REPORT FROM 2023 SHELF-WIDE HYPOXIA CRUISE

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AND
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The bottom area of low oxygen in Louisiana coastal waters west of the Mississippi River, commonly known as the ‘Dead Zone,’ was mapped from July 23 – July 28, 2023, and was estimated to be 7,920 square kilometers (3,060 square miles) (Figure 1). The 2023 size is the sixth smallest in 36 years of coast wide hypoxia data. The size is less than the often-compared size of the state of New Jersey, or just over 13 times the size of Lake Pontchartrain, LA. The five-year running average of hypoxia is 2.3 times greater than the Mississippi River/Hypoxia Task Force Action environmental goal. The area mapped is much smaller than the predicted area of approximately 10,800 square kilometers (4,155 square miles).

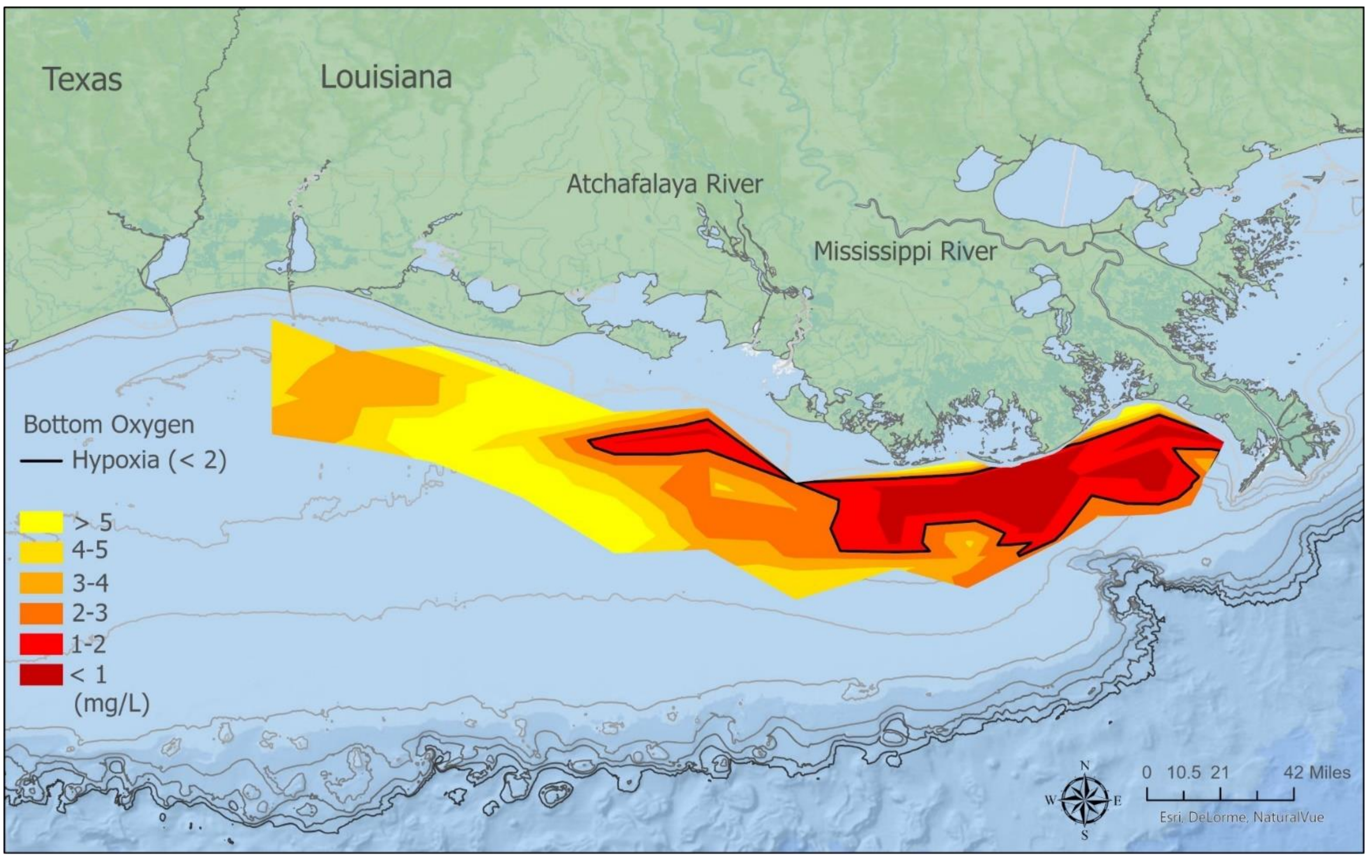

Figure 1. Distribution of bottom-water dissolved oxygen concentration for July 23-28, 2023. The combined area less than 2 mg l^{-1} and 1 mg l^{-1} are the darkest colors and outlined by the black line. Data source: CN Glaspie, NN Rabalais*+, and RE Turner*, *Louisiana State University and +Louisiana Universities Marine Consortium. Funding: National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science.*

<u>Comparison with recent summers</u>
While the nitrogen (as dissolved nitrate plus nitrite, NO_3^- and NO_2^-) load of the Mississippi was typical for May (a long-term predictor for hypoxic zone size in summer), the discharge of the Mississippi River was lower than average for the month of the July research cruise in 2022 and 2023 (Figure 2). A comparison of the three years shows the variability among years, but a comparison of 2023 versus 2022 with smaller than average bottom-

area size of hypoxia clearly indicates the reduced discharge of the Mississippi River in July of 2022 and 2023 (Figure 2, right panel) compared to 2021, a year with higher May Mississippi River discharge.

