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Association between hypoxia and red tide between 2003-2019 on the West Florida Shelf

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Abstract

- Areas of bottom hypoxia were identified on the west Florida shelf using CTD data
- Hypoxia was present in 9 out of the 17 years that data were available and shoreward of the 50-meter bathymetry line
- Two clusters of recurrent hypoxia were described: Offshore of the Big Bend coast and an area stretching from Charlotte Harbor to Cape Sable
- There were 4 hypoxic events that were characterized by multiple CTD casts per month; 3 of these events happened during a year that an extreme red tide occurred (2005, 2014, and 2018)
- The vertical extent of the hypoxia for the 2005, 2014, and 2018 events ranged from 1-10 meters off the seafloor and suggests possible severe stress to demersal organisms

Introduction

Hypoxia in the Gulf of Mexico is normally thought about in the context of the dead zone that annually resides southwest of the Mississippi River mouth. For this paper, hypoxia is defined as dissolved oxygen concentrations equal to or less than 2 milligrams per liter. Hypoxia along the west Florida shelf has not been considered to be a typical feature due to the relatively wide and shallow continental shelf. The shelf has ample wind energy, and the water column tends to be well mixed for a majority of the year. However, during the summer months warm sea surface temperatures, increased runoff during the wet season, and harmful algal blooms (HAB) may contribute to an increased likelihood of hypoxia on the shelf. One such event was observed by a NOAA NMFS longline survey in 2014 in which a large fish kill was found near stations in which bottom oxygen levels were hypoxic and close to the edge of a shoreward-extending HAB (Driggers et al. 2016). Thus, the motivation for this study was to examine the hypoxia-HAB connection suggested by Driggers et al. We used a variety of data sources to examine the occurrence of hypoxia from 2003 to 2019. Previous work using local ecological knowledge identified 2005, 2014, and 2018 as particularly devastating HAB events that had measurable ecological and economic harm (Karnauskas et al. 2018). For this working paper we wanted to better understand the spatiotemporal expression hypoxia on the west Florida shelf particularly near the Big Bend region of Florida to inform the Gulf of Mexico gag grouper assessment. Our primarily motivating question was: how common was hypoxia on the west Florida shelf?

Methods

Oceanographic survey data collected on the west Florida shelf from 2000 through 2019 were aggregated from multiple sources into a singular dataset. The data were obtained from the Southeast Area Monitoring and Assessment Program (SEAMAP), NOAA National Marine Fisheries Service (NMFS) surveys, NOAA South Florida Ecosystem Research surveys, NOAA National Centers for Environmental Information (NCEI) oceanographic database, World Ocean Database (WOD), and the Rolling Deck to Repository (R2R) database. The survey data consisted of cruises with multiple stations where environmental and water column data were collected from the surface to near seabed. The water column data were acquired by Seabird SBE-911 profilers (CTD) outfitted to record conductivity (converted to practical salinity units), temperature (degrees Celsius), depth (meters), and dissolved oxygen (converted to mg l^{-1}). The aggregated CTD data were quality controlled to produce a consistent dataset for downstream analyses.

The quality control methods followed the guidelines defined by the WOD (Garcia et al. 2018). Briefly, range checks defined by WOD on all the variables for coastal North Atlantic were used to remove data that were outside the boundaries. Additionally, data were removed if it was greater or less than five standard deviations of the overall mean value, except salinity and oxygen were allowed to have a lower tail that extended to zero. Data that already had QA/QC flags produced by the original source were used to remove flagged data points to ensure analyses were based upon high quality data. Finally, the bottom of the profile was not always near the seabed because CTD altimeters were not consistently used nor were shipboard echosounders calibrated per station across all data sources. As a result, the NOAA Coastal Relief Model (CRM, NOAA National Geophysical Data Center, 2001) was used to assess whether the CTD data were near the seabed. Reported CTD bottom depths that were within 5 meters of the CRM depth were assumed to be bottom and depths that were not within the 5m cutoff were flagged and considered near bottom. The 5m depth cutoff was a tradeoff between the accuracy of the CRM (0.5 - 4.7m), CTD depth binning where the reported depth can include data above and below, and desire for data retention.

The data were grouped by month to provide snapshots of the spatial distribution of near bottom dissolved oxygen concentrations. The monthly data were then interpolated using ordinary kriging using a spherical variogram model. Longitude and latitude were used as covariates in the interpolation. All data manipulation was performed in the R statistical computing environment (ver. 4.0.2, R Core Team, 2020) and interpolation was performed using the *gstat* R package (ver. 2.0-6, Gräler et al. 2016, Pebesma, 2004).

