2016 oyster habitat evaluation using hydrocoast salinity data and two approaches to suitability analysis in the Pontchartrain Basin, SE Louisiana

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Front Cover: Oyster boat in-transit with cultch barge in the Biloxi Marsh. Photograph courtesy of Pat Quigley – Gulf Coast Air Photo.
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Executive Summary

*Crassostrea virginica* (eastern oysters, hereafter referred to simply as oysters) are bivalves that are found in estuarine water from the Canadian Maritime provinces along the western Atlantic coast to Brazil (Préau et al., 2016 & references therein). Oysters are have been commercially harvested in the Pontchartrain Basin of southeastern Louisiana since the middle nineteenth century. Due to their commercial and cultural significance, it is of benefit to understand habitat and production suitability dynamics through time and across the basin. One of the most productive areas for oyster is the Biloxi Marsh, which is a Pontchartrain Basin coastal line of defense against storm surge from tropical systems (Lopez, 2006). It is of tremendous importance, therefore, to sustain this oyster habitat to help maintain the integrity of the Biloxi Marsh in the future.

Lake Pontchartrain Basin Foundation (LPBF) scientists have studied oyster habitat suitability, on the basis of surface salinity throughout the Pontchartrain Basin. The results of the first analysis were released in a 2016 technical report. The report, by Préau et al, entitled “Oyster habitat evaluation using hydrocoast salinity data and two approaches to suitability analysis in the Pontchartrain Basin, SE Louisiana” is available on LPBF’s website. The 2016 report examined oyster habitat suitability from 2013-2015 using surface salinity data generated for LPBF’s bi-weekly hydrocoast surface salinity maps. This document serves as an addendum to the results of the previous report and evaluates hydrocoast surface salinity data from 2016. Primarily, this work replicates many of the analyses of the previous report; however some additional analyses are included that were not performed in Préau et al. (2016).

The primary objective of this work is to continue the analysis of surface salinity data for oyster habitat and production suitability within the Pontchartrain Basin. At the writing of this document, LPBF has a repository of 4 complete years (2013-2016) of surface salinity data to utilize. The theoretical framework for the work done here was developed by Mark Chatry and Thomas Soniat. The Chatry Optimal Oyster Salinity (COOS) method is an empirical method that identifies the optimal salinity regime for each calendar month. The Soniat Optimal Oyster Salinity (SOOS) method uses four parameters that characterize substrate and salinity regime. The values used in the parameters are based on theoretical and field validated values.

The results of the analyses do not vary significantly from the previous report. Overall, the most suitable areas using the COOS and SOOS methodologies in 2016 are largely coincident with one another. As with previous years, the most suitable areas as reflected by the COOS method is located farther west than the SOOS method, which is reflected in Figs. 5-10. To quantify how much COOS varies from SOOS year to year, a new analysis is introduced which is not in the original report. This analysis tracks the outlines of the most suitable areas for oysters and the centroids of those polygons (Figs. 11 & 12). In the years 2013-2015 the most suitable areas moved northwestward between 6 miles (COOS method) and10 miles (SOOS method). In 2016, the most suitable areas moved southeastward 8.5 miles (COOS) and 9.6 miles (SOOS) from where they were in 2015. The overall movement of suitable areas cannot be attributed to a
single cause. However, some of the observed migration in suitable areas from 2015 to 2016, may be influenced by the opening of the Bonnet Carré Spillway and riverine flooding within the Pontchartrain Basin.

Places where hypoxia was observed in 2016 are added to the existing dataset (2008-2015). An update to the hypoxia map shows expanded areas of ‘frequent’ and ‘occasional’ hypoxia. Here, frequent refers to hypoxia that was observed more than 50% of the time in the area surveyed. Occasional hypoxia means the area was found to be hypoxic less than half the time it was surveyed. The most significant finding is that areas of frequently observed hypoxia in Chandeleur and Breton Sounds have now been shown, definitively, to contiguous for the first time in 2016 (Fig. 13).