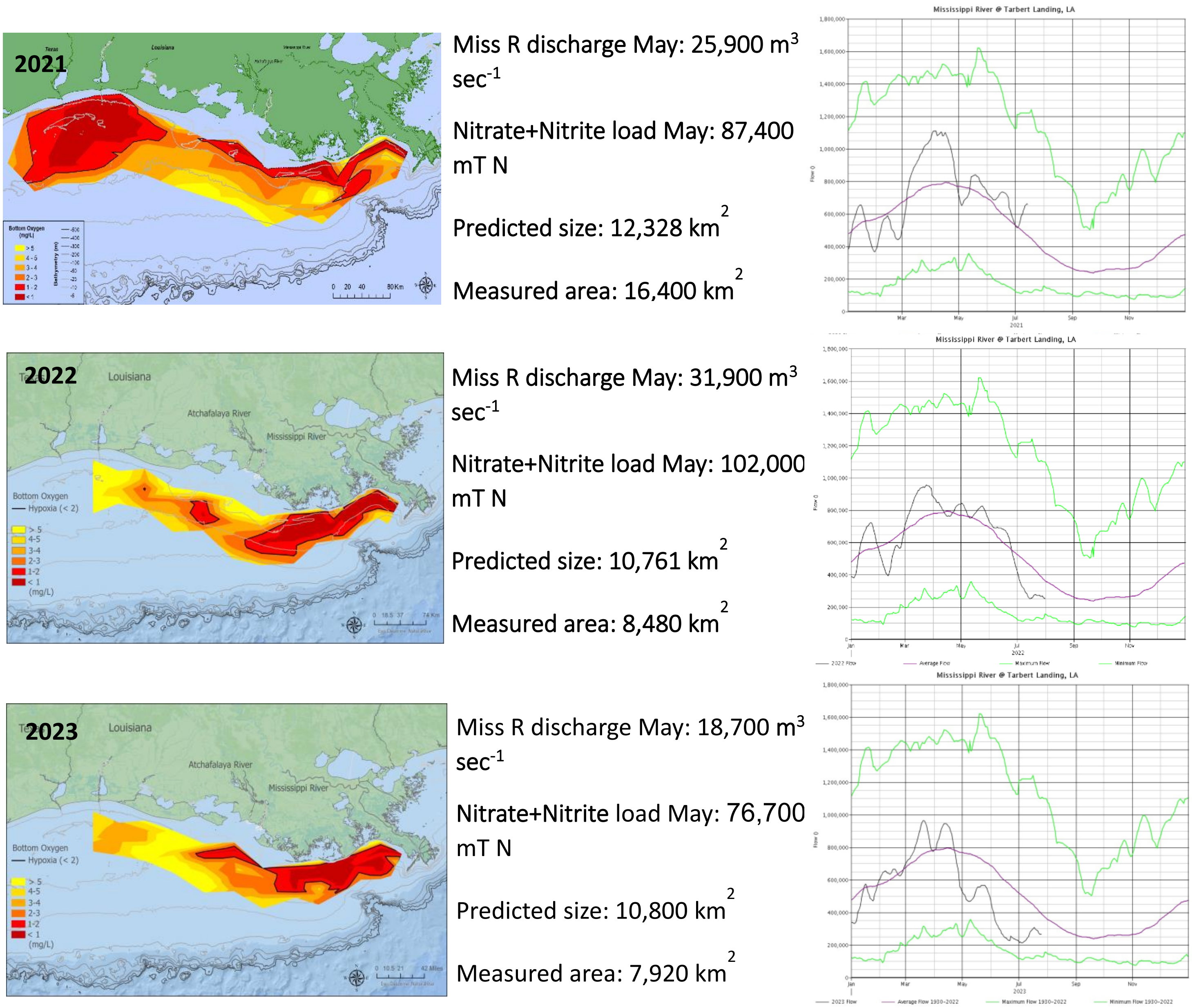

Figure 2. Comparison of Mississippi River properties and distribution of dissolved oxygen condition in July 2021, 2022, and 2023. Left panel: bottom-water dissolved oxygen (see full description in Figure 1), Middle panel: Mississippi River discharge for the month of May and the nitrogen load, also for the month of May, as dissolved nitrate plus nitrite (NO3+NO2-N) (data from the US Geological Survey and the US Army Corps of Engineers), the predicted size of the bottom-area of hypoxia in late July (provided by NOAA NCCOS), and the measured estimate of bottom-water dissolved oxygen less than 2 milligrams per liter in late July (LUMCON and LSU Hypoxia Studies), and Right panel: daily Mississippi River discharge at Tarbert Landing for the identified year (black line), average discharge for 1930-2022 (purple line), and maximum and minimum discharge for the same period (green lines). [Note, we know the figures are small in the right panel; focus on the black line versus the purple line.]

Specifics of 2023 hypoxia cruise

The 2023 hypoxia cruise was characterized by smooth sailing and blue, blue waters. It was difficult to document any of the expected influence of the Mississippi and Atchafalaya River plumes. Suspended sediments were minimal, and Secchi disk depths (a measure of water clarity) in the area west of the Atchafalaya River were deep, indicating much less turbidity from suspended matter (including sediments and particulate organic carbon). The "Coastal and Marine Forecast" called for 2-ft seas for the cruise departure on July 23, but the predictions for calm winds and seas of 1-ft to less than 1-ft for the cruise duration.

The winds were variable at the beginning primarily from the south with occasional winds from the north and mostly 5 m s^{-1} or less (Figure 3). The winds were primarily from the south before the cruise.