Results & Discussion

Between 2003 and 2019, hypoxia was present 9 out the 17 years examined (Figure 1). The spatial distribution of all the hypoxia events extended the whole range of the west Florida shelf shoreward of the 50-meter bathymetry line. The distribution can be categorized into two clusters: the Big Bend area north of Tampa Bay and the southwest Florida coast from Charlotte Harbor reaching down to Cape Sable (Figure 2). For the majority of the months that hypoxia was detected (5 out of 9), there was only one CTD cast per month that had hypoxia. The remaining four hypoxic events were characterized by two or more CTD casts per month that had hypoxia, and three of these events (2005, 2014, and 2018) occurred in the same year in which an extreme red tide event also occurred. In August 2005, there was hypoxia in two CTD casts in the Big Bend area and offshore of Boca Grande (Figure 2). The 2014 hypoxia was observed in the Big Bend area in five total CTD casts across August and September surveys. The 2018 hypoxia was restricted to a small area off Sanibel Island and was observed in October, which is later than other hypoxic events identified in this paper. In August 2010, there was also a large hypoxic event observed in 15 CTD casts; however, this year was devoid of any significant red tide. The 2010 hypoxia was likely due to a large bloom of a non-toxin producing dinoflagellate *Peridinium quinquecorne* reported by the Florida Fish and Wildlife Research Institute. Both the 2010 and 2018 hypoxia events were restricted to the southwest Florida coast and occurred in less than 15 meter water depth (Figures 4 and 7).

The 2005 and 2014 hypoxia events were observed in the Big Bend area of Florida (Figures 3, 5, and 6). It is difficult to compare the spatial and temporal extent of 2005 to 2014 because there was less CTD coverage in 2005. The lack of CTD data is primarily due to Hurricane Katrina canceling survey work on the west Florida shelf in late August and September. In contrast, there were no comparable tropical systems to affect surveys in 2014. The exact connection between red tides and hypoxia is uncertain, but it is likely that the decomposition of sinking biomass from a large bloom reduced near bottom dissolved oxygen due to increased metabolic demand (Pitcher and Probyn, 2016). Furthermore, strong stratification in August, defined by large vertical density gradients, likely reduced wind-driven mixing contributing to thick hypoxia layer near the bottom (Figure 8). The stratification weakened September 2014 and the thickness of the hypoxic layer shrank. Given the large vertical extent of the observed hypoxia, which ranged from 1 to 10 meters off the seafloor (Figure 8B), there were likely significant effects on resident marine organisms including large fishes such as gag.

The lack of comprehensive oceanographic survey data hampers a robust spatiotemporal description of hypoxia identified in this paper. For example, given the large spatial distribution of the red tide event in 2005 identified by FWRI sampling, it is likely that the hypoxic region was much larger. Unfortunately, the survey data used in this paper does not extend into the nearshore area limiting any estimate of the shoreward extent, and September 2005 was not sampled, and it is unknown if hypoxia persisted similarly to 2014. The interpolated data must be used with caution, which is why maps of prediction variance are included to assist in assessing the uncertainty of the results (Figures 3-7B). More generally, data limitations may have obscured more comprehensive identification of hypoxia since the bottom of the cast may not represent the sea floor. For example, there were 6287 CTD casts in the QA/QC dataset and after filtering for data that came within 5 meters of the CRM depth or less only 1690 CTD casts remained. Because the bottom of the CTD casts were rarely close to the seafloor, there may have been cryptic bottom hypoxia that went unobserved. As a result, the hypoxia identified here is most likely an underestimate of the number of hypoxic events and an underestimate of the spatiotemporal scope of these events on the west Florida shelf.

