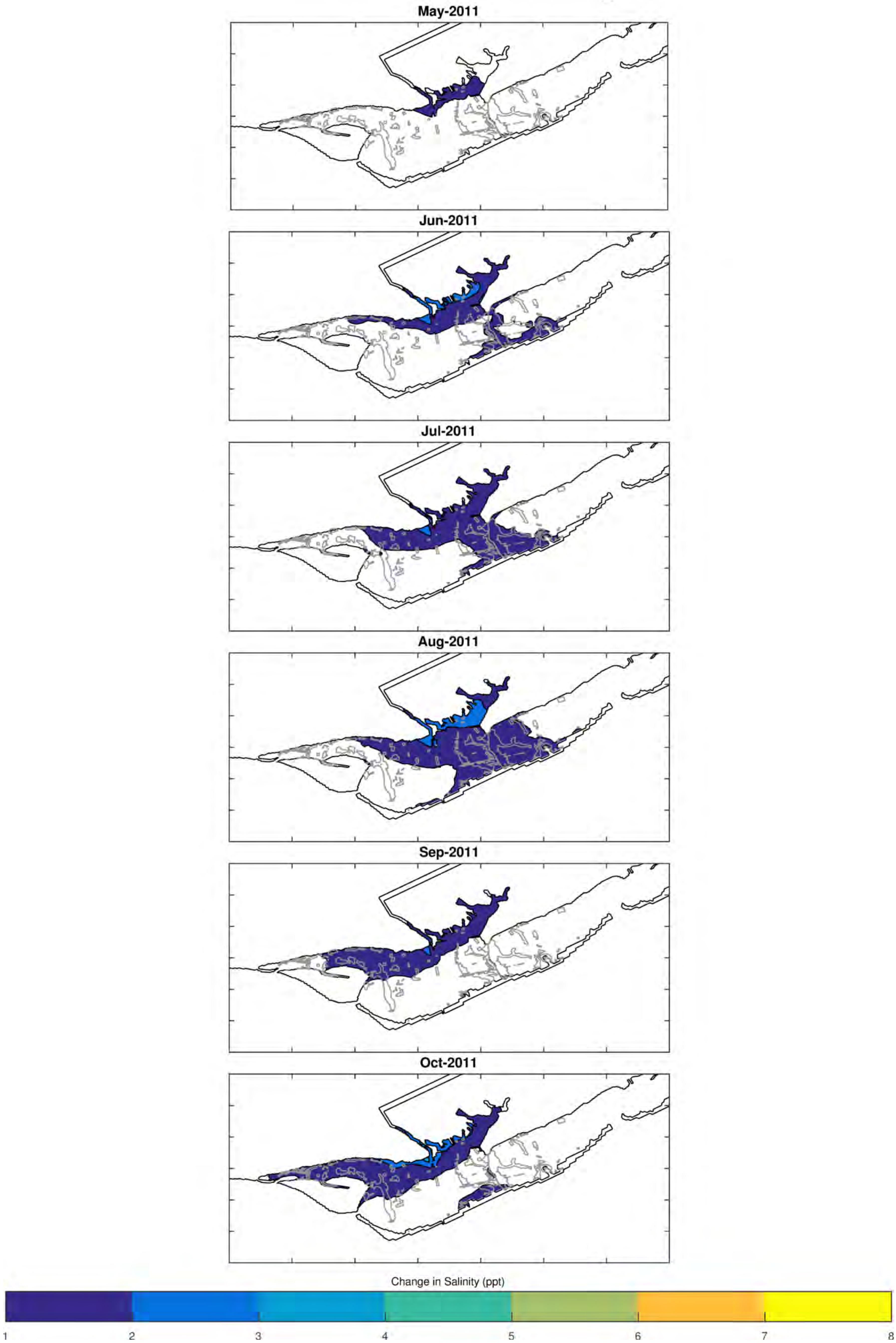

Figure 3-27.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2011)