The final analysis that is included here is oyster boat density within the Pontchartrain Basin (Figs. 14 & 15). A total of 10 aerial surveys were conducted throughout 2016, during which the number of actively harvesting oyster boats were counted. The count and locations of the boats was compiled and a density map was generated. Figure 14 showing the results of this analysis, along with various features such as the Louisiana public seed grounds and cultch plants, as well as oyster harvesting grounds in Mississippi. Essentially, the oyster boat density map shows that harvesting takes place in what are generally considered to be ‘suitable’ areas according to both the COOS and SOOS methods. Additionally, this data not only show active harvesting but it can be used, in conjunction with other maps, to find where suitable areas are being underutilized.
Introduction

The Lake Pontchartrain Basin is an estuary in southeastern Louisiana (Fig. 1). The basin is characterized by a wide range of environments, which include swamp, freshwater, intermediate, brackish and saline marshes. Salinity in the Pontchartrain Basin ranges from near 0 parts per thousand (ppt) in Lakes Maurepas and Pontchartrain, to 37 ppt east of the Chandeleur Islands. Salinity, and the duration of certain salinity regimes, has been shown to be an important factor that governs oyster propagation and growth (Galstoff, 1964; Cake, 1983; Soniat & Brody, 1988). *Crassostrea virginica* (eastern oysters) are bivalves that are found in estuarine and coastal waters along the Atlantic seaboard from the Canadian Maritimes to Brazil (Buroker, 1983). Since the middle nineteenth century, the coastal zone offshore southeast Louisiana has been cultivated for oysters (Deseran & Riden, 2000). For much of the last 35 years, more oysters have been produced in Louisiana than in any other state in the U.S. (st.nmfs.noaa.gov). For reasons such as these, understanding trends in oyster habitat and production suitability over time is of tremendous importance from both a scientific and economic standpoint. The Biloxi Marsh is one of Louisiana’s best areas for oyster production (Préau et al., 2016). LPBF supports oyster production and habitat sustainability in the Biloxi Marsh because it serves as one of southeast Louisiana’s coastal lines of defense (Lopez, 2006). As such, the Biloxi Marsh protects parts of the Pontchartrain Basin by helping to reduce storm surge associated with tropical systems. Maintaining oyster production in a sustainable fashion supports the integrity of this vital coastal feature.

![Figure 1: Pontchartrain Basin study area.](image-url)
Identifying the optimal conditions for oyster propagation, growth and harvesting is a key factor in delineating areas best suited for oyster reef restoration. Determining optimal habitat conditions for oysters has been a goal of scientists and resource managers dating back to the 1800s (Galstoff, 1964). An oyster habitat suitability index (HSI) was created by the U.S. Fish and Wildlife Service (USFWS) covering two life stages, larvae and adult (Cake, 1983). A field evaluation of Cake’s (1983) HSI suggested that modification of some variables should be considered (Soniat & Brody, 1988). A four parameter model using three salinity parameters was found to be useful for both data rich and data poor estuaries (Swannick et al., 2014), which suggests salinity may be the most influential parameter (Préau et al., 2016).

In a study completed in 1983 for the Louisiana Department of Wildlife and Fisheries (LDWF), Chatry et al. (1983) used historical oyster seed production data to examine the relationship between salinity and seed oyster production in three sites in southeast Louisiana. This research resulted in the establishment of an optimal salinity regime for 12 calendar months using salinity observed prior to good seed production years (Fig 2a).

![Figure 2: (a) Optimal salinity regime associated with high seed production from (Chatry et al., 1983). (b) Table of Chatry’s optimum salinity values, in parts per thousand (ppt), for each month.](image)

Salinity in the setting year, particularly in the summer, was found to be a prime determinant of seed production in the ensuing year. A more recent method for evaluating conditions ideal for oyster habitat was developed by Soniat and is available online at [http://oystersentinel.org](http://oystersentinel.org) (Soniat, n.d., Soniat & Brody 1988; Soniat, 2012). This HSI modifies the work of Cake (1983) and encompasses four parameters that characterize optima for salinity and substrate based on theoretical values found in literature and field validation (Soniat & Brody, 1988) (Fig. 3). In this
work, these two methods are applied to Hydrocoast surface water salinities to determine areas most aligned with optimal salinities.

