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Supplementary Materials to Article

Salinity and marine mammal dynamics in Barataria Basin: Historic patterns and modeled diversion scenarios – SUPPLEMENTARY MATERIALS

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2.3.1. ICM overview and boundary conditions

There were only 14 monitoring stations which collected flow discharge within the entire ICM domain that were able to be used for model calibration and validation; none of which were within the confines of the Barataria Basin. However, the CRMS network has dozens of water level loggers within Barataria Basin; water level was used as a calibration parameter as a proxy for flow patterns during the calibration procedure. The CRMS stations monitor salinity in addition to water level, so there was a wealth of salinity concentration data for use in model calibration and validation. Water level, salinity, and flow data from the USGS and other data sources were used to supplement the data available from CRMS. Model performance for water surface elevation, flow, and salinity are provided for the calibration and validation periods in Table S1 and

Table S2, respectively. Error terms and model-to-observed comparisons were split into zones of predominant salinity concentrations to provide finer resolution on model performance across the entire salinity gradient that is present in coastal Louisiana.

Table S1. ICM performance statistics for calibration period (2010-2013). From Brown et al. (2017a).

Parameter	units	No. Stns	Mean		Median		Standard Deviation		Root Mean Square Error			
			Obs	*Pred*	*Obs*	*Pred*	*Obs*	*Pred*	*Daily*	*2 weeks*	*Monthly*	*Annual*
Stage	*M*	*204*	0.24	0.24	0.24	0.24	0.17	0.14	0.12	0.10	0.10	0.08
Flow rate	*m^3/s*	*14*	968	1031	911	984	656	684	221	208	124	157
Salinity (0-1 ng/kg)	*ng/kg*	55	0.4	0.6	0.2	0.4	0.4	0.5	0.6	0.6	0.5	0.4
Salinity (1-5 ng/kg)	*ng/kg*	51	2.8	3.0	2.2	2.3	2.1	2.2	2.3	2.1	1.9	1.2
Salinity (5-20 ng/kg)	*ng/kg*	74	11.6	11.0	11.2	10.7	5.0	4.4	4.2	3.7	3.4	1.9
Salinity (>20 ng/kg)	*ng/kg*	4	22.0	22.3	21.8	22.9	6.2	3.9	6.1	5.6	5.4	3.9

Table S2. ICM performance statistics for validation period (2006-2009). From Brown et al. (2017a).

Parameter	units	No. Stns	Mean		Median		Standard Deviation		Root Mean Square Error			
			Obs	*Pred*	*Obs*	*Pred*	*Obs*	*Pred*	*Daily*	*2 weeks*	*Monthly*	*Annual*
Stage	*M*	204	0.24	0.27	0.23	0.26	0.18	0.15	0.14	0.12	0.09	0.07
Flow rate	*m³/s*	14	1088	1163	1042	1112	525	523	229	214	122	151
Salinity (0-1 ng/kg)	*ng/kg*	47	0.4	0.6	0.2	0.4	0.4	0.5	0.7	0.6	0.4	0.4
Salinity (1-5 ng/kg)	*ng/kg*	59	3.3	3.1	2.7	2.7	2.2	1.9	3.0	2.9	2.1	1.8
Salinity (5-20 ng/kg)	*ng/kg*	74	11.3	10.8	10.9	10.8	4.4	3.3	4.6	4.4	3.4	2.6
Salinity (>20 ng/kg)	*ng/kg*	4	21.7	21.7	22.0	22.3	5.4	3.3	6.9	6.3	4.4	3.6

The original model calibration and validation period conducted for the 2017 CMP included simulations from 2006 through the end of 2013 [30], whereas the simulations conducted for this analysis required a 25-year time series from 1990 through the end of 2014. If available, observation data dating to 1990 was retrieved for the same monitoring stations used by Brown et al. [30], and the same rating curves were applied to fill any gaps in observed data. Only one of the five tidal boundary stations used for Gulf water surface elevations had a consistent record of observations dating to 1990. The observed tidal water surface elevations were adjusted for long-term subsidence and gage drift by the repeating the procedure used to develop offshore water surface elevations for the 2017 CMP [32]. Any missing tidal data was filled by utilizing tidal elevation predictions from NOAA following the same procedure used to develop the 2017 CMP future scenario boundary conditions [26]. These tidal predictions do not account for eustatic sea level rise (ESLR); therefore, the tidal predictions were adjusted vertically to account for 0.08 meters of global mean sea level rise that has occurred from 1993 through 2016 [33], a rate of change equal to $3.968x10^{-7}$ meters every hour which was the time step of tidal prediction data.