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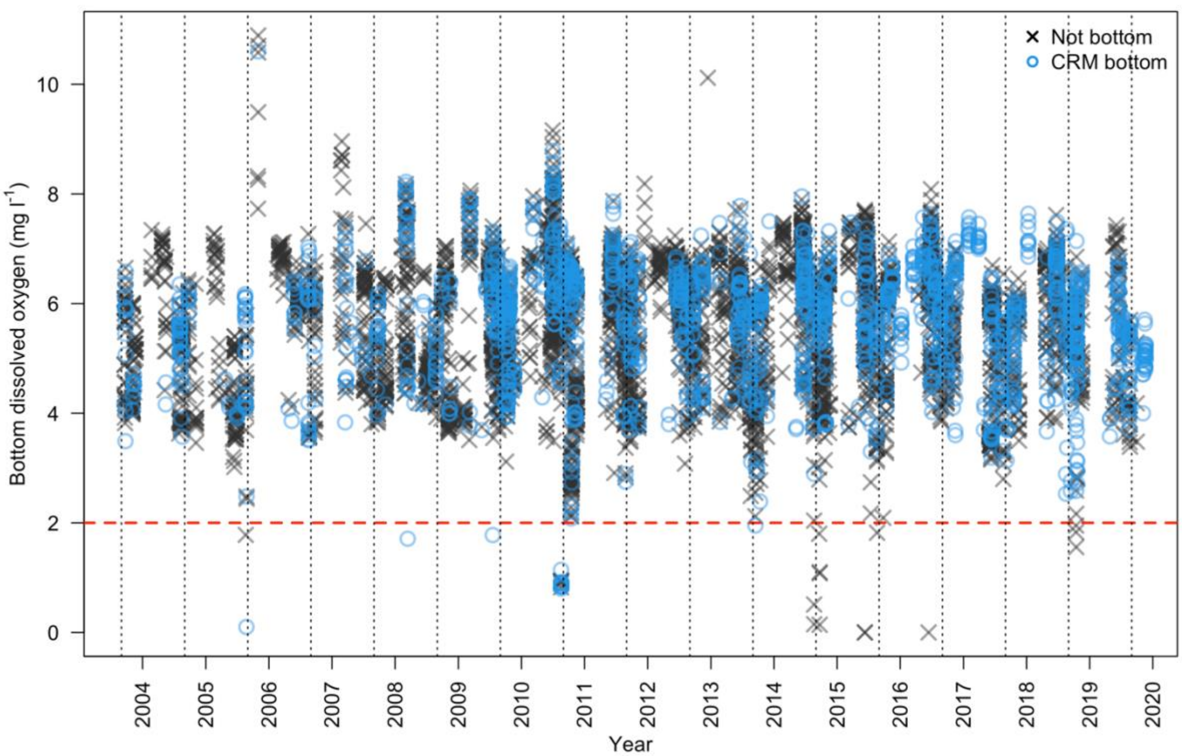

Figure 1. Time series of all near bottom dissolved oxygen concentrations from CTD casts on the west Florida shelf. The Xs indicate the deepest points of CTD casts that were not on the bottom defined by the Coastal Relief Model (CRM) bathymetry, and the Os indicate the deepest points of the CTD casts were on the bottom. The red dashed line denotes dissolved oxygen concentration of 2 mg l^{-1} and typically referred to as the delineation of hypoxia. The vertical dotted lines reference the approximate peak of red tide season on September 1st of every year.