**Data Sources & Methods**

Préau et al. (2016) formed the approach and methodology that is followed throughout this document. In an effort to reduce redundancy, this report will not go into a lengthy description with regards to methodology. Instead, the purpose of this section is to give essential information so that readers have a basic understanding of data and methods used to generate the results here. For a complete explanation of methods, the reader is directed to Préau et al. (2016).

**Hydrocoast Salinity Data**

LPBF produces a biweekly set of maps characterizing conditions in the Pontchartrain Basin, including surface water salinity. During each Hydrocoast mapping period, isohalines (contours) representing surface water salinity in the basin are created using salinity data from fixed stations and from supplemental data collected by LPBF and others. Isohalines are manually delineated using GIS software. Isohaline generation takes into account coastal processes, topography, hydrology, rainfall, wind characteristics, tides, currents, and bathymetry (Lopez et
al., 2015; Préau et al., 2016). Using GIS software, raster surfaces are generated by interpolating the salinity contours for each biweekly salinity map. Raster surfaces were created for each Hydrocoast map over the calendar year 2016. The 2016 surfaces were then analyzed using the two oyster salinity suitability methods to generate a “best oyster area” for each approach (Préau et al., 2016).

**Chatry Optimal Oyster Salinity (COOS) Regime**

Two methods are used to map oyster habitat suitability in the Pontchartrain Basin. The first is COOS. Chatry et al. (1983) identified an ideal salinity regime for each calendar month. The regime reflected salinities during eight “good” (>20 seed oysters per square meter) seed production years. Chatry et al. (1983) documented oyster setting, seed and salinity over a ten-year period at three locations in Breton Sound. The monthly salinity mean and range associated with “good” production years can be seen in Fig. 2a. Optimal monthly salinity values are applied to Hydrocoast data to identify locations most aligned with ideal values (Fig. 2b). For the purposes of this analysis, the mean salinity value was used to identify good oyster salinity areas in the study area. Five classes of suitability are defined (class 1 = most optimal). Classification is based on the sum of monthly deviations from what optimal salinity is for each month. They are as follows; class 1 = 0-25 ppt deviation, class 2 = 25-50 ppt deviation, class 3 = 50-75 ppt deviation, class 4 = 75-100 ppt deviation and class 5 = >100 ppt deviation.

**Soniat Optimal Oyster Salinity (SOOS) Regime**

Soniat (2012) uses three salinity variables and one substrate variable to determine an area’s suitability for oyster propagation. The premise of this approach is that the primary parameters of good oyster habitat are suitable salinity over suitable cultch, defined as hard substrate (Soniat 2012). Parameters are percent suitable cultch cover, mean annual salinity, mean spawning season salinity and minimum monthly salinity. Linear curves relate salinity values to a dimensionless suitability index that ranges from 0 (unsuitable) to 1 (ideally suitable; Fig. 3). Variables have equal weight, and the composite HSI index is the geometric mean of all variables. In the absence of detailed bottom information, it is assumed substrate (V1 - cultch) is 100% suitable coverage in all areas, and assign it an index value of 1. Biweekly Hydrocoast salinity data were interpolated for 2016 and the linear relationships as described in Préau et al. (2016) were applied to the salinity surfaces to get an index surface for each variable. Finally, the geometric mean of those three surfaces was calculated to get a composite HSI surface. Five classes of suitability are delineated based on composite HSI with class 1 being most optimal. Composite HSI values associated with each class are as follows: class 1 = 0.75-1 HSI, class 2 = 0.5-0.75 HSI, class 3 = 0.25-0.5 HSI, 0-0.25 HSI, class 5 = 0. For a complete description of all GIS methods for the COOS and SOOS methodologies, see Préau et al. (2016) Appendices 1 & 2.
**Polygon Outlines & Centroid**

To better understand and visualize how the most suitable areas for oysters change over time, polygon outlines and polygon centroids of the best areas were examined and displayed for each year 2013-2016. For COOS, classes 1 and 2 were combined, because the class 1 area was very small. For SOOS, only class 1 was considered. It was more appropriate to include COOS class 1 & 2 to make a comparison to SOOS class 1. Once the polygons were rendered, to see how the overall character of the polygons shifts over time, the Feature to Point tool in ArcGIS was applied. This tool maps a single point associated with each polygon that represents the polygon’s center of mass, the point at which polygon area is equal in all directions.

