The Commonwealth of Massachusetts
Division of Marine Fisheries
251 Causeway Street, Suite 400, Boston, MA 02114
p: (617) 626-1520 | f: (617) 626-1509
www.mass.gov/marinefisheries

MEMORANDUM

To: **Dan McKiernan, Director**
From: **Tracy Pugh, Ph.D. Senior Marine Fisheries Biologist, Invertebrate Fisheries Project**
Cc: **Mike Armstrong, Bob Glenn, Kathryn Ford**
Date: **November 18, 2020**
Re: **2020 Cape Cod Bay dissolved oxygen monitoring summary**

Attached is a summary of the dissolved oxygen (DO) monitoring projects conducted in Cape Cod Bay during the summer and fall (July – Oct) of 2020. I would like to take this opportunity to recognize several individuals who were instrumental to the completion of this work. Synthesis of the results is based on conversations between myself and collaborators at Woods Hole Oceanographic Institution (Dr. Rocky Geyer and Dr. Malcolm Scully) and the Center for Coastal Studies (Dr. Amy Costa and Owen Nichols). Nick Lowell, the developer of the Data Deck Hub System and loggers used by the Study Fleet, was extremely helpful and responsive to my requests regarding data management and quality control questions. DMF staff member Vin Manfredi kept up with all of the incoming data and made it possible for me to track the results of the study fleet's loggers and communicate with the fleet in a timely manner. Communications with the fleet and other Cape Cod Bay fishermen primarily went through Beth Casoni (MA Lobstermen's Association), which streamlined the process and allowed for rapid dissemination of information about the status of the low DO event. Finally the Dept. of Fish & Game's GIS team of Dan Koch, Elaine Brewer, and Kevin Robicheau were extremely responsive while developing and testing the GIS data dashboard and I look forward to working with them to develop the final mapping applications.

2020 Cape Cod Bay dissolved oxygen monitoring and results summary

In 2019 we observed the first known instance of severely hypoxic (dissolved oxygen < 2.0 mg/L) conditions in the southern-most portion of Cape Cod Bay. This event resulted in dead lobsters, crabs, and finfish found in the traps of commercial lobstermen fishing the area. In response to concerns that similar events may occur in the future, the MA Lobstermen's Association, MADMF, the Center for Coastal Studies (CCS), and researchers from Woods Hole Oceanographic Institution (WHOI) initiated efforts to increase monitoring of water quality in Cape Cod Bay. Thankfully it appears that while we did observe low dissolved oxygen (DO) this year, it resulted in fewer reports of dead lobsters (1 confirmed report plus 1-2 unconfirmed reports from nearby), and conditions may not have been as bad as last year's event.

A decrease in the DO content of the bottom waters in Cape Cod Bay has been documented as a normal seasonal event, taking place annually in the late summer and early fall. This is at least partially driven by upstream inputs of nutrients and resulting blooms of phytoplankton and plankton that then sink to the bottom to decay. The decomposition of organic materials depletes oxygen from bottom waters, and under stratified conditions oxygen can not be replenished by mixing with the surface. The stratification of Cape Cod Bay is also a normal occurrence, isolating very warm surface waters from cooler, denser bottom waters. This stratification limits mixing and prevents the replenishment of oxygen to the bottom waters. The extent and severity of the DO decline observed in 2019 was more extreme than anything reported in the past.

To increase monitoring capacity, this spring the Lobster Foundation of Massachusetts created the Cape Cod Bay Study Fleet, and was awarded funding from the Massachusetts Climate Change Resilience in Fisheries and Aquaculture Grant Program to purchase data loggers and data deck hub boxes to deploy on five different vessels (Figure 1). These data loggers are attached to traps, and record DO and water temperature every 15 minutes. The data are downloaded wirelessly to the deck hubs every time the gear is hauled and transmitted via cell phone signals to a server on shore. The Study Fleet deployed 25 loggers starting in July of 2020, and data have been collected from these loggers all summer and fall (Figure 2). Data from the study fleet loggers are being analyzed by DMF staff, and shared with our collaborators at WHOI.

Starting this September DMF, CCS, and WHOI were awarded two years of funding from the National Sea Grant American Lobster Initiative to increase monitoring work and direct analytical efforts towards better understanding the drivers of water quality in Cape Cod Bay. Researchers from CCS have supplemented their normal monthly monitoring with additional transects in the southern portion of the Bay, increasing both the temporal and spatial resolution of data collection in September of this year. WHOI researchers have deployed two data loggers in the southern portion of the Bay, which will be retrieved and downloaded later this fall.

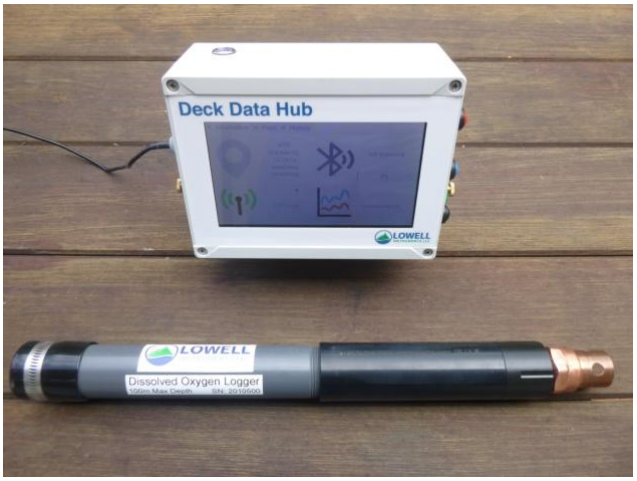

Figure 1. Data deck hub box and a dissolved oxygen / temperature logger (image courtesy of Lowell Instruments).