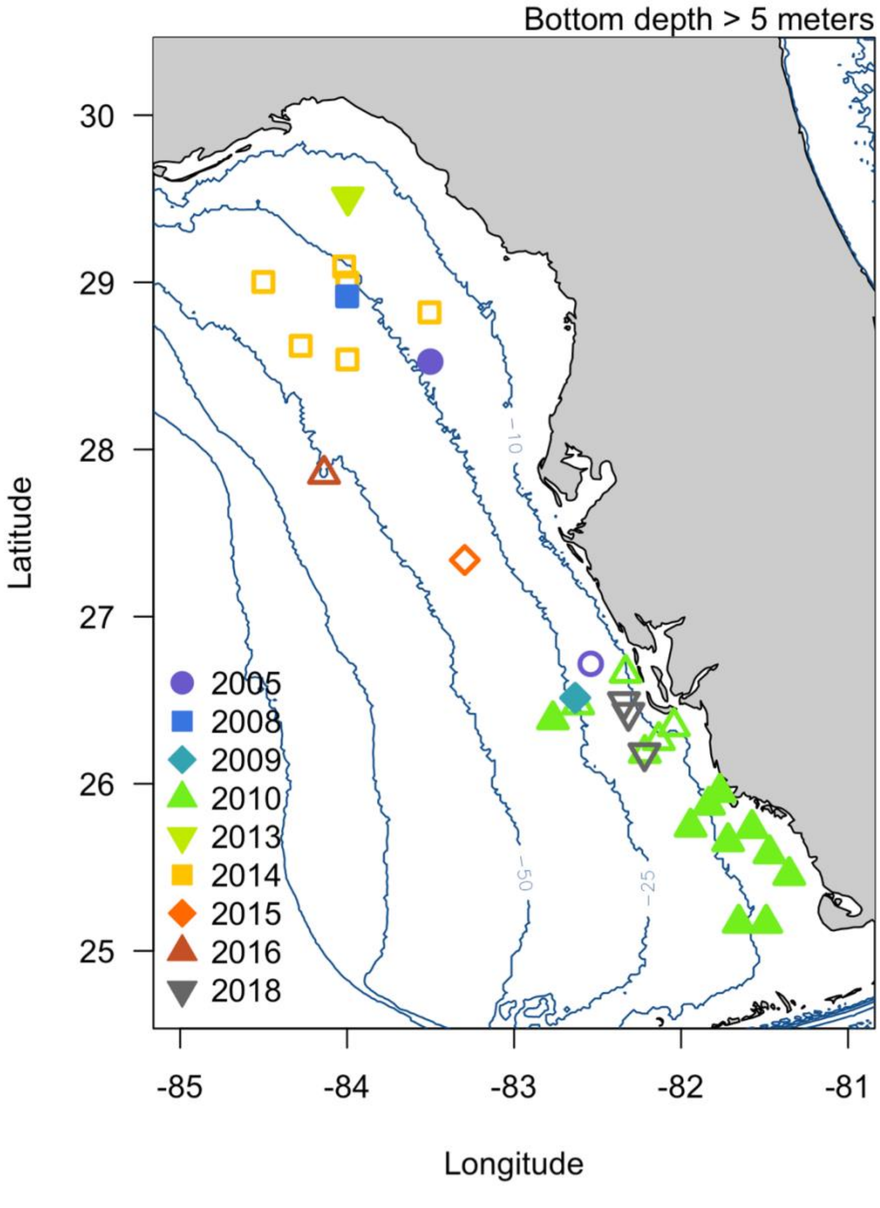

Figure 2. Spatial distribution of all CTD casts with hypoxic near bottom dissolved oxygen concentrations. Filled symbols are on the bottom as defined by the Coastal Relief Model and open symbols are not on the bottom. Bathymetric contours at 10, 25, 50, 100, and 200 meters are included as reference.