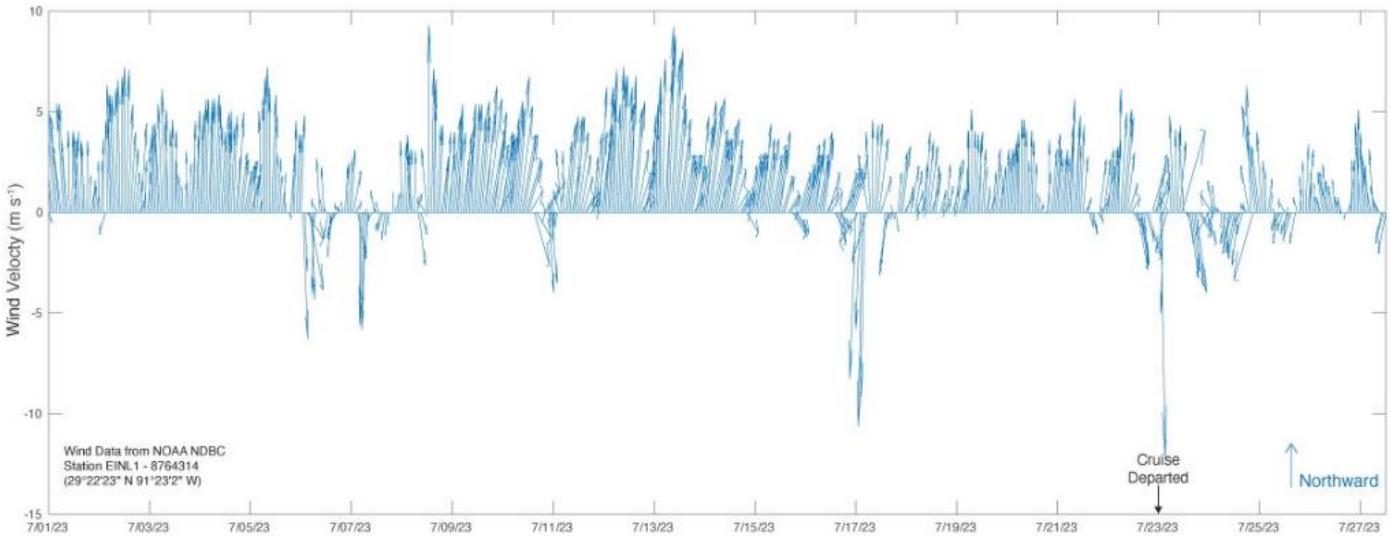

Figure 3. Wind speed and direction for the period of two weeks before the shelfwide hypoxia cruise and during the cruise beginning on July 23, 2023. Wind speed (m s^{-1}) and direction at Burrwood, LA (the arrows indicate the direction to which the winds were directed).

The calm seas were sufficient to maintain stratification, i.e., no water column mixing, at least on the eastern side of the study area. The stratification of warmer oxygenated water in the lower water column layers over the cooler, saltier bottom water was sufficient to exclude dissolved oxygen from the overlying water from diffusing into the near-bottom hypoxic waters and to maintain low dissolved oxygen. Low oxygen waters were often extremely low, near anoxic (no oxygen), resulting in the generation of hydrogen sulfide, which is toxic to animals.

The surface salinity for most of the mapped area was higher than 30 psu (practical salinity units) approaching full salinity for the coastal waters of the northern Gulf of Mexico at 35-36 salinity (Figure 4). The water column salinity from the Mississippi River to the Atchafalaya River transitioned from around 30 psu at the surface to 36 psu at the bottom, maintaining strong stratification and resulting in low bottom-water dissolved oxygen. The differences on the western portion of the study area were weaker, with a difference from 34 psu at the surface to 36 psu at the bottom, with no hypoxic bottom water.

With low discharge from the Mississippi River and the lower nutrients associated with it (not yet measured), one would expect limited phytoplankton production. Other than stations near the Mississippi River near Southwest Pass, the surface water chlorophyll concentrations were indicative of low phytoplankton biomass, less than 10 µ chlorophyll l^{-1} (Figure 5).

Still, there were sufficient quantities of organic matter from the spring vertical flux of surface phytoplankton, decayed or decaying phytoplankton cells, and organic detritus that could be degraded by bacteria to consume oxygen. Other studies of surface water production and flux of organic matter on the northern Gulf of Mexico shelf west of the Mississippi River indicate that the spring organic matter production is coincidental with high nitrogen-rich discharge from the Mississippi River and is sufficient to carry over potential organic matter into the same year's summer and beyond through several summers.