**Hypoxia & Oyster Fleet Activity**

Hypoxia is defined here as water that has less than 2 mg/l of dissolved oxygen, and often occurs near the bottom of the water column. Since 2008, LPBF and other researchers have periodically monitored hypoxia within parts of the Pontchartrain Basin (Lopez et al. 2010, Henkel et al. 2012, Moshogianis et al. 2012, Moshogianis et al. 2013). During LPBF surveys, a YSI hand held water quality meter with a 98 ft. (30 m) cable was used to measure dissolved oxygen concentrations at approximately 2 ft. (0.6 m) above bottom, mid-depth, and 2 ft. (0.6 m) below the surface.

Hypoxic areas identified from these surveys were examined for recurrence frequency. Polygons delineating hypoxic areas from all survey years (2008 and 2010-2016) were converted to raster layers. Each raster’s cell values were set equal to 1, indicating hypoxia was observed at that location that year. All rasters were combined into a single raster by summing cell values. The resulting raster represents the geographic extent of all areas where hypoxia was observed, with each cell value indicating the number of times it was observed. Note that Chandeleur Sound was surveyed over 8 years, 2008-2016 (no surveys were conducted in 2009), whereas Breton Sound was surveyed over 4 years, 2013-2016 (Préau et al., 2016).

Oyster fleet activity is periodically monitored via airborne reconnaissance. In 2016, ten flights were conducted over the Biloxi Marsh-Breton Sound-Chandeleur Sound region to count the number of boats actively harvesting oysters. From this data, an oyster boat density map was generated. The density map has a cell size of 1640 by 1640 ft. (500 by 500 m) and the search area was set to a square 3.1 by 3.1 mi (5 by 5 km). In other words, the density value given at each cell represents the density of oyster boats within a 3.1 square mile area. Boat density is reported as the number of boats per unit area, but boats per unit area of water was the desired information. To account for this discrepancy, a water density map based on the U.S. Geological Survey land cover shapefile (Homer et al., 2015) was generated. A raster was created using the land cover shapefile; land cover classes that are water dominated are given a value of 1 and non-water 0. Using this raster, a water density map was generated and used to calculate boat density per unit water. The water density raster is multiplied by the oyster boat density raster (Spatial Analyst > Map Algebra > Raster Calculator). The resulting density raster is the number of oyster boats per unit area of water.
Results

The following Figs. 4-12, are the results of analyzing surface salinity in the Pontchartrain basin for 2016. Additionally, previous years’ data, 2013-2015, (Préau et al., 2016) are included to both compare and average the data over the time period 2013-2016. **Figure 4** is the average surface salinity throughout the Pontchartrain Basin in 2016.

![2016 Average Surface Salinity](image)

Figure 4: Map of the Pontchartrain Basin showing the average surface salinity for 2016, ppt = parts per thousand. Average salinity map generated from bi-weekly Hydrocoast maps.

Lake Pontchartrain average surface salinity did not exceed 5ppt, which classifies it as freshwater to oligohaline in 2016. The Biloxi Marsh and Breton Sound regions were mesohaline and ranged from about 10 to 15 ppt (salinity increases eastward). Chandeleur Sound ranged from about 10 to near 30 at the Chandeleur Islands. Salinity gradient was generally steeper east of the Bird’s Foot Delta than east of the Biloxi Marsh-Chandeleur Sound region.
Chatry Optimal Oyster Salinity (COOS) in the Pontchartrain basin for 2016 is shown in Fig. 5. In offshore Louisiana, Chatry class boundaries were generally oriented north-south. Class width followed salinity gradient in the basin (i.e. class widths were broad through Biloxi Marsh and Chandeleur Sound where salinity gradient is low). The most optimal oyster salinity (class 1) found in the Pontchartrain Basin during 2016 was an area approximately 9 mi² (15km²) located just east of the Mississippi River Gulf Outlet (MRGO). Areas of low suitability were coincident with water masses that are both too fresh and too salty, which are noted on the figure.