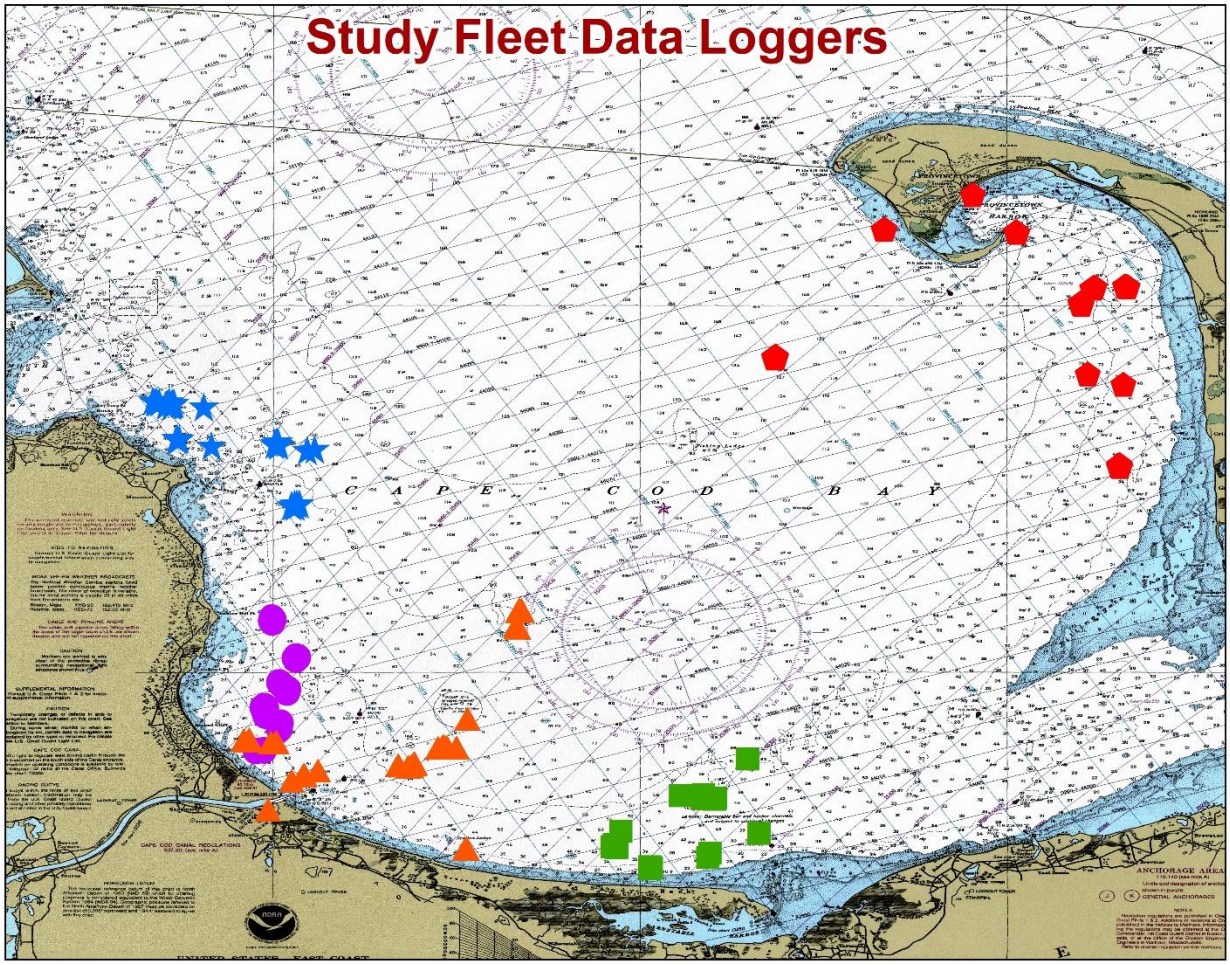

Figure 2. Data logger locations throughout the months of July, August, and September, grouped by captain/region. In the text, loggers are referred to by general region as: Provincetown = red locations, Barnstable = green locations, Canal = orange locations, Sagamore = purple locations, and Manomet = blue locations.

Monitoring results - 2020

Data from the Study Fleet loggers show that DO varied in some instances over very short spatial distances, and the loggers documented relatively drastic changes in DO over short periods of time. DO generally declined in most areas in August, particularly in the latter half of the month. The most frequent and widest-spread observations of extremely hypoxic conditions (<2 mg/L) occurred in Sept (see Figure 3). These occurred primarily in the south-southwestern-most portions of the Bay, near Barnstable, the Canal, and Sagamore. The duration of these extremely hypoxic events appeared to be relatively brief, lasting only a couple days at most; no logger recorded more than a total of 45 hours of severely hypoxic conditions (through October). However, periods of hypoxic conditions (<4 mg/L) persisted longer in many locations. There were also multiple occasions when a location was hypoxic, then experienced improved conditions but subsequently became hypoxic again.