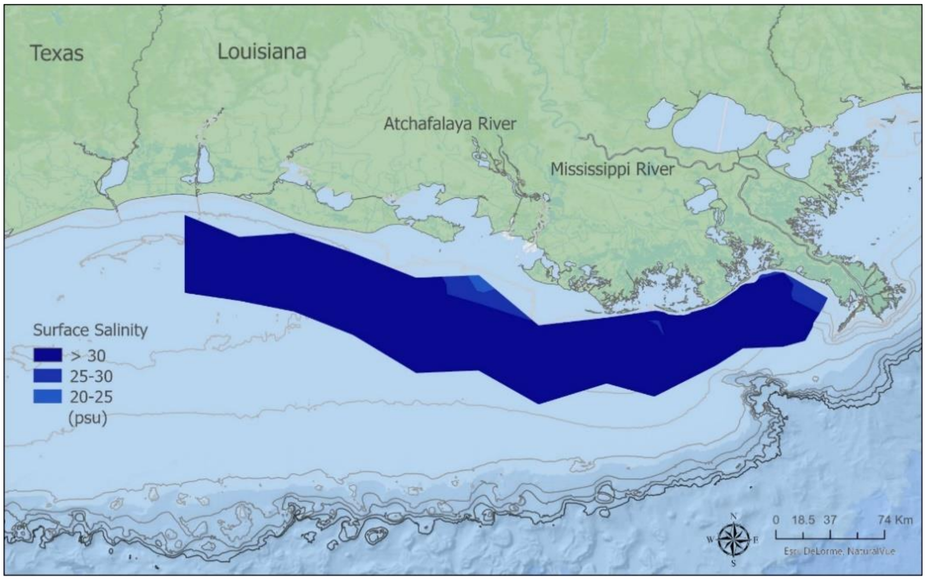

Figure 4. Surface salinity in practical salinity units (psu) for the period July 23-28, 2023.

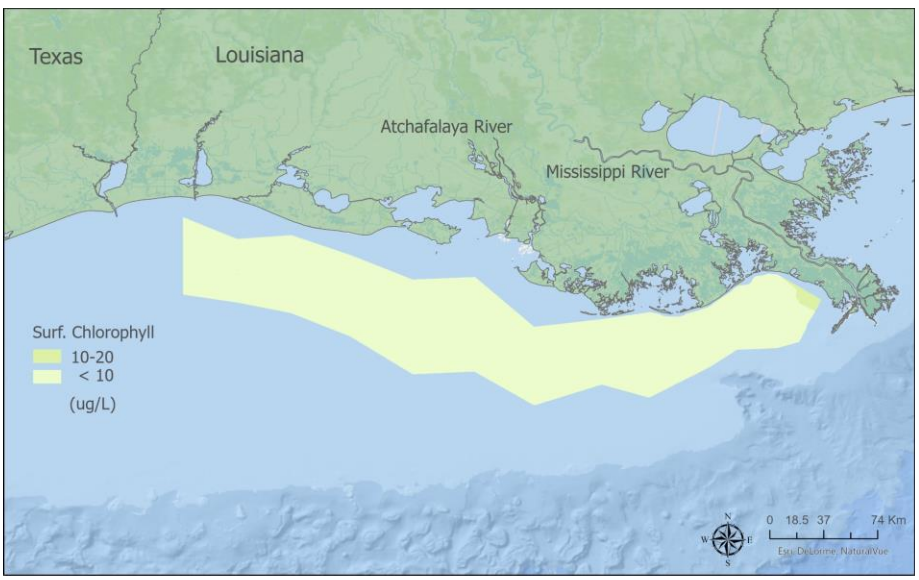

Figure 5. Surface phytoplankton biomass as measured by chlorophyll (μg l^{-1}) for the period July 23-28, 2023.

While there was little evidence of phytoplankton in the surface waters, the bottom waters had high concentrations of chlorophyll (up to 10 μg l^{-1}, as well as degraded chlorophyll (phaeopigments) in concentrations equal to or higher than the chlorophyll. These values indicate phytoplankton production in bottom waters and/or recently fluxed surface phytoplankton, along with substantial degraded phytoplankton. The organic matter near the bottom could have contributed to reduced dissolved oxygen through bacterial respiration. Bottom oxygen values were less than surface dissolved oxygen, but not below 2 mg l^{-1}.

<u>An Ocean Heat Wave?</u>

Because of the recent interest in ocean heat waves and high coastal water temperatures, we will address the initiation of the El Niño event of 2023, which is an Ocean Heat Wave in the context of the summer 2023 Hypoxia Shelf-wide Cruise. The El Niño event that is beginning to form in the eastern Pacific Ocean is also associated with a Northern Atmospheric wave that between the two will increase temperatures above the 2023-year average but are expected also to increase rainfall in the northern North America region in the 2023 winter and spring months, as happened in 2022.

However, the 2023 period of increased rainfall in spring was followed by a drought advisory for the majority of the Mississippi River watershed (Figure 6).