The model boundary conditions for the 2017 CMP simulations assumed a fixed rating curve for the Davis Pond fresh water diversion, which directs fresh water from the Mississippi River in to the upper portions of Barataria Basin (located on the West Bank of the river across from St. Rose, LA). For this analysis, the rating curve was replaced with either the observed flowrate as monitored and reported by USGS (station 295501090190400), or by a salinity-based operational control logic, which is described in the following sections.

2.3.2. Scenarios analyzed with the ICM

In addition to the hindcast simulation, three scenarios were run assessing the impact of fresh water diversions off the Mississippi River into Barataria Basin under the historic sea level rise rate of (defined by Sweet et al., 2017 as 0.08 m ESLR over the past 25 years). The three fresh water diversion scenarios were all 25-year simulations and included all ICM subroutines (including ICM-LAVegMod and ICM-Morph) in order to assess landscape morphology as a function of assumed sediment diversions and the subsequent impact on salinity dynamics of this changing landscape. The three diversion scenarios using historic rates of ESLR examined:

1. Only the Davis Pond fresh water diversion is activated and is operated on the salinity-based control rules defined in its operational control plan [35]:
   a. During summer months (June through November), 283 cubic meters per second, cms, (10,000 cubic feet per second, cfs) of river flow is diverted if salinity in Little Lake at the Bay Dos Gris gage location (USGS station 292800090060000) is greater than 5 ng/kg. In actual operations, the diversion is dynamically controlled to attempt to maintain a consistent salinity level. However, this level of detail was not implementable in the model code and the diversion remains open until the salinity at the station drops below 1 ng/kg.
   b. During winter months (December through May), 283 cms (10,000 cfs) of river flow is diverted if salinity in Barataria Bay near the Grand Terre gage location (USGS station 291929089562600) is greater than 15 ng/kg. The model keeps the diversion open until the salinity at the station drops below 10 ng/kg.
2. Both the Davis Pond fresh water diversion and the Mid-Barataria sediment diversion were activated. The Davis Pond diversion used the same operational control as above, and the Mid-Barataria diversion utilized an operational regime optimized to maximize the sediment-to-water ratio in diverted flows (e.g. get the most sediment with the least amount of water). This optimized control rule is similar to the rule modeled for the 2017 CMP, but with different flow threshold triggers. In this analysis, the Mid-Barataria diversion is first activated when the Mississippi River is flowing at 12,743 cms (450,000 cfs). The diverted flowrate increases linearly from zero at activation to a diverted flowrate of 2,124 cms (75,000 cfs) when the river is at or above 28,317 cms (1,000,000 cfs).
3. The final scenario tested under historic sea level rise rates was a simulation where neither Mid-Barataria sediment diversion nor Davis Pond fresh water diversion was activated. This scenario was included to provide an analysis of the relative impacts on salinity in Barataria Basin by the proposed Mid-Barataria sediment diversion and the actual Davis Pond fresh water diversion as it is permitted to be operated.

All three historic sea level rise rate scenarios tested assumed the 20^{th} percentile subsidence rate across the coastal zone as defined in [26] and [36]. Rates for total subsidence including both deep and shallow processes are difficult to quantitatively measure, and the 20^{th} percentile rates were used for historic scenarios to remain consistent with the assumed subsidence rates used during model calibration and validation efforts undertaken for the 2017 CMP [30]. While future scenarios of ESLR include varying rates of exponential acceleration (which increase, by definition) in later decades, the historic rates simulated in these three scenarios did not include any acceleration term. Under exponentially increasing sea level rise scenario simulations, the baseline salinity within the estuary increased substantially from present-day values [37, 45]. Such a scenario, if simulated here, would potentially dampen any freshening impact that may be the result of freshwater and sediment diversions; therefore, to assess sensitivity of Barataria to freshwater inputs under a conservatively low salinity condition, the historic rates of sea level rise were chosen for these three scenarios.