![Figure 5: Map and table of oyster salinity suitability in the Pontchartrain Basin for 2016 using COOS.](image)
Figure 6 shows the Soniat Optimal Oyster Salinity (SOOS) for the Pontchartrain Basin in 2016. Like the Chatry method, Soniat suitability class boundaries were generally oriented north-south in offshore Louisiana. Suitability class width was also narrower where salinity gradient was high and wider where salinity gradient was low. The most suitable class for oyster production and habitat (class 1) occurred within a region up to about 12 mi (20 km) offshore the Louisiana coast. In general, the most optimal classes (1 & 2) were larger by area using SOOS than they are using the COOS. Additionally, following the Soniat method, the most suitable salinity was farther east than what the COOS shows. Areas of low suitability were coincident with water masses that were both too fresh and too salty, which are noted on the figure.
Chatry and Soniat average oyster suitability from 2013-2016 is shown in Fig. 7. The average suitability classes for 2013-2016 did not deviate substantially from 2016. One noticeable difference, however, is that the Chatry average suitability map (Fig. 7a) does not contain any class 1 areas. In general, the Chatry average 2013-2016 suitability map shows that class 2 (here the most suitable) was located slightly west than in the 2016 map (Fig 5). The Soniat average 2013-2016 suitability class 1 was narrower in width than it is in 2016. Additionally, the landward edge of class 1 (Fig. 7b) was substantially displaced from where class 1 was in 2016 (Fig. 6), particularly in the area just north of the MRGO.
Figure 7: Multyear average salinity suitability using the (a) COOS and (b) SOOS methods for the years 2013-2016.
**Figure 8** is the optimal oyster salinity suitability using both the COOS and SOOS methods from 2013 to 2016. The 2016 COOS (**Fig. 8d**) departed from previous years in that the best suitability classes (1 & 2) were shifted eastward by several miles. The western margins of 2016 COOS classes 2-4 were also shifted to the east in comparison to 2013-2015. The 2016 SOOS is different from 2015 in that suitability classes 1-4 have moved eastward. The location of SOOS class 1 is near the location of class 1 in 2013 and 2014 (**Fig. 8e,f,h**). However, the western SOOS classes 2-4 were noticeably constricted and displaced eastward in comparison to previous years (**Fig. 8e-h**).
Figure 8: Maps of yearly salinity suitability using the (a-d) COOS and (e-h) SOOS methods through the years 2013-2016.
Figure 9 zooms into the Biloxi Marsh/Breton Sound subbasins, which contained the most optimum salinity conditions for oyster production and habitat during 2016.

Figure 9: Close-up maps of the Biloxi Marsh and Breton Sound subbasins, highlighting the differences between salinity suitability using the (a) COOS and (b) SOOS methods. Heavy dashed line indicates extent of frequently observed hypoxic conditions (i.e. > 50% of observation years 2008-2016. Thin dashed line indicates extent of occasionally observed hypoxic conditions (i.e. 1-50% of observation years 2008-2016). Note no observations were
This figure highlights the similarities and differences between the COOS and SOOS methodologies more closely than previous figures. Areas of hypoxia are noted by dashed lines. The Biloxi Marsh was by far more suitable for oysters in general than the Breton Sound region. **Figure 10** is a breakdown of the areas in each suitability class for the two subbasins for 2016.

![Figure 10](image)

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<th>Biloxi Marsh</th>
<th>Breton Sound</th>
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**Figure 10:** (a-d) Histograms and (e) table of salinity suitability in the Biloxi Marsh and Breton Sound subbasins using the COOS and SOOS methods.
**Figure 11a** shows the outline of every COOS class 2 or better polygon within the Biloxi Marsh, and **Fig. 11b** shows the outline of every SOOS class 1 polygon within the Biloxi Marsh.

Fig. 11: Map of (a) COOS class 2 or better and (b) SOOS class 1 polygon outlines within the area of the Biloxi Marsh.
Figure 12 is locations of the centroids for the polygons in Fig. 11 and shows how far and in what direction the centroids moved year to year. Here, a centroid represents the center of mass of each polygon. In other words, the centroid is the location on the map where the distribution of polygon area is equal in all directions. In both Figs. 11 & 12, COOS class 1 and 2 are combined to show the most suitable oyster production areas because COOS class 1 areas are very small.