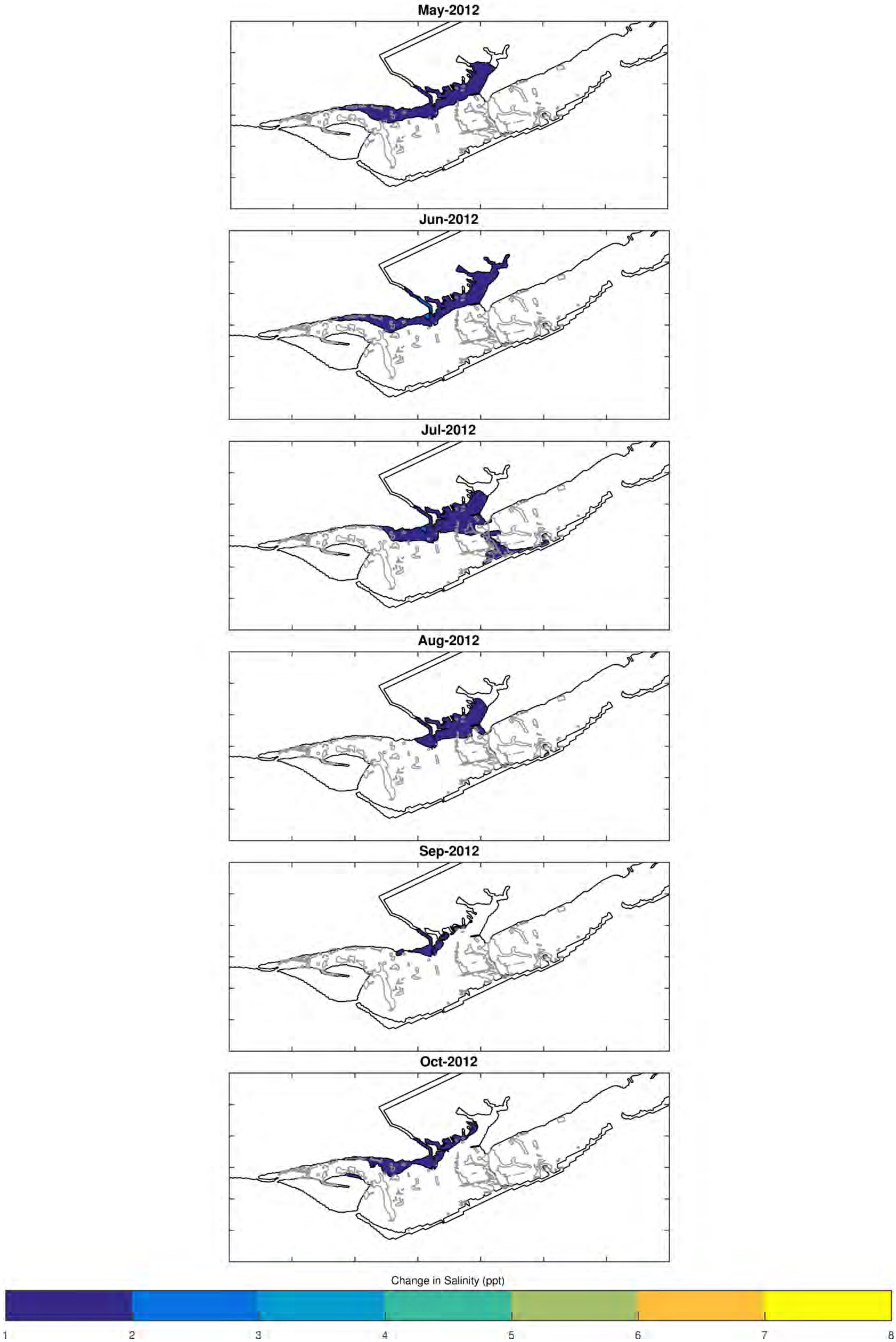

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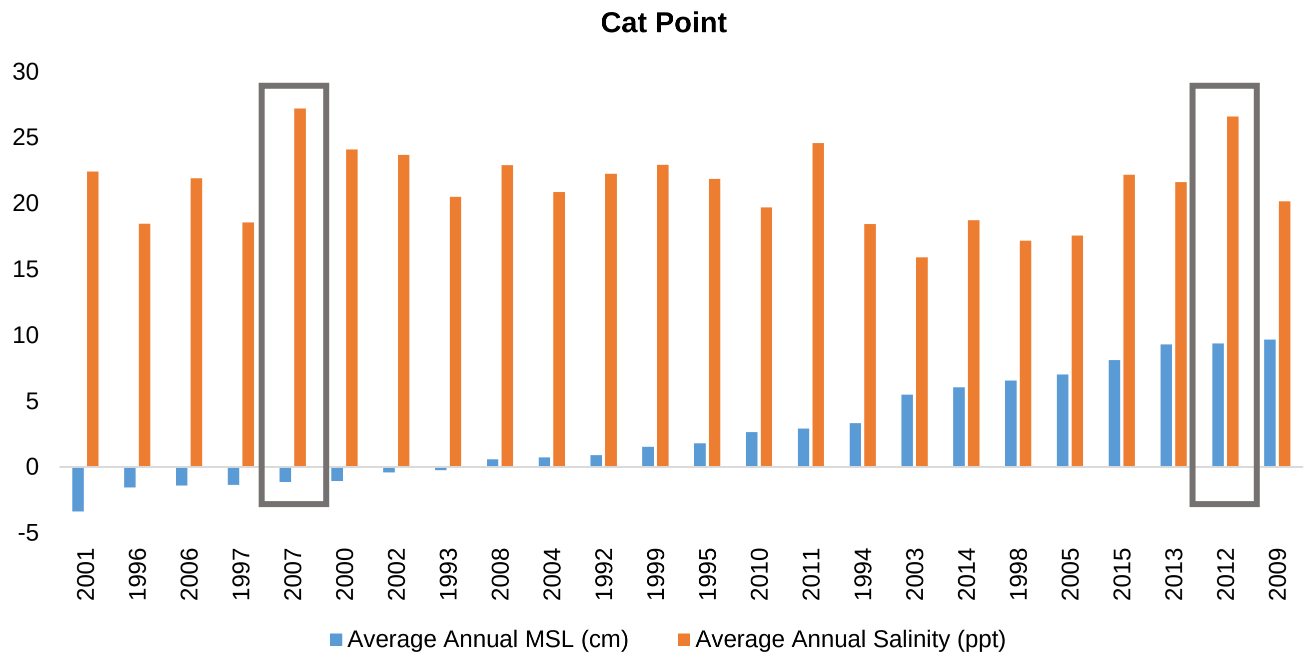
Figure 3-28.
Modeled Average Monthly Bottom Salinity Differences, Increased