To contrast these three conservative scenarios (e.g. larger freshening impact of diversions under lower ESLR), a final scenario was tested which included the operation of both Mid-Barataria and Davis Pond (with the same operational rules described above), but assessing the salinity response if higher rates of both ESLR and subsidence are to be realized over the next 25 years. To test this sensitivity to higher relative sea level rise (RSLR) rates which combined both subsidence and ESLR, the High Scenario from the 2017 CMP analysis was used. This scenario assumes higher rates of subsidence (50^{th} percentile values) and a ESLR rate of 0.33 meters over 25 years, which due to an acceleration term equates to 0.83 meters over the 50-year planning horizon used for the 2017 CMP, and 2.0 meters by the end of the 21^{st} century [26]. This final scenario simulated was compared directly to the High Scenario Future Without Action model output developed for the 2017 CMP analysis [37, 45].

2.3.3. Delft3D overview and boundary conditions

In order to generate the bathymetry and topography, multibeam and LIDAR data collected and provided by the USACE, the USGS, and the Institute have been used. The cell averaging method was used to generate the bathymetry starting from raw data. Specific attention was given in order to well capture the fine-scale structures, to correctly representing the wetland areas and to ensure that all channels were hydrologically connected.

The boundaries of the model include the Mississippi River inflow, other smaller tributaries, the Gulf of Mexico (tide and salinity boundaries), and the atmospheric boundaries (i.e., wind field, rainfall, etc.).

For the Mississippi River inflow boundary, daily average discharge provided by USGS at the Baton Rouge station was used. Also, for the other fresh water inflows USGS discharge data were used. These include Bonnet Carré (if open), Caernarvon and Davis Pond fresh water diversions, Amite, Tickfaw, Natalbany, Tangipahoa, Tchefuncte, Pearl, Pascagoula, and Mobile rivers. For Lac Des Allemandes and the GIWW at Bayou Lafourche boundaries, model output provided by the ICM (refer to section **Error! Reference source not found.**) were used as boundaries.

The Gulf of Mexico boundary (**Error! Reference source not found.**) extends from south of ouma, La., to east of Pensacola, Fla. Astronomical tidal boundary conditions have been used. They are based on the TOPEX/Poseidon Global database. For salinity, monthly average values have been set. This profile varies between 34 and 36.5 ng/kg and it had been generated from historical data from the National Oceanographic Data Center Ocean Archive System (http://www.nodc.noaa.gov/cgi-bin/OC5/GOMclimatology/gomregcl.pl). Additional information can be found in [39].

Spatially variable wind, air temperature, relative humidity, cloud coverage, solar radiation and rainfall have also been included into the model. A spatial field of 5 km x 5 km was prepared from these data to force the model. They have been extracted from the National Oceanic and Atmospheric Administration NOAA available database (NOAA-National Climatic Data Center, NOAA Earth System Research Laboratory Physical Sciences Division, and NOAA-based STAGE III River Forecast Center Operational NEXRAD database) [39].