Fig. 12: Map of (a) COOS class 2 and better and (b) SOOS class 1 polygon centroids (polygon outlines shown in Fig. 11) within the area of the Biloxi Marsh. Centroids are only from the SOOS class 1 polygons between the LA-MS state line and the MRGO. Lines with arrows show direction of centroid movement year to year.
Figures 11 & 12 demonstrate that from 2013 to 2015 the most suitable areas within the Biloxi Marsh migrated northwestward by less than about 6 miles per year. From 2015 to 2016, the most suitable areas shifted southeastward nearly 10 miles. Both COOS and SOOS methods showed this same trend.

Hypoxic areas in the Chandeleur Sound and Breton Sound regions for the time period 2008-2016 are shown in Fig. 13. The areas of hypoxia in Chandeleur Sound have stayed relatively stable in comparison to the results of Préau et al. (2016). The area of occasional (<50% of observation years) hypoxia grew slightly in Chandeleur Sound. The area of frequent (>50% of observation years) hypoxia observation was also larger in Chandeleur Sound than in previous years (Préau et al., 2016). In Breton Sound, the area of >50% hypoxia observation was substantially larger than in Préau et al. (2016). Growth in the area of frequent hypoxia is likely due to the increasing number of observation years in Breton Sound.

Fig. 13: Map of hypoxia observed within the Pontchartrain Basin through the years 2008-2016. Observations in the Chandeleur Sound took place 2008 to 2016 (none were made in 2009). Observations in Breton Sound were made every year from 2013 to 2016.
Figure 14 is the density of boats on private leases that were actively harvesting oysters in 2016. This map also shows the locations of cultch plants in Louisiana as well as oyster reefs and harvesting zones in Mississippi. The highest density of oyster boats occurred in several zones or ‘hotspots’ within the Biloxi Marsh region. The largest high density area of oyster boats actually occurred in Mississippi waters. However, this area is a Mississippi cultch plant, which is noted on the map. The high density zones in offshore Louisiana were coincident with SOOS suitability class 1 and COOS suitability class 2 in 2016 (Figs. 5 & 6).

Figure 14: Map of oyster boat density.
*Denotes actively working oyster boats are surveyed by visual spotting by a coastal scientist during low altitude aerial reconnaissance of LA waters east of the MS River. Boats that are in-transit or anchored are not counted. All flights conducted from 7AM to noon. 2016 survey dates: 02/26, 03/22, 04/19, 05/24, 05/30, 06/13, 08/01, 08/22, 09/20, 10/06. Base map is LANDSAT imagery.
** Numbers given are unit area of water
Figure 15 is graphical representation of oyster fleet density per suitability class and the average number of boats per survey within each class.

Fig. 15: (a,b) Histograms of average boat density and average number of boats per aerial survey per COOS class, and (c,d) Histograms of average boat density and average number of boats per aerial survey per SOOS class.
Discussion

General findings

The following summarizes the general results of the analysis of 2016’s Hydrocoast surface salinity data. Data for 2016 is also combined with previous years’ data to illustrate trends from 2013-2016.

- The most suitable areas for oyster habitat in 2016, using both the Soniat and Chatry methods, are located farther east than in 2015.
- Both Soniat and Chatry suitability classes 1-4 are located farther east in 2016 than in previous years.
- The best areas for oyster habitat (classes 1-3) in 2016, compared to previous years, appears to be smaller in the areas of Biloxi Marsh directly south of Bay St. Louis, MS.
- Biloxi Marsh is substantially more suitable for oysters than Breton Sound in 2016, which is similar to previous years.
- Areas where hypoxia was observed enlarged in 2016 and hypoxic areas in Chandeleur and Breton Sounds are contiguous. This may reflect more effort being focused on mapping the extent of hypoxia.
- The density of oyster boats was twice as high in areas where suitability is expected to be better (classes 1 & 2) than in other areas (Fig. 14). Additionally, the average number of oyster boats is higher in class 2 for both methods (Fig 15).

COOS differences between 2016 and previous years

One striking difference between oyster habitat suitability, as indicated by COOS and SOOS, in 2016, compared to previous years, is the location and geometry of suitability classes (Figs. 3, 6a-d, 11 & 12). In previous years, COOS classes 2 and 3 were wider in more southerly locations along the Bird’s Foot Delta. With respect to the overall location of the most suitable classes, 2016 does not differ significantly from 2013 and 2014. However, the most suitable classes are shifted west in 2015 as compared to 2013, 2014 and 2016.