Future Withdrawals - Remedy (2012)



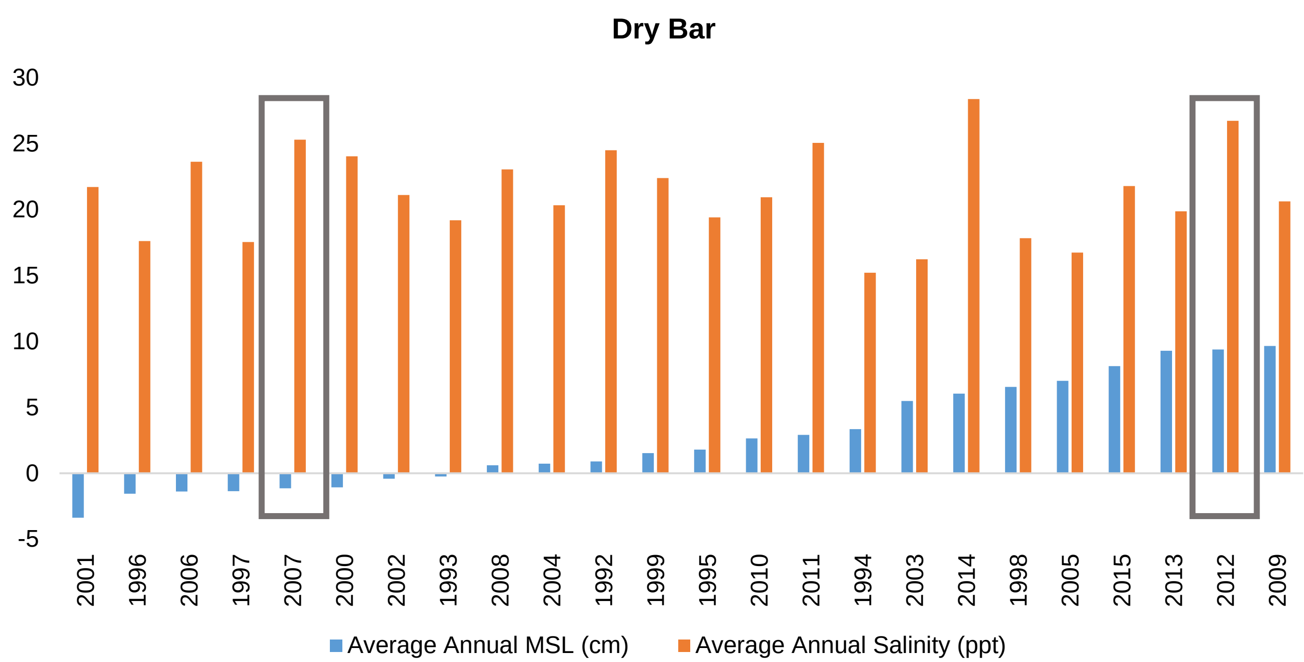


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Figure 4-5.
Annual Average Mean Sea Level and Salinity at Cat Point and Dry Bar