3. Results

3.1

3.2.1. ICM results – hindcast period

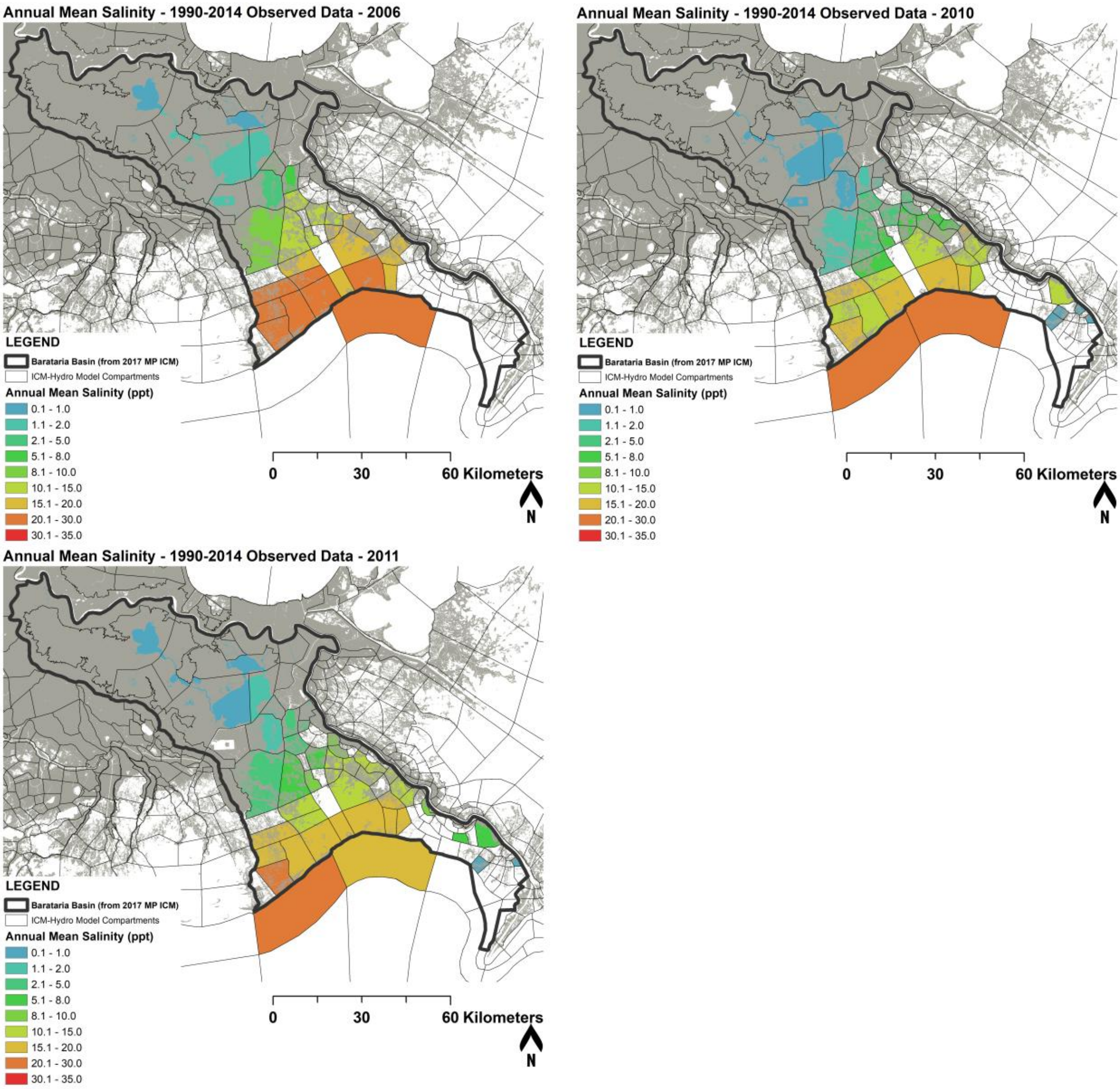

Figure S1. Observed mean annual salinity averaged across ICM-Hydro model compartments for a low river year (2006 - lop left), an average river year (2010 - top right), and a high river year (2011 - bottom left).