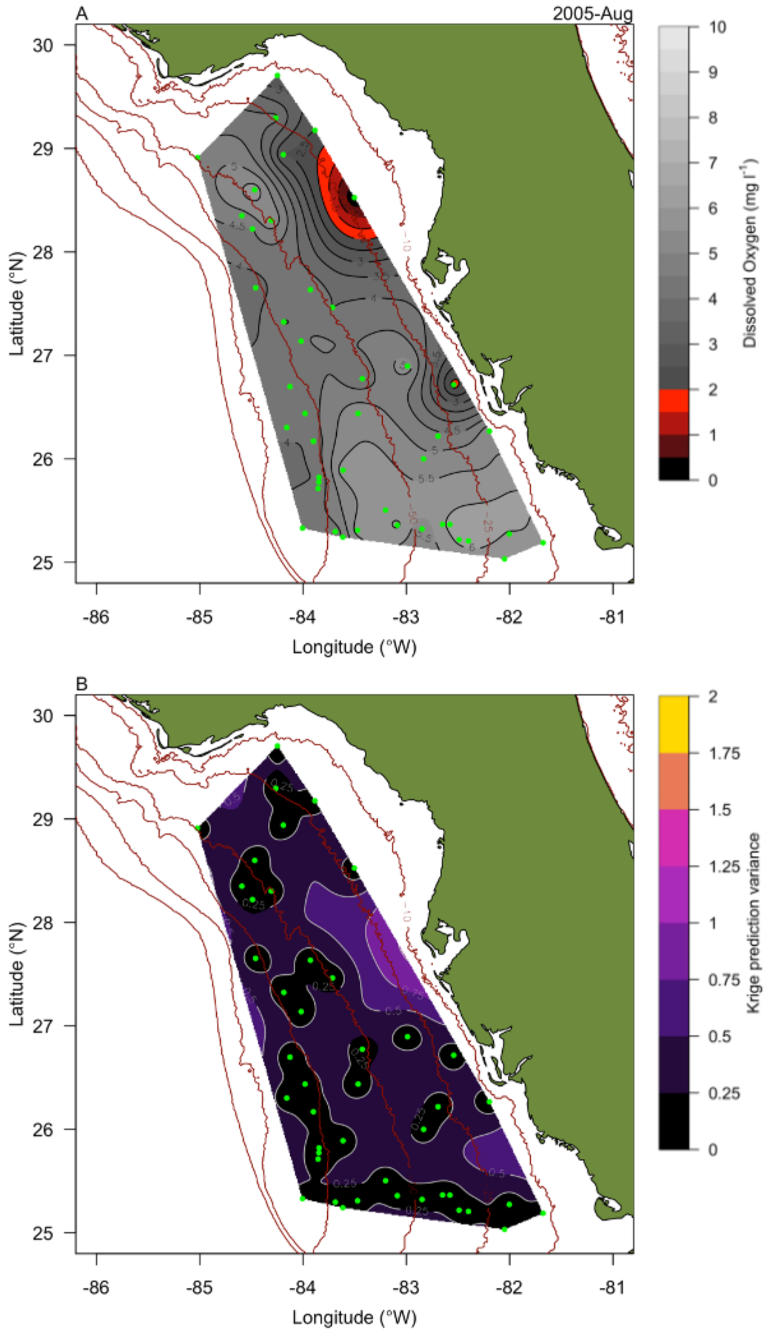

Figure 3. (A) Interpolated near bottom dissolved oxygen concentrations during August 2005. (B) Estimated variance of Kriged predictions using a spherical variogram model. Bathymetric contours at 10, 25, 50, 100, 200, and 300 meters are included as reference. Green dots indicate the locations of CTD casts used for interpolation.

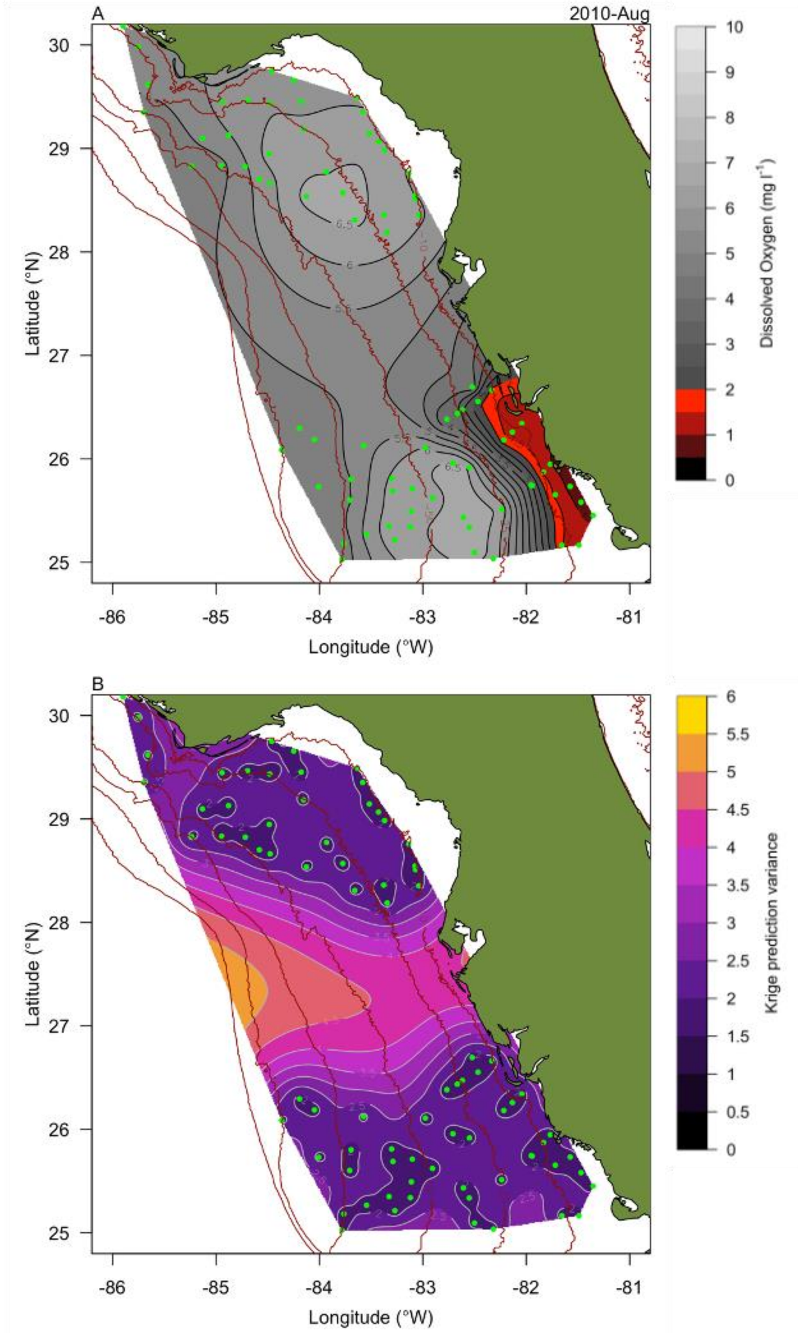

Figure 4. Same as Figure 3 but for August 2010 and change in variance scale in plot B.