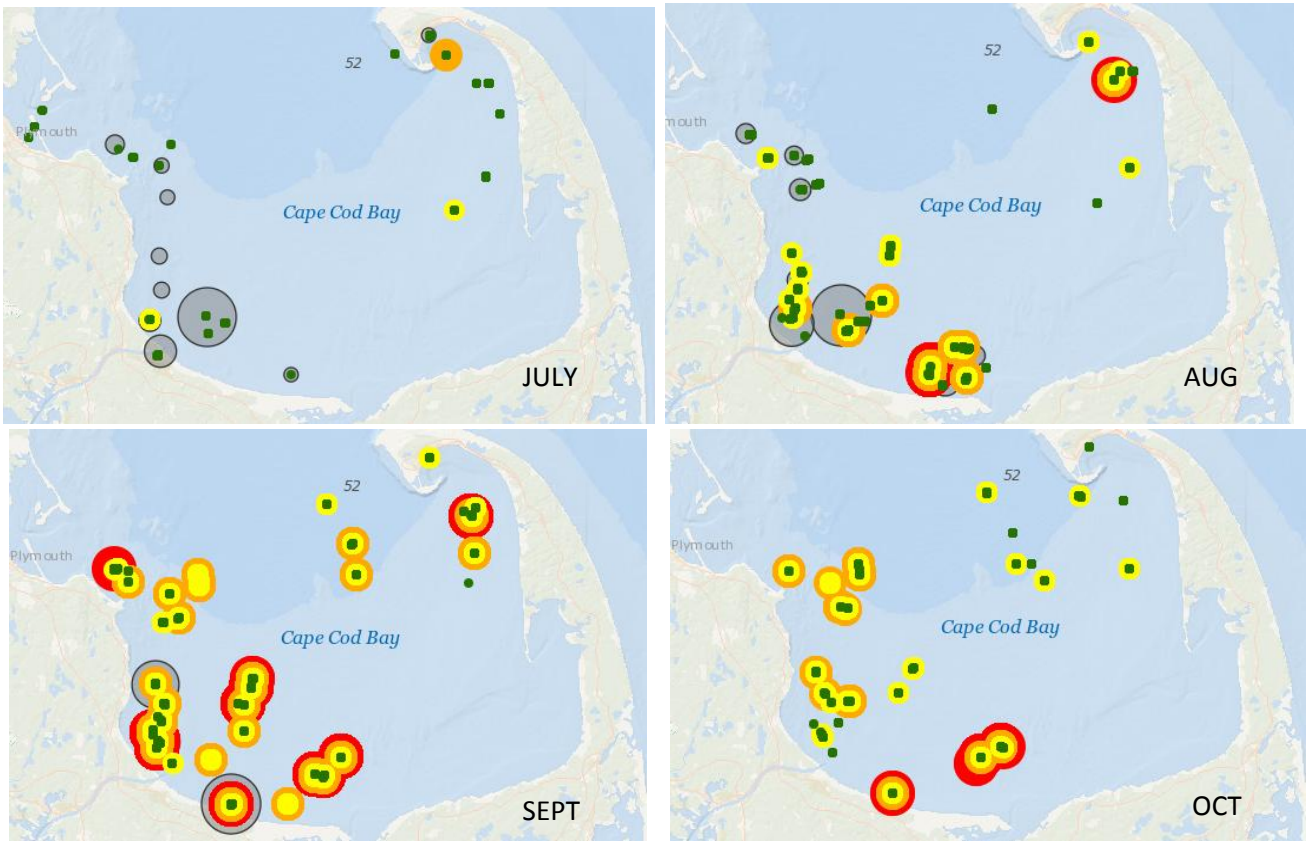

Figure 3. Screen captures from the DFG Cape Cod Bay project GIS data dashboard, showing monthly locations of data loggers and indicating in which locations low DO was observed. Yellow (DO 4-6 mg/L), orange (2-4 mg/L), and red (<2 mg/L) indicate locations where DO was low. Black and green indicate obeservations with DO > 6.0 mg/L. Note that size of the point has no meaning (sizes differ to display overlapping points).

Barnstable region

Near Barnstable, one logger (ID 2006072) documented a brief period of severely hypoxic conditions (less than 2 mg/L) for about 32 hours in mid-August, and was hypoxic (less than 4 mg/L) for about 48 hours during that time (Figure 4). DO then rapidly improved over the course of just a few hours. A similarly rapid decline followed by a rapid improvement occurred in mid-September (documented by loggers 2006066, 2006067 and 2006068; Figure 4). Low DO values were recorded again in mid-Oct (logger 2006068, Figure 4), although DO levels varied dramatically within an hour and may indicate that something was intermittently blocking the sensor. The possibility of something in the trap interfering with the sensor requires further investigation. There were a number of data gaps in these loggers; examination of these missing files issues will be part of the trouble-shooting process that will take place this winter.

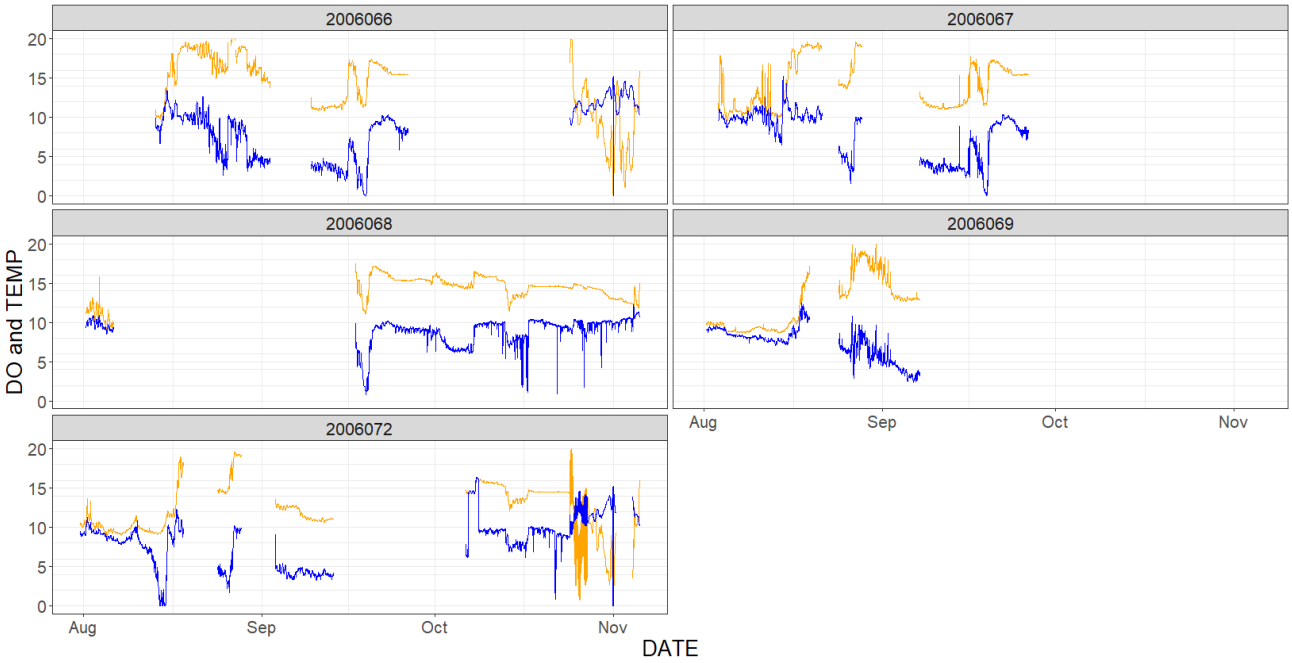

Figure 4. Data from five loggers in the Barnstable region; DO (mg/L; blue line) and temperature (°C; orange line). Note there are still some QC issues included in these graphs.