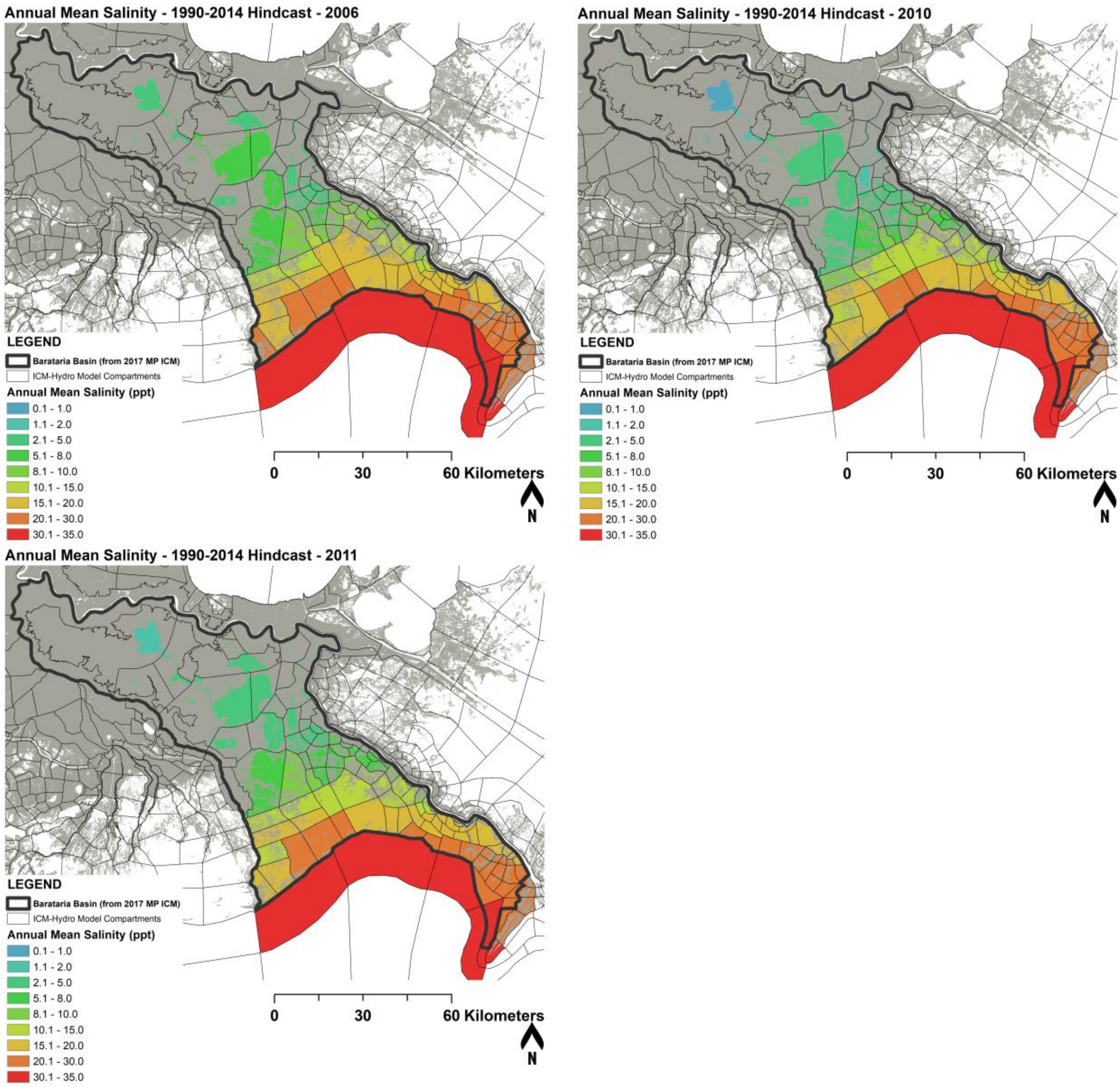

Figure S2. Hindcast model-predicted mean annual salinity for a low river year (2006 - lop left), an average river year (2010 - top right), and a high river year (2011 - bottom left).

