LONG- AND SHORT-TERM OXYGEN DYNAMICS IN MYSTERY BASIN, A FLORIDA BAY BASIN

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ABSTRACT

Adam Michael Rok: Long- and Short-Term Oxygen Dynamics in Mystery Basin, a Florida Bay Basin
(Under the direction of Christopher S. Martens)

Recent phytoplankton blooms, seagrass die-offs and major storms have significantly altered benthic communities and nutrient element cycling in Florida Bay. Central Florida Bay, where numerous small basins isolated by shallow shoals are located, has experienced many of these disturbances. New insights about the dynamics of this system were obtained through the quantification of temporal variability in physical and biogeochemical processes in Mystery Basin. Time-series measurements of dissolved oxygen concentration distributions, current speed and direction and meteorological data show a system that features dramatic daily oxygen fluctuations (70 µM/day). Regular daytime supersaturation leads to outgassing of oxygen and nighttime sub-saturation leads to diffusion of oxygen into the basin, with the average being a slightly net positive source of oxygen. Longer term fluctuations in oxygen appear to be controlled by Basin water temperatures, which themselves are dominated by atmospheric conditions.

To Mom and Dad

For instilling in me a love of the water and a desire to continue to explore the world around me.
Thanks for all the advice and direction.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FB	Florida Bay
MB	Mystery Basin
SOD	Sediment Oxygen Demand
NPP	Net Primary Production

LONG- AND SHORT-TERM OXYGEN DYNAMICS IN MYSTERY BASIN, A FLORIDA BAY BASIN

Introduction:

Florida Bay (FB), a 2200 km^2 estuary, is mostly contained in the Everglades National Park and Florida Keys National Marine Sanctuary (Rudnick et al. 2005). It is a shallow water system, with the majority of the bay having a water depth of less than 3 meters (Fourqurean and Robblee 1999). The shallow water depth allows for full depth penetration of sunlight, driving primary production, largely by seagrasses, throughout the entirety of the Bay (Yarbro and Carlson 2008). Seagrass meadows are the dominant ecosystem in most areas (Carlson et al. 2018). FB can be divided into four unique physical areas, each experiencing differing freshwater imports and exports and salinity variations (Nuttle et al. 2000), creating zonation within the bay.

During the last 50 years, major ecological disturbances recorded in the Florida Bay system (Butler et al. 1995) have included large-scale phytoplankton blooms that have led to massive sponge population die-offs (Butler et al. 1995; Phlips et al. 1999) and seagrass bed thinning and die-offs (Fourqurean and Robblee 1999; Zieman et al. 1999; Carlson et al. 2018). In addition to these events, there have been multiple major storms, including hurricane Donna, whose eye passed north over Duck Key and directly into Florida Bay, east of Marathon, on September 10, 1960, and most recently, Irma, whose eye crossed north over Cudjoe Key into the Gulf of Mexico on September 10, 2017. These and other major storms have generated dramatic impacts on the ecosystem zones they pass over, modifying chemistry, turbidity, sediment deposition and benthic vegetation (Smith et al. 2009). Biogeochemical changes from these events could have lasting impacts on the bay as new ‘normal’ conditions are reached after each successive event.

Large phytoplankton blooms, generally lasting for months, have occurred throughout most areas of Florida Bay (Butler et al. 1995). Blooms sometimes follow major storms and are associated with elevated nutrient concentrations (Hoer 2015, Hoer et al. in prep). Due to their large spatial and temporal scales, these episodic bloom events can have significant impacts on all pelagic and benthic communities in the Bay. The blooms generally lead to extreme water column turbidity and extensive losses of sponge biomass (Butler et al. 1995; Sharp B. FWC-M, Pers. Comm. 04/15/2018) along with other ecological disturbances such as rapid changes in nutrient concentrations and hypoxia. It is generally thought that extensive seagrass die-offs are caused by hypersaline conditions that often occur in the Bay during the winter/spring months (Johnson et al. 2018). Florida Bay has a natural seasonal salinity high during winter/spring and a low during fall/summer (Kelble et al. 2007). These die-off events typically occur during the seasonal salinity high when parts of the bay can reach a salinity of upwards of 40 psu (Kelble et al. 2007).

Significant alterations of biological and chemical parameters occur during and after each storm and bloom disturbance. Due to the fact that most of these events are not one-off scenarios, it is important to understand their links to both short term and longer time scale changes in various chemical parameters and water transport processes. This study focuses on the central/western Bay area because of the longer flushing rates thought to occur there as a result of more restricted water circulation in basins surrounded by shallow sills (Lee et al. 2016).

Specifically, this region of Florida Bay has been observed to have flushing rates on the order of 2 to 4 weeks (Lee et al. 2016).

Other studies of coastal oxygen dynamics designed to reveal temporal and spatial variability have been conducted in water bodies around the world. Understanding what processes could lead to hypoxic conditions in these environments has been the main driver for these types of studies. Hypoxic conditions can cause harm to benthic habitats and fish communities (Rabalais et al. 2002) and lead to alterations in biogeochemical cycles (Mortimer 1941, Smith et al. 1989). In the Gulf of Mexico there has been research on what biogeochemical and physical factors lead to the formation of hypoxic 'dead zones.' Here it has been found that physical processes creating strong stratification and elevated primary production due to excess nutrient load lead to the development of these hypoxic zones (Rabalais et al. 2002). Similar studies have also been done in the Baltic Sea. In this system it has been found that oxygen levels are controlled by sporadic water renewal and rates of vertical mixing (Gustafsson and Stigebrandt 2007). As hypoxic levels grow and change in aquatic systems throughout the world, it is important to understand what processes control oxygen distributions and renewal rates so that better management practices may be put into place and future impacts be assessed.