Sagamore and Canal regions

The loggers deployed in the region from Sagamore east to roughly Scorton's Ledge documented the most instances of severly hypoxic conditions. In the Sagamore region and Canal region, loggers documented a relatively steady decline in DO from mid-August through mid-September (Figure 5 and 6). In the Sagamore region, hypoxic to severly hypoxic conditions persisted for several days from Sept 8th through Sept 15th (Figure 5). Low DO conditions were observed again in early October, but improved rapidly around Oct 10th. In the Canal region two loggers documented several days of hypoxic conditions, including periods of severe hypoxia, near Sagamore (2002053) and near Scorton's Ledge (2002057) in early September (Figure 6). Three other loggers (200652, 2006054, and 2006655), all in deeper water, documented a few days of hypoxic conditons from September 14th through September 19th (Figure 6).

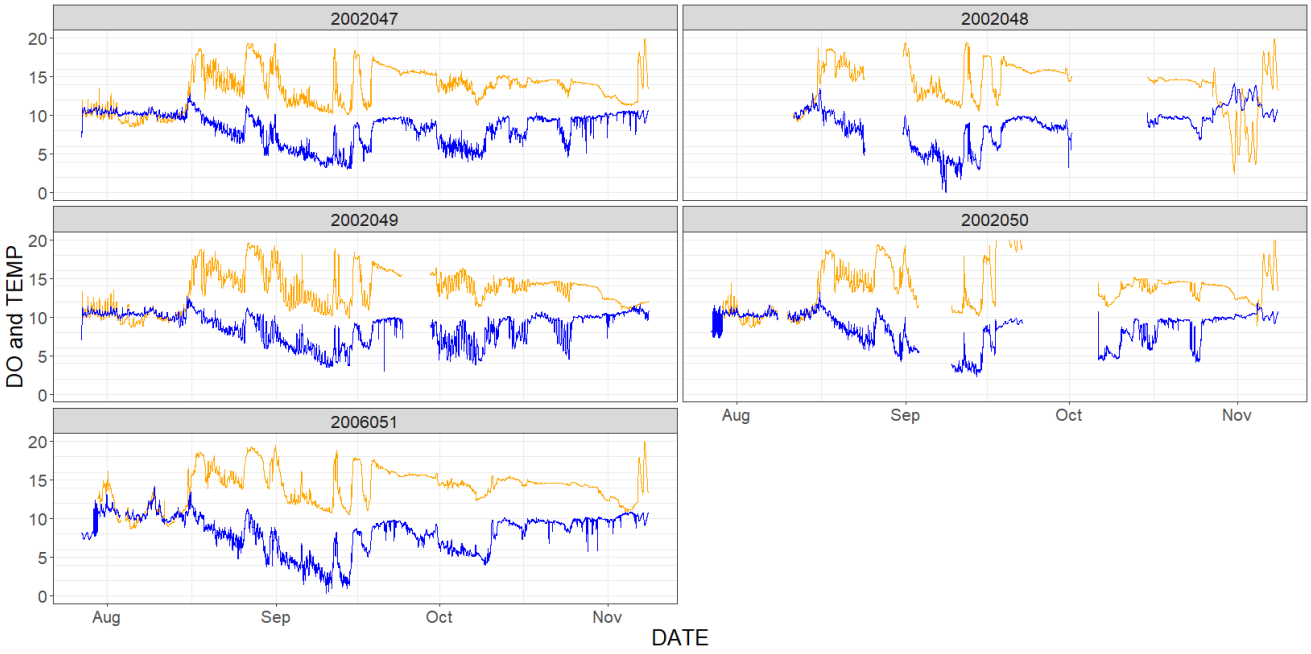

Figure 5. Data from five loggers in the Sagamore region; DO (mg/L; blue line) and temperature (°C; orange line). Note there are still some QC issues included in these graphs.