SOOS differences between 2016 and previous years

The most notable difference between 2016 and previous years (Figs. 4, 6e-h, 11 & 12) is the locations of suitability classes 1-3. In 2016 SOOS classes 1-3 are narrower and the western margins are shifted eastward in comparison to previous years. SOOS class geometry closely resembles 2013 and 2014. In contrast, the most suitable classes (1 and 2) are shifted east in 2016 relative to 2015.

Interpretations

Several natural and anthropogenic events happened within the Pontchartrain Basin that may explain observed differences between COOS and SOOS in 2016. It is beyond the scope of
this work, however, to pinpoint or attribute any single event or set of events that may be responsible for observed salinity change/oyster suitability in the Pontchartrain Basin. The first event of note is the opening of the Bonnet Carré spillway, an anthropogenic event, which took place on 10 January 2016 and lasted until 31 January. The spillway protects the city of New Orleans from riverine flooding by diverting Mississippi River water into Lake Pontchartrain. Bonnet Carré is located about 33 river miles (53 km) upstream of New Orleans and water from it discharges directly into Lake Pontchartrain along its southwestern shore. From there, water flows into Lake Borgne via the Rigolets and Chef Menteur Passes and eventually into the Gulf of Mexico. The spillway has a total operational capacity of ~250,000 ft³/s (7,079 m³/s). In January 2016, the spillway was operated for a total of 22 days with a peak discharge of 203,000 ft³/s (5,748 m³/s) (U.S. Army Corps of Engineers, 2017). The opening of Bonnet Carré Spillway no doubt freshened the Pontchartrain Basin, however it is impossible to know the magnitude of the impact on oyster suitability without doing a hydrological analysis.

In addition to the opening of Bonnet Carré, two meteorological events occurred in 2016, which led to significant riverine flooding in watersheds that drain into the Pontchartrain Basin. The first event occurred in March 2016. A slow-moving southward dip in the jet stream combined with Gulf moisture to create a major storm event in the states of Louisiana, Texas, Arkansas and Mississippi (Breaker et al., 2016; PMSC, 2017). The storm event caused significant flooding along the Pearl, Amite, Bogue Falaya, Natalbany, Tangipahoa, Tchefuncte and Tickfaw Rivers, all of which flow into the Pontchartrain Basin. Recurrence intervals of peak streamflow on these rivers ranged from 14 years on the Tickfaw to 250 years on the Tangipahoa (Breaker et al., 2016). In August 2016 a second flooding event, created by a slow-moving low pressure system, affected the Pontchartrain Basin. This event caused flooding along the Amite, Comite, Natalbany, Tangipahoa, Tchefuncta and Tickfaw Rivers, all of which flow into Lake Pontchartrain. The recurrence interval of peak streamflow for all of these rivers exceeded 100 years, and in many cases exceeded 500 years (Watson et al., 2016).

The Bonnet Carré spillway opening and the March and August flooding events no doubt impacted surface salinity in the Pontchartrain Basin, though no conclusive result can be made on the impact of any single phenomenon. However, these events, quite possibly, are responsible for the observed differences in suitability class location and geometry between previous years and 2016. The relative impact of each event or combination is not known. Differences in optimal oyster salinity year to year do not appear significant enough to change the overall character of oyster habitat suitability in the basin. For example, the COOS class 2 and SOOS class 1 polygon centroids only shift eastward by less than 10 miles, in spite of the large influx of freshwater in 2016. However, these processes have not been modeled within the Pontchartrain Basin. The southeastern coast of Louisiana is hydrologically and geomorphologically complex; therefore it is unclear how freshwater (stream or precipitation) inputs exactly affect salinity values or gradient. Simply put, the salinity gradient is expected to be altered by these events; but the exact nature of that alteration is poorly constrained.
Limitations & scope

In this study, only surface water salinity is considered when determining oyster habitat suitability, which limits the strength of these findings. Several factors other than salinity influence oyster populations, and individual growth and mortality. Many of these are difficult to quantify, especially within such a large spatial area. These results should not be interpreted as indicators of where the best oyster habitats are, because of the exclusion of a bottom character parameter. Presence of hard bottom, or cultch, has been indicated as necessary for oyster larvae settlement and growth, and quality of hard bottom, such as vertical relief, may also be important (Galtsoff, 1964; Schulte et al., 2009). That said, “good” areas identified in this analysis could be interpreted as places where oysters are more likely to occur, given presence of some hard substrate (Préau et al., 2016).