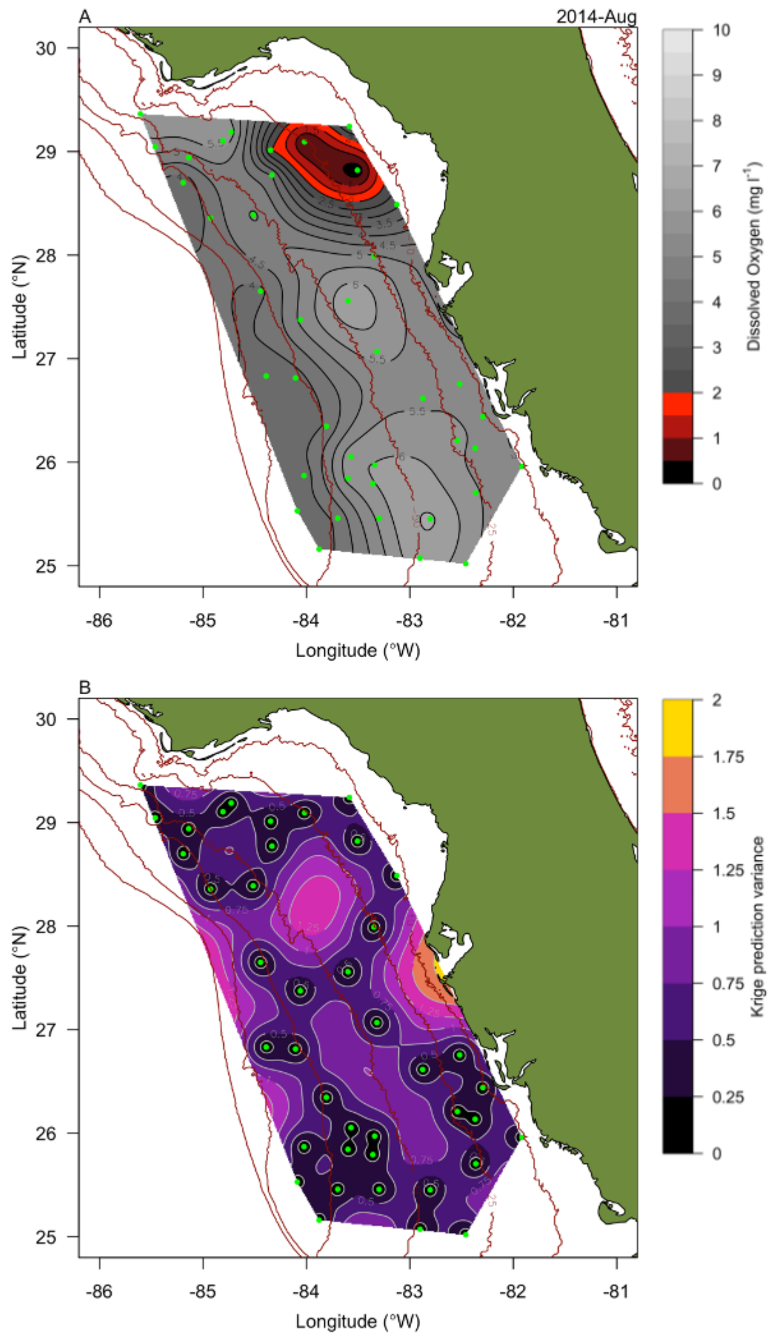

Figure 5. Same as Figure 3 but for August 2014 and change in variance scale in plot B.