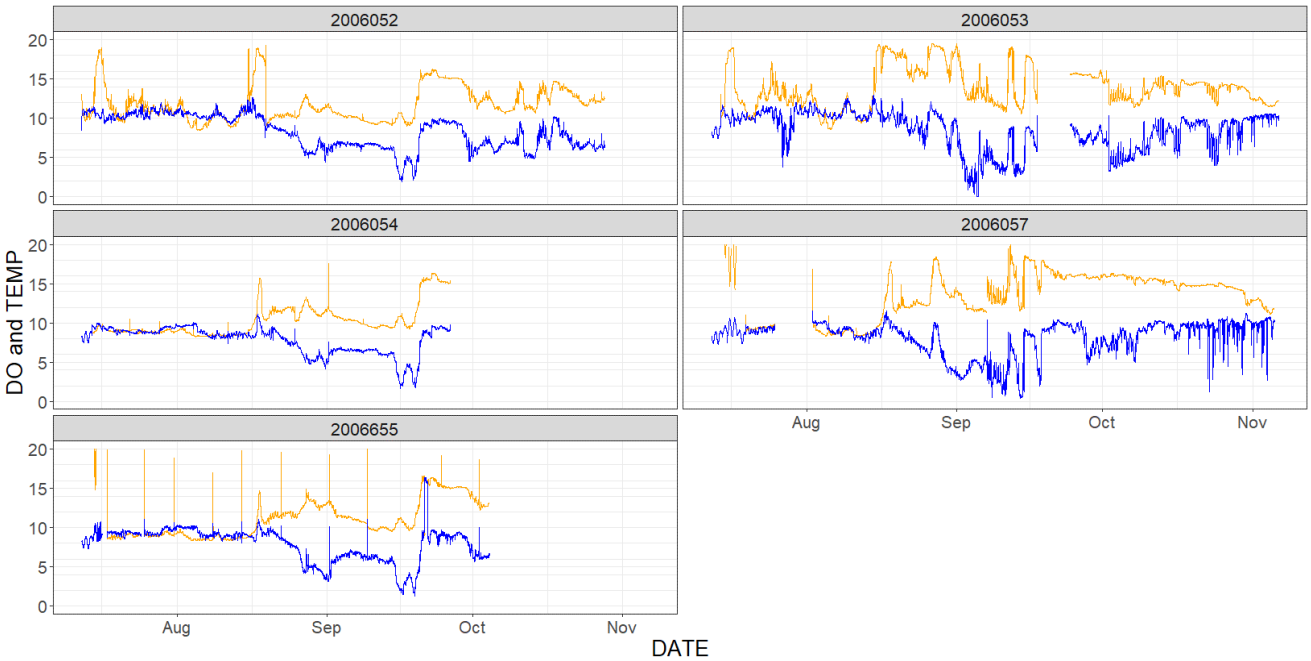

Figure 6. Data from five loggers in the Canal region; DO (mg/L; blue line) and temperature (°C; orange line). Note there are still some QC issues included in these graphs. Note also that logger ID 2006655 was recording at 1-minute intervals, thus it often captured data while the gear was on the boat deck (visible as brief temperature spikes in the graph). The other loggers recorded at the standard 15-minute intervals.

Manomet region

Loggers deployed in the Manomet region also documented a decline in DO from August through much of Sepember (Figure 7). Hypoxic conditions in this region were documented in late September and early October, but severe hypoxia was not observed in these locations (the one severely hypoxic reading from logger 2002045 shown below and visible in Fig. 3 has been identified as an erroneous reading). DO values in this region through most of October appeared to be slightly lower than values in the Sagamore region just to the south.

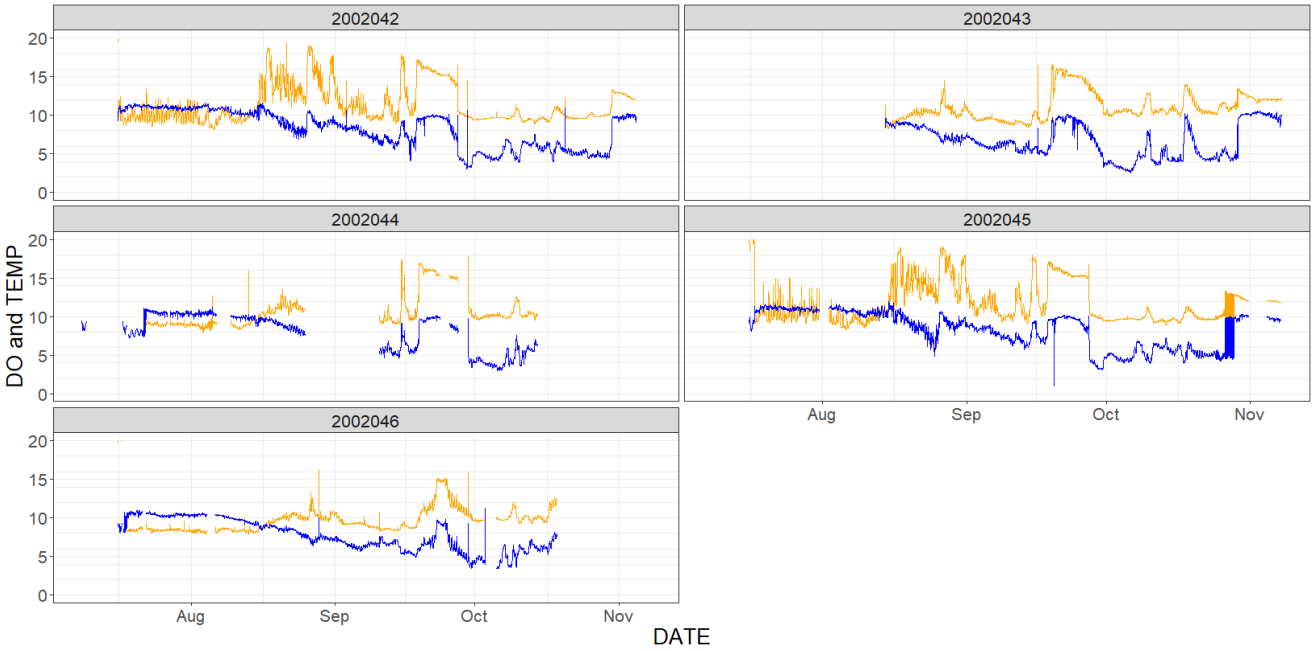

Figure 7. Data from five loggers in the Manomet region; DO (mg/L; blue line) and temperature (°C; orange line). Note there are still some QC issues included in these graphs.

Provincetown region

Dissolved oxygen conditions in the northeastern portion of Cape Cod Bay generally remained normal (above 6 mg/L) through August (Figure 8). Several loggers documented dramatic daily changes in temperature through late July and early August, but DO levels were generally more stable. At one location in the region (logger 2006061), the logger documented a general decline to low DO values, with very brief periods of hypoxic to severely hypoxic conditions. The degree of variation observed here suggests something might have been interfering with or blocking the sensor as the frequent rapid changes in DO seem highly implausible. A nearby logger (2006064) recorded much more stable conditions.