3.2.2. ICM results – impact of diversions under various future conditions and operational regimes

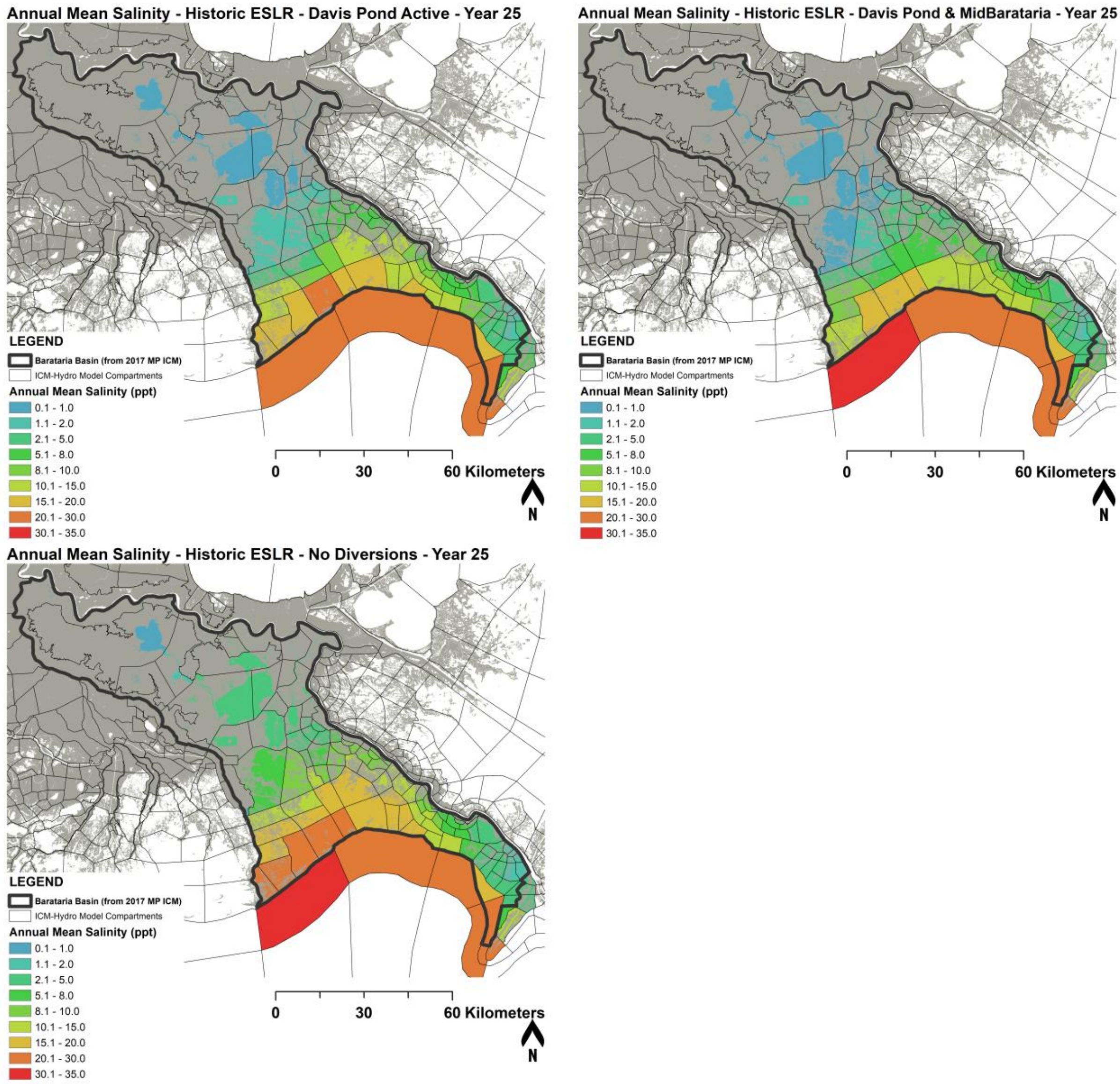

Figure S3. Model-predicted mean annual salinity under historic sea level rise rates during year 25 for with only Davis Pond diversion active (top left), with both Davis Pond and Mid-Barataria diversions active (top right), and without any diversions active (bottom left).