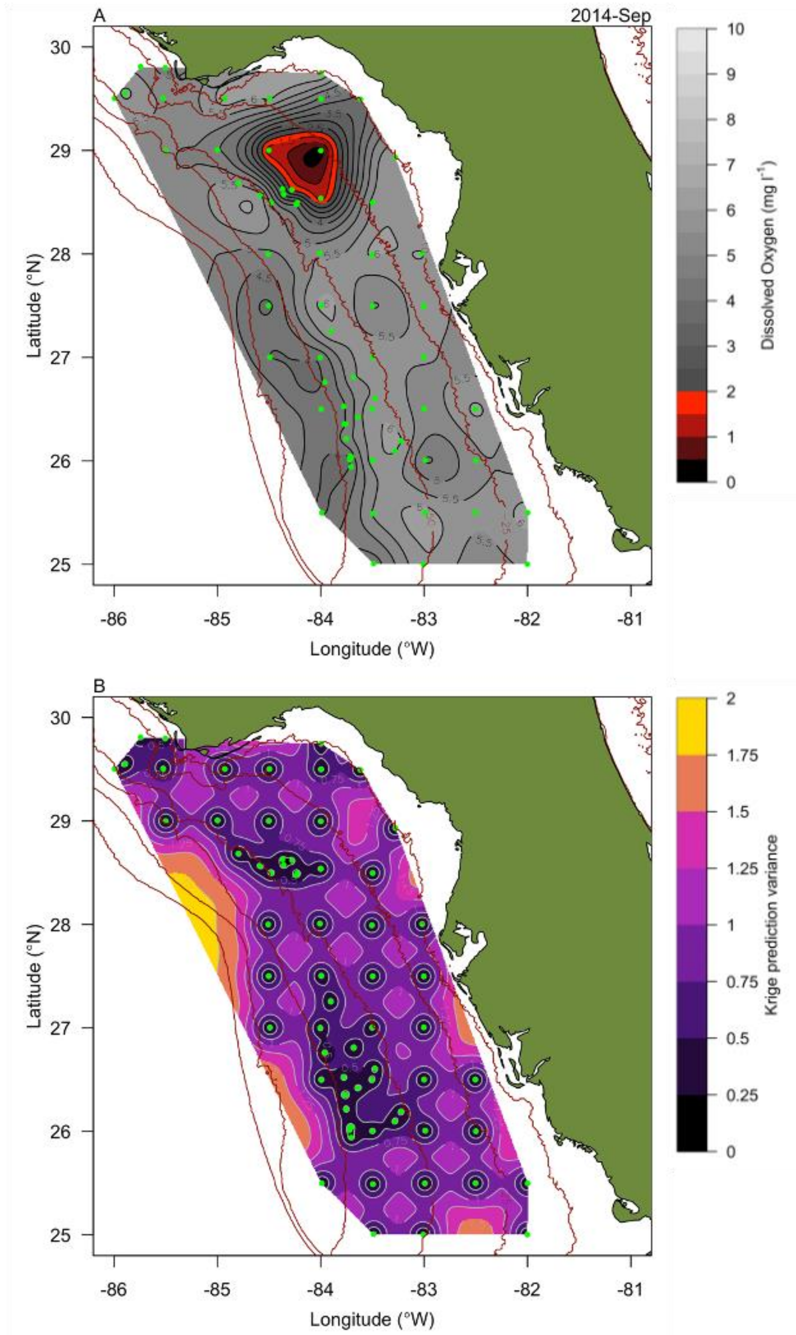

Figure 6. Same as Figure 4 but for September 2014.