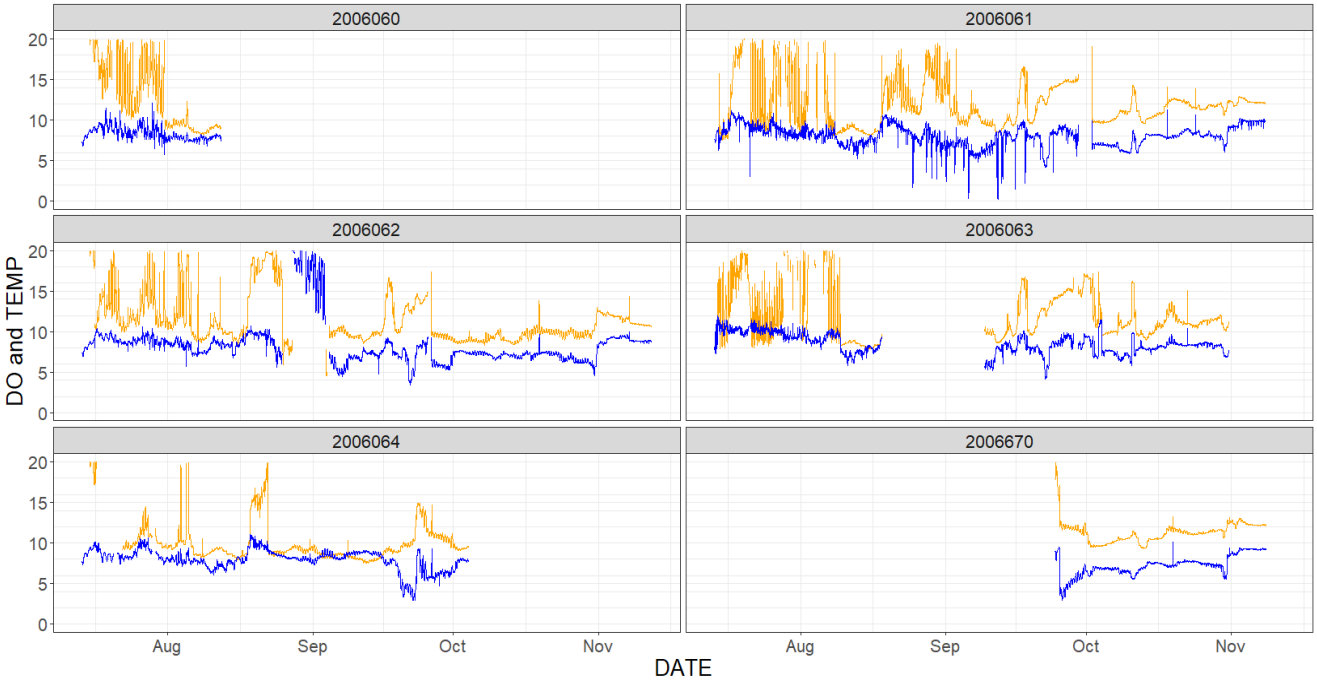

Figure 8. Data from six loggers in the Provincetown region; DO (mg/L; blue line) and temperature (°C; orange line). Note there are still some QC issues included in these graphs. Note that logger 2006060 malfunctioned, and was replaced later in the season by logger 2006670.

CCS survey data

Because of the declining DO documented by the Study Fleet's loggers in late August, CCS implemented weekly surveys to sample the entire water column along mutliple transects in the southern portion of Cape Cod Bay. Their survey results identified regions of hypoxic and severely hypoxic bottom water that tended to shift from week to week (Figure 9). On the Sept 3 and Sept 10 sampling dates, the hypoxic regions were very close to shore in waters ranging from ~30 to ~50 feet deep. On Aug 31 the severely hypoxic zone was in 60-75 feet of water, and on Sept 16 it was even deeper, ranging from about 70 to 90 feet of water. Our collaborators at WHOI have suggested that the movement of the low DO water mass is related to upwelling or downwelling conditions driven by wind speed and direction. Strong northerly winds will push surface waters towards the shore, causing downwelling along the southern shoreline, which would push the low DO mass away from shore

into deeper waters. Conversely southerly winds would blow surface waters away from shore, allowing for upwelling along the shoreline, which would cause the low DO mass to move closer to shore.