3.2.1. Delft3D results

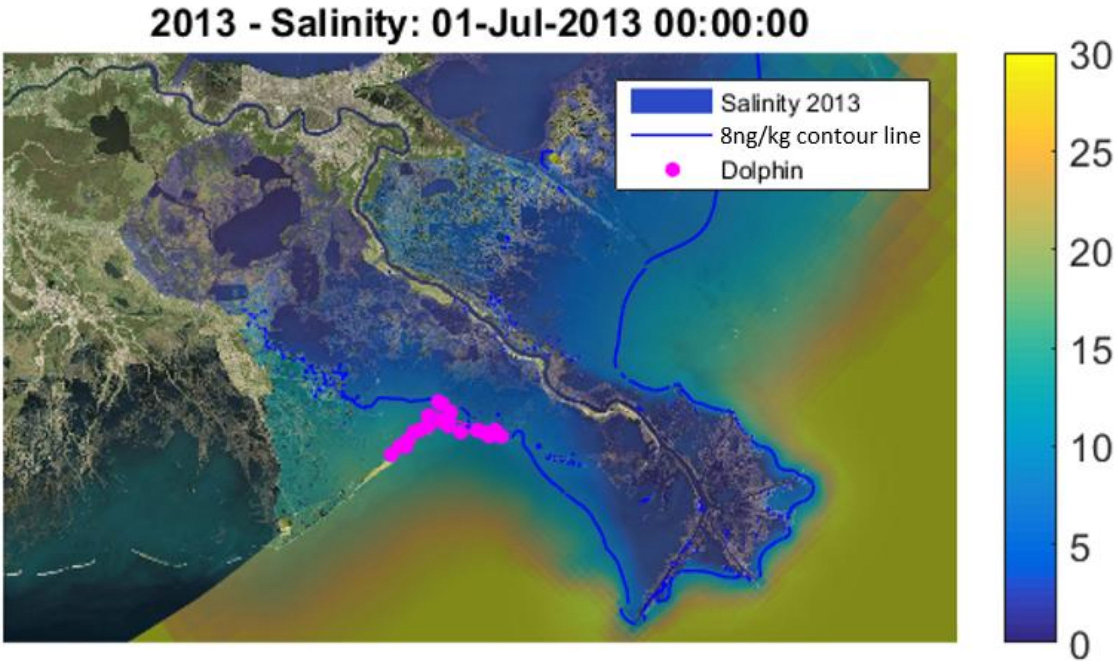

Figure S4. Basin wide salinity model output (ng/kg) and dolphin locations (pink dots). Example for 2013 simulation.

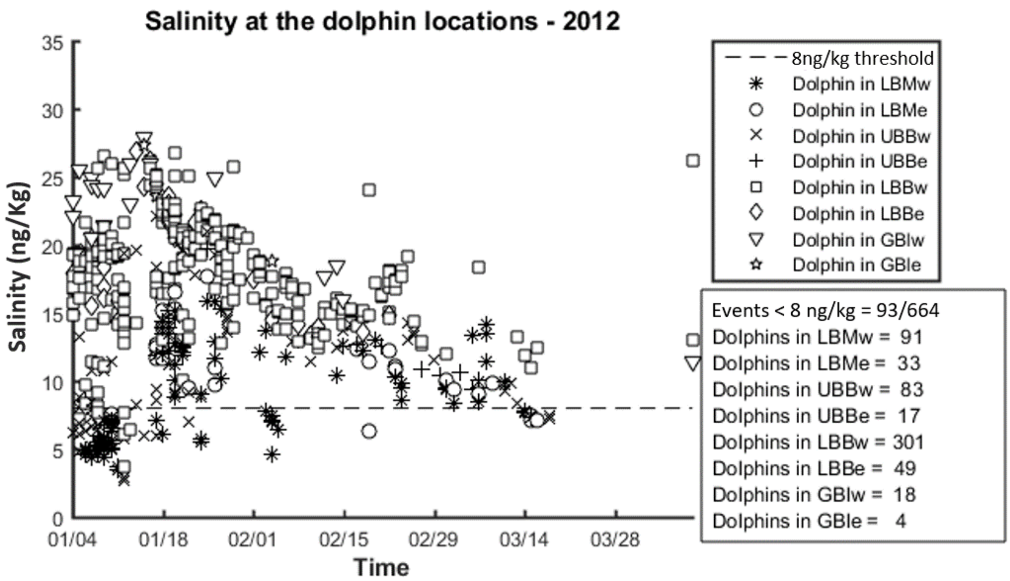

Figure S5. 2012 basin wide salinity model output and dolphin locations over time.