This study does not include historical salinity trends. Results use one year of data per map. Historical salinity trends (~ 3 years of data) have been suggested as an important consideration of oyster habitat quality (Cake, 1983), but is sometimes excluded (Soniat et al., 2013). Data is limited to Hydrocoast salinity data. While we could have included a total of four years of salinity data for the 2016 model, this would have involved including a different methodology which would have made the results across years less comparable (Préau et al., 2016).

Neither methodology considers oyster metapopulation dynamics, which can be an important factor. Relationships and genetic exchange among different oyster reefs may influence reef success and these effects are not considered for either method (Munroe et al., 2012). Different parts of estuaries have different oyster populations with varying levels of connectivity through dispersal of larvae. Metapopulation dynamics have been demonstrated to affect gene flow in oyster populations and excluding it reduces the applicability of our results (Munroe et al. 2012; Préau et al., 2016).

The primary limitations of Chatry et al. (1983) approach include a lack of data and elements inherent in the methodology itself. For example, higher or lower mean optimal salinities will have different levels of impacts during different months, and there is no clear relationship with how deviations from optimal mean monthly salinities affects seed production. We assume that deviations from Chatry et al. (1983) mean salinity optimum has a negative linear relationship with respect to habitat suitability. Other studies suggest a range of salinities for any given month are ideal and deviations from this ideal salinity range are non-linear (Cake, 1983). We do not make these assumptions for three main reasons: 1) the USACE uses Chatry and others’ (1983) optimal salinity regime to quantify habitat management goals (USACE 1984, 2012), 2) a simple relationship between the optimal salinity described by Chatry et al. (1983) and Hydrocoast salinity outputs is desirable, and 3) making any assumptions that strongly affect the results is undesirable (Préau et al., 2016).

Surface salinities are the only measured salinity used for all of the analyses, whereas bottom salinities would have been better to characterize oyster habitat. Therefore, a major assumption here is that the estuary is fully mixed vertically. Vertical stratification has been
observed in this estuary during the study period (Moshogianis et al., 2013). This phenomenon has at least two major effects; 1) at certain times and locations, bottom salinities are different than surface salinities and 2) vertical stratification is associated with hypoxia which can negatively impact oysters (LDWF, 2011; Moshogianis et al., 2013). To remediate this limitation, areas with frequently observed hypoxia are indicated. Additionally, oyster fleet density for 2016 likely underestimates areas of oyster suitability.

**Conclusion**

In conclusion, this report summarizes oyster habitat suitability for the years 2013-2016. The results presented here show that areas most suitable for oysters were roughly the same in 2016 as they were in previous years. The general shape and character (north-south orientation in Biloxi Marsh) in the suitability classes were the same in all years. However, there were differences in geometry (i.e. classes were more constricted or less constricted) in some areas. Overall, using both COOS and SOOS, the same general areas were suitable in 2016 as they were in 2013 through 2015. Of note is that in 2013-2015 suitable areas shifted westward about, but in 2016 the most suitable areas shifted back toward the east. In 2016 the most suitable areas were actually (on average) located farther east than in 2013. This report also shows that areas of hypoxia in the Pontchartrain Basin grew in 2016, which can be used to better inform about overall suitability rather than using salinity alone. In other words, although an area may be suitable from a salinity standpoint, if the area experiences hypoxia every year, oysters will not survive. Year to year differences in suitability may be attributed to the opening of the Bonnet Carré Spillway in January 2016 or to riverine flooding in southeastern Louisiana in March and August of that same year. No single event can be singled out at this point, however hydrological modeling could improve understanding of salinity dynamics driven by these events. Future work, therefore, might focus on understanding how riverine flooding and spillway openings of varying magnitudes affect salinity and oyster suitability via hydrologic modeling of Pontchartrain Basin.
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