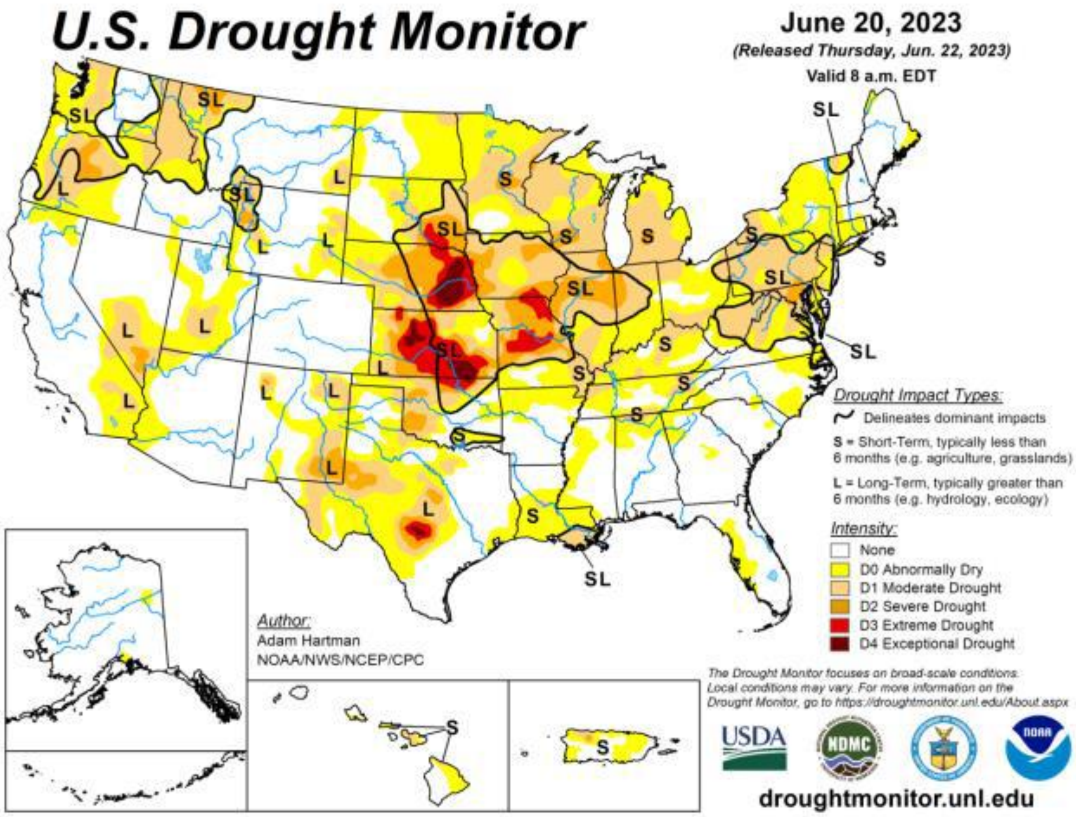

Figure 6. Illustration of the U.S. Drought Monitor for the United States (June 20, 2023; www.https://droughtmonitor.uni.edu) with emphasis for this document on the upper Mississippi watershed.

Climate change with shifts in North American air temperatures and extremes in rainfall and drought have manifested in continued high discharge of the nutrient-enriched discharge of the Mississippi river in spring followed by reduced river discharge during summer and manifested in changes in the summer dissolved oxygen dynamics of the 'dead zone' of the northern Gulf of Mexico.

Surface water temperatures of 88-90 ºF were common during the 2023 shelf-wide hypoxia cruise depending on the time of day and closeness to shore. However, the northern Gulf of Mexico values were not close to those reported at 103 ºF in Miami, FL. Bottom water temperatures in the hypoxic zone varied depending on depth and closeness to shore. The values were 75 ºF where the bottom waters were hypoxic, to 80-88 ºF where the bottom waters were not stratified and similar to the surface water temperatures.

A Way forward?

The long-term nitrogen loading from the Mississippi River to the northern Gulf of Mexico has not decreased since the Hypoxia Action Plan of 2001. The lower Mississippi River discharge in summer of 2022 and 2023 was abnormally low compared to the long-term trend and resulted in less bottom-water hypoxia during the 2022 and 2023 shelf-wide hypoxia cruise.

There remains a need for nutrient reduction mitigation within the Mississippi River watershed for the environmental and human health within the watershed and for the reduction of low dissolved oxygen in the northern Gulf of Mexico.

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