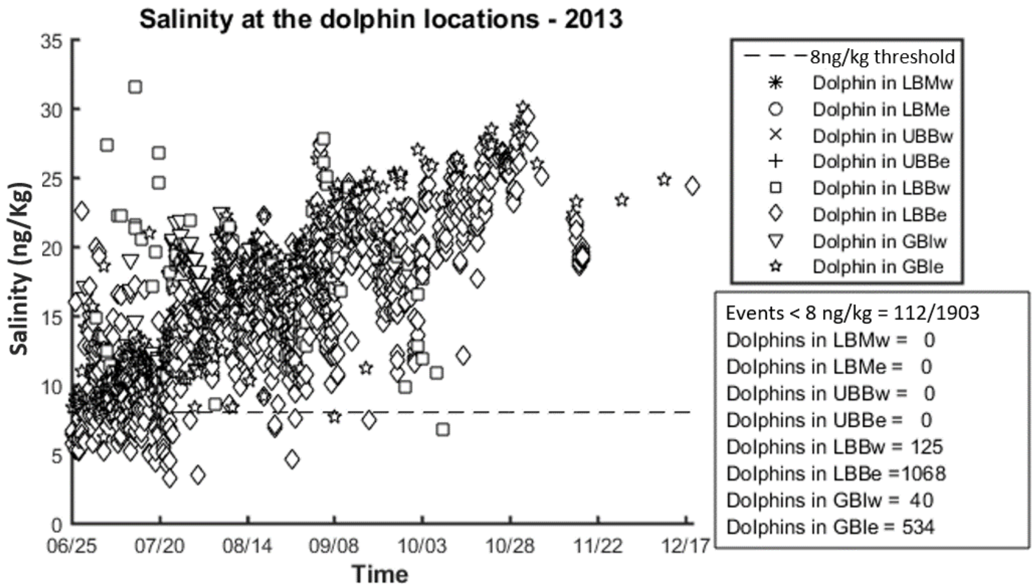

Figure S6. 2013 basin wide salinity model output and dolphin locations over time.

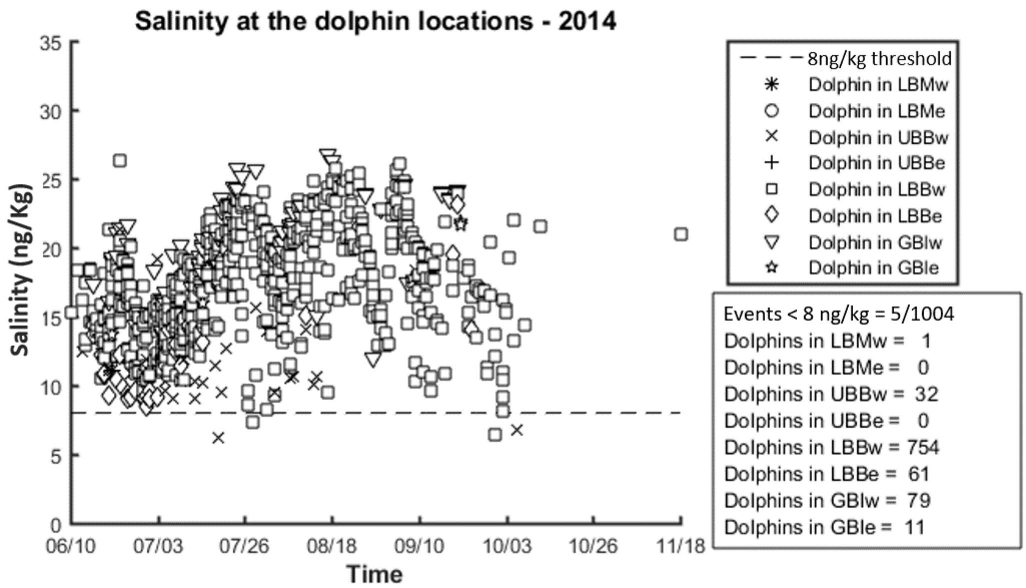

Figure S7. 2014 basin wide salinity model output and dolphin locations over time.