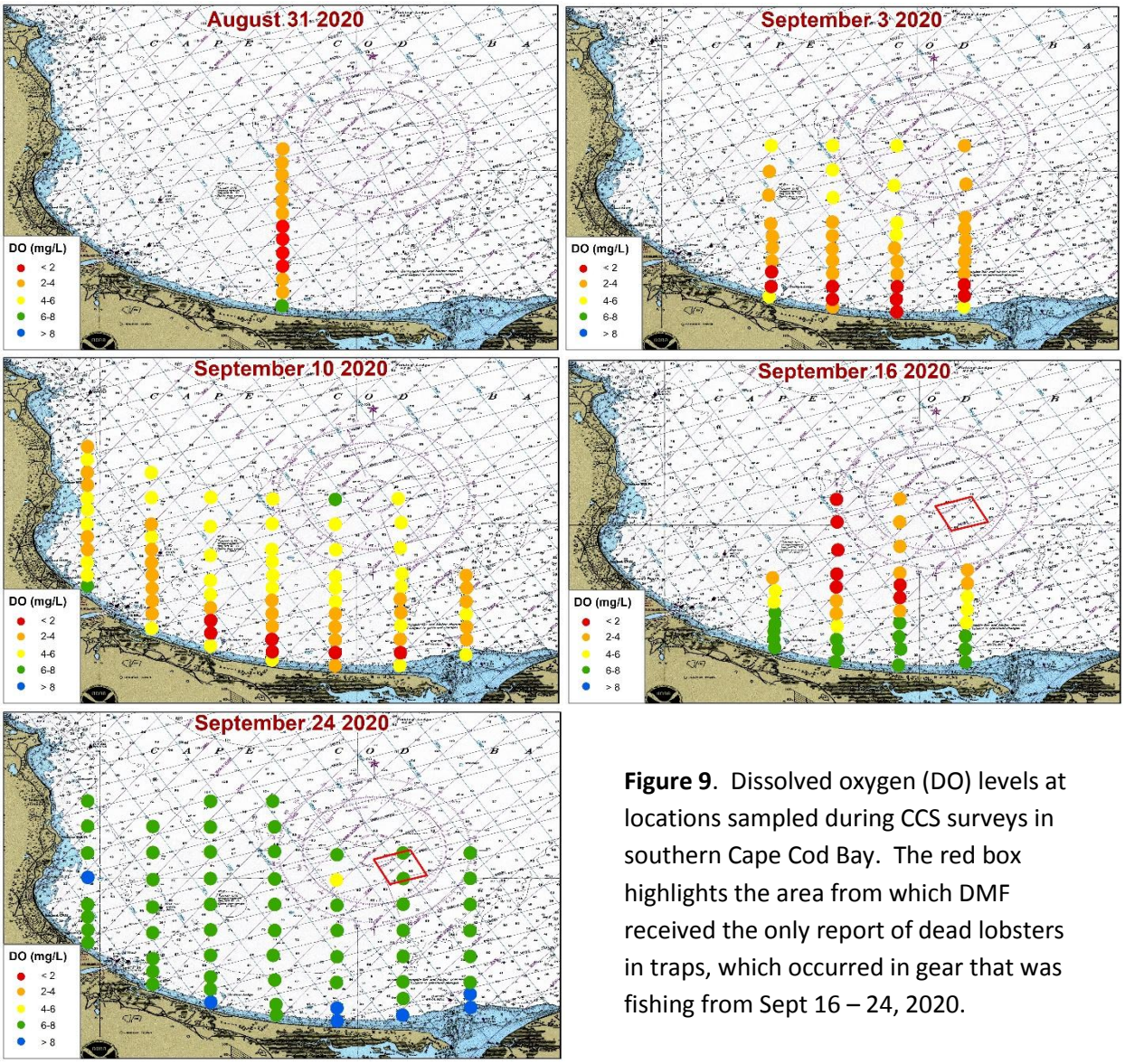

Figure 9. Dissolved oxygen (DO) levels at locations sampled during CCS surveys in southern Cape Cod Bay. The red box highlights the area from which DMF received the only report of dead lobsters in traps, which occurred in gear that was fishing from Sept 16 – 24, 2020.

2020 Summary

Dissolved oxygen in the south and southwestern portions of Cape Cod Bay declined starting in August, and depending on location reached hypoxic levels in mid to late August (Barnstable area), early to mid September (the Sagamore/Canal area and the Barnstable area), and late September to early October (Manomet area). Severely hypoxic conditions were only observed in the region from Sagamore to Barnstable Harbor, extending north to approximately 90' deep. Fleet loggers in the Manomet region did not record severely hypoxic conditions. The Provincetown region did not experience the same overall decline in DO observed in other areas, but did experience a very brief period (several hours) of low DO in mid September. With fewer reported instances of dead lobsters in the catch and only brief periods of severe hypoxia recorded by the study fleet's loggers, it appears that conditions in 2020 were better than in 2019.

Cape Cod Bay experienced relatively calm conditions for much of the summer, with less than 3 foot seas for most of July and early August (Figure 10), likely contributing to the development of stratification and isolation of bottom waters, resulting in depleted DO. CCS surveys from late August through September documented very strong thermal stratification until the Sept 24th survey date, when stratification broke down in most of the surveyed area (all but the deepest sample stations), and temperature and DO values were relatively consistent from the surface all the way to the bottom. There was a very short duration storm in late August, resulting in roughly five to six foot seas for several hours on August 26. By the second week in September Cape Cod Bay started to experience more frequent wind/wave events, some persisting for multiple days. The predominantly northerly winds that generated this increased wave action likely pushed the low DO mass into deeper waters before the rough seas finally broke it up by mixing oxygenated surface waters to the bottom. However, in some portions of the Bay relatively low DO persisted into October.

The mass of low DO appears to move around the affected portion of the Bay within the depth range of approximately 30 to 90 feet, with these shifts likely driven by wind conditions. The movements of the low DO water mass explain some of the variation observed in the Study Fleet loggers, with conditions changing relatively rapidly over the course of a day in several instances. More work is needed to link up the wind and wave conditions with the DO and temperature data recorded at specific locations by the Fleet's loggers.