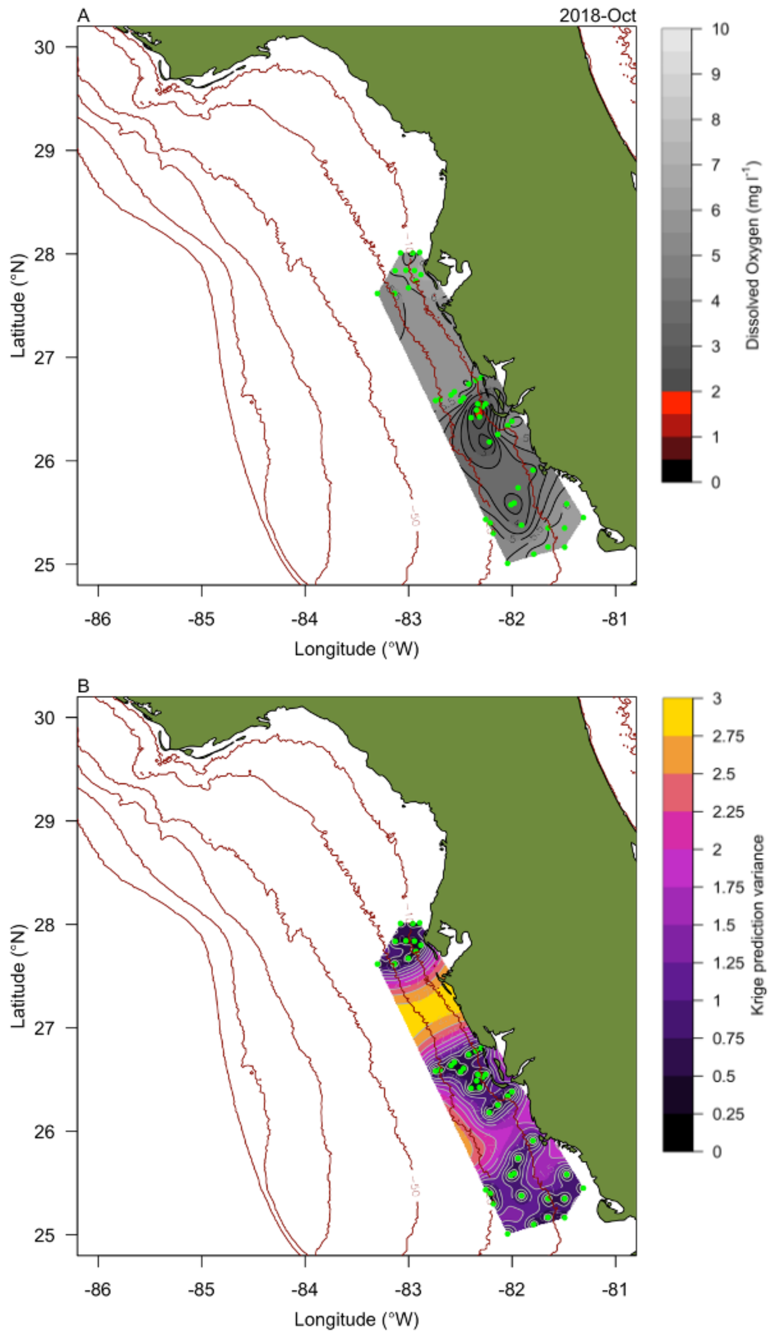

Figure 7. Same as Figure 4 but for October 2018 and change in variance scale in plot B.

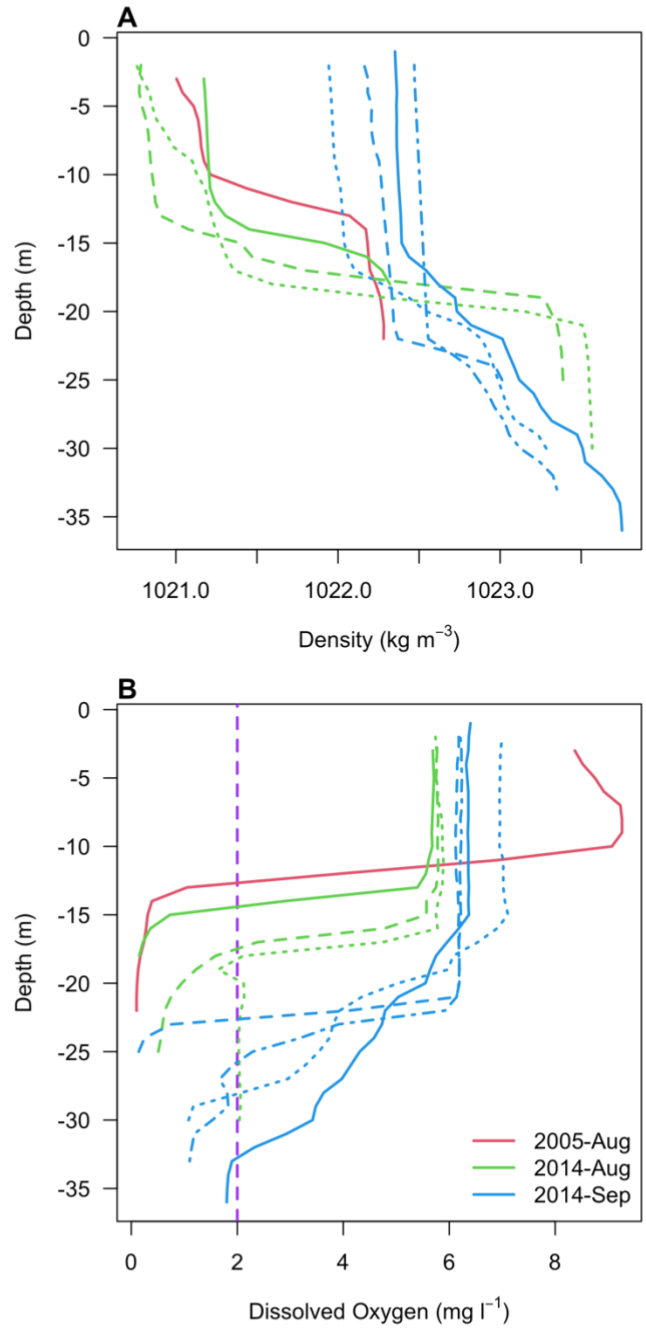

Figure 8. Water column profiles with near bottom hypoxia from CTD casts. These profiles are the same CTD casts with hypoxia used to create Figures 3-5. (A) Density versus depth profiles. (B) Dissolved oxygen concentrations versus depth profiles. The purple dashed line denotes dissolved oxygen concentration of 2 mg l^{-1} and typically referred to as the delineation of hypoxia. The different line types help to distinguish individual casts per month-year.