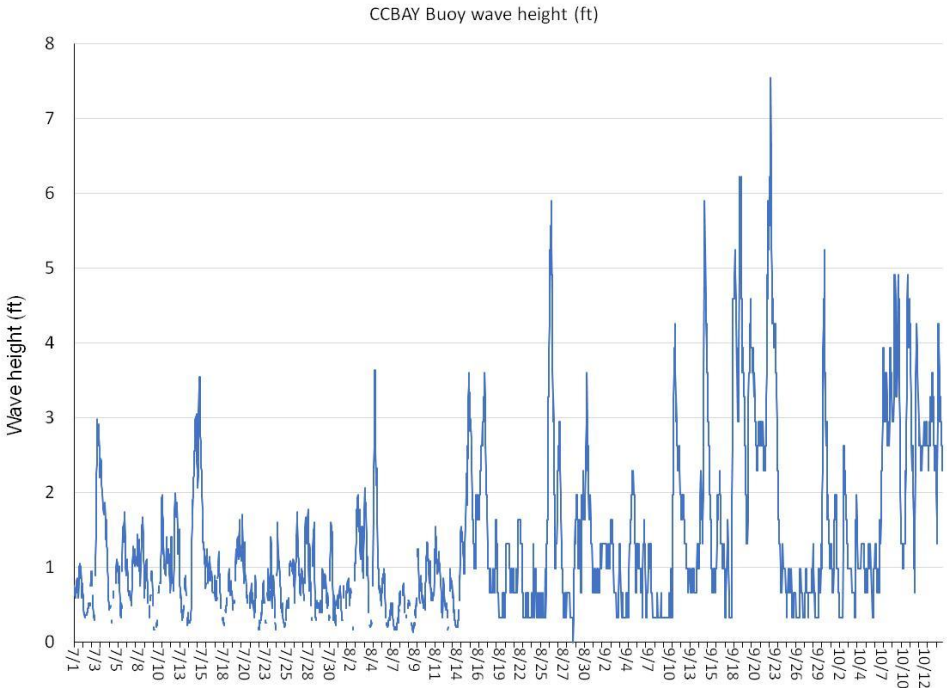

Figure 10. Wave height (feet) at the Cape Cod Bay Buoy (Station 44090) from July 1 through Oct 14, 2020.

Preliminary conclusions

The data we have collected this year from the Study Fleet and from the CCS surveys make it clear that a relatively large portion of Cape Cod Bay does experience low DO (Figure 11). It is difficult to compare this year's low DO levels to last year's, because unfortunately we don't have similarly high resolution data from the 2019 event. The mass of low DO water appears to shift around in the Bay, likely in response to wind and wave conditions. It appears that relatively high seas for more than half a day are needed to actually alleviate hypoxic conditions, as more than five foot seas persisting for several hours on Aug 26 had little effect on the overall decline of DO into September. The monitoring work would benefit from adding more fishing vessels to increase spatial coverage into the middle and north-northwestern portions of the Bay. We recommend that additional financial support be secured to add vessels to the Study Fleet for next year.

Our collaborators at WHOI and CCS will continue to compile data from this year, as well as previous years, to attempt to understand what drives the seasonal decline in DO in the southern portion of Cape Cod Bay, as well as what may have been different about 2019 to result in the severely hypoxic conditions that resulted in the deaths of trapped lobsters, crabs, and finfish.

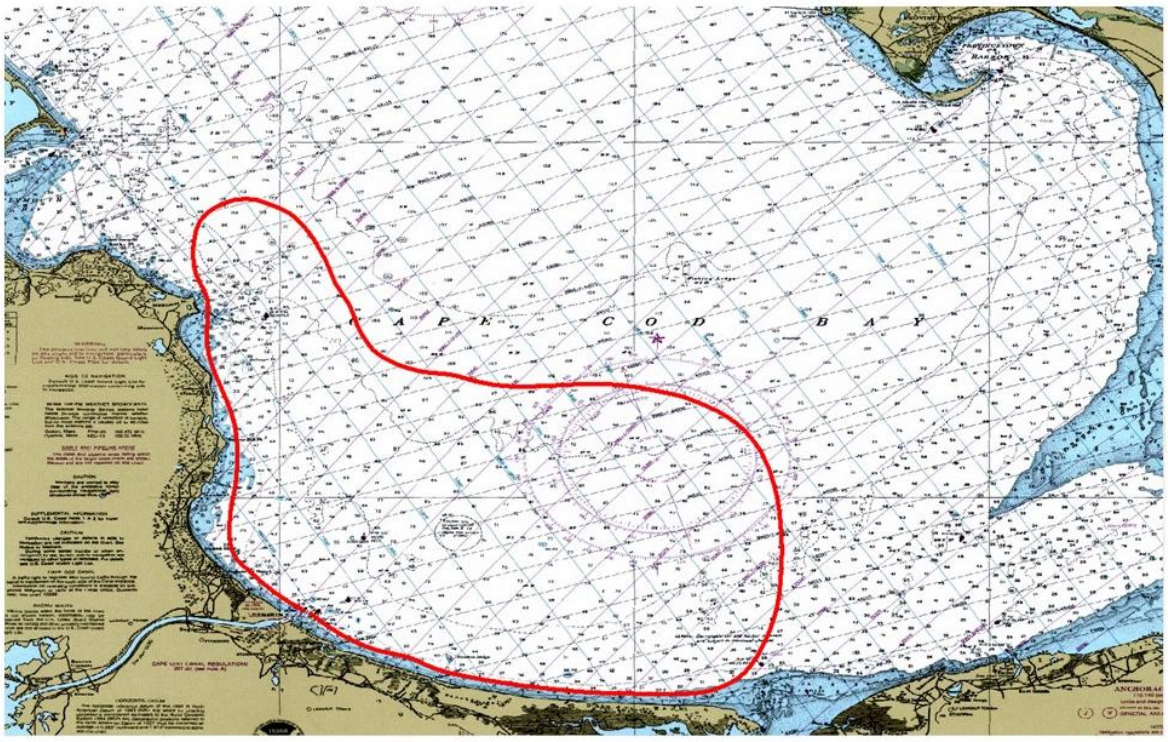

Figure 11. The affected region in 2020, where dissolved oxygen values less than 4.0 mg/L (representing hypoxic conditions) persisted for more than a day. Note that other than the vicinity around Provincetown (see Fig. 9), we are uncertain about the areas to the north and east of the outline, as we have no data in those areas.

Cape Cod Bay Dissolved Oxygen Study Collaborators

Massachusetts Lobstermen's Association and the Lobster Foundation of MA:
Beth Casoni

2020 Cape Cod Bay Study Fleet participants:
Bill Chaprales
Kurt Holmes
Bill Lister
Willy Ogg
Mike Rego

Center for Coastal Studies (CCS):
Amy Costa
Owen Nichols

Lowell Instruments:
Nick Lowell

MA Dept. of Fish & Game:
Elaine Brewer
Dan Koch
Kevin Robicheau

Woods Hole Oceanographic Institution (WHOI):
Rocky Geyer
Malcolm Scully