Mystery Basin (MB), a small but representative basin in central Florida Bay, has experienced several recent blooms and major storm events. Quantification of oxygen dynamics in MB provides information useful for understanding the impact these events can have on the health of the central Bay area. We selected Mystery Basin as a representative site based on several factors including the availability of previous research by Hoer et al. on water flushing rates and sponge biomass surveys before a massive 2013 bloom event (Hoer 2015; Hoer et al. 2019). The goal of this study was to better understand the dynamics behind short- and long-term oxygen changes within a central FB basin. To accomplish this goal, we generated a model that could be utilized to determine oxygen budgets based largely on in-situ oxygen production by primary producers, air-water gas exchange, sediment oxygen demand, and tidally driven water exchange rates. The results should help lead to a more quantitative understanding of the temporal dynamics in central FB and how they may change due the various seasonal and episodic events.

Experimental Sites and Methods:

A variety of in-situ sensors were deployed at 14 sites in Mystery Basin in order to collect the continuous time-series data needed to understand oxygen dynamics.

Study Sites:

All data for this study was collected within Mystery Basin, a small basin approximately 4.2 km^2 in area, centered at 24°56’30.51” N, 80°49’32.18” W in Florida Bay. Mystery Basin is located within the Everglades National Park boundaries and exists within a matrix of other shallow basins ranging in area from 3.5 to 15 km^2. Its water exchange with surrounding areas is restricted by shallow sills, most of which have a depth of less than 50 cm (relative to mean low water height) depending on seasonal changes in overall Florida Bay water level (Lee et al. 2016). However, the deepest sill located on the North-West side of the basin (depth of approximately 65 cm at mean low water and width of 1 km) allows for the largest and most consistent tidal exchange within surrounding waters (Hoer 2015). The center of the basin is the deepest, with a seasonally-averaged depth of 1.5 m (during 2017-2018 deployment), relative to mean low water, becoming shallower near the sills. Mystery Basin has a typical tidal range of approximately 0.25 m (based on observed 2017-2018 data). The exposed sediment of the basin consists mostly of calcium carbonate mud and sand. The other areas, including most of the sill areas, are covered by seagrass beds (Perkins 1977; Prager and Halley 1997). Seagrass beds ring the outside of the basin (Fig. 1), covering approximately 20% of the benthic environment (Hoer 2015, Hoer et al. 2019). Mystery Basin waters generally experience seasonal salinity changes ranging from as low as 33 psu in the spring to as high as 37 psu in the fall (Kelble et al. 2007). Previous research has demonstrated that Florida Bay's depth changes seasonally, following the winter/spring dry season and summer/fall wet season (Nuttle et al. 2000; Lee et al. 2016).

In-situ Oxygen and Current Sensor Array:

From December 2017 until April 2018 a multi-sensor array was deployed in the center of Mystery Basin (HOBO 1, Fig. 1) to continuously measure oxygen concentrations and current velocity. An Aanderaa Seaguard® logger system collected data from four oxygen optodes, one pressure (depth) sensor and one Z-pulse DCS (doppler current sensor) from December 4, 2017 to April 3, 2018. Oxygen optodes were deployed in a vertical array, with measurements being taken at 10, 20, 30 and 60 cm above bottom. Aanderaa Optodes have a precision of 2 μM and were 2-point calibrated in oxygen saturated and depleted water before deployment and then again within one month after the sensors were recovered. Sensors were wrapped in copper wire to prevent bio-fouling. The Z-pulse current sensor was placed 80 cm off bottom and the pressure sensor was 10 cm off bottom. All sensors took continuous measurements every 5 minutes for the duration of their deployment. Due to mechanical/electrical problems, there was some loss of data from the oxygen, depth and current sensors in mid-December, 2017 and mid-January, 2018.

Sediment Oxygen Demand:

Sediment oxygen demand (SOD) was measured using the stirred benthic chamber method as utilized in many previous studies (e.g. Bowman and Delfino 1980; Edberg and Hofsten 1973; Hall and Berkas 1988). Three clear, one dark and one blank control chamber were deployed at multiple sediment sites near the center of Mystery Basin. The chambers were 30 cm long x 30 cm wide x 20 cm tall. The chambers covered the sediment for approximately 7 to 8 hours before being lifted, flushed with new Basin water and re-deployed over a fresh patch of relatively clear sediment. The chambers were deployed at random locations, with the only stipulation being that they be placed over an area of sediment that had little observable macro algae or seagrass in order to avoid the influences of primary production and respiration. The blank control chamber was a clear chamber, closed off at the bottom allowing for a measurement of changes in oxygen within the water column alone, separate from the sediment. Resulting rates of oxygen change in the dark chamber were used as the measured SOD values. The chambers were slowly stirred with a mixing bar to ensure a uniformly mixed system. An Aanderaa oxygen optode was placed inside each chamber to continuously measure the oxygen production or draw-down during the course of each experiment.

Air-Sea-Gas Exchange:

Air-sea-gas exchange was estimated for the entire length of the in-situ deployment using the equation (Donelan and Wanninkhof 2002):

Eq 1. $$F = k(C_w - {}^*C_0)$$

Where F is the air-sea gas flux (mol/m^2/hr), k (m/hr) is the gas transfer velocity, C_w (mol/m^3) is the measured concentration of oxygen in the water column at 60 cm off bottom and $^*C_0$ (mol/m^3) is the concentration of oxygen in seawater (calculated using the formula presented in Garcia and Gordon 1992). Unit conversions are made between µM and mol/m^3 for oxygen concentration and from cm/hr to m/hr for transfer velocity. The gas transfer velocity was calculated using the equation described in Borges et al. (2004):

Eq 2. $$k = (4.045 + 2.58u_{10})*(600/Sc_o)^{1/2}$$

Where u_{10} is the wind speed (m/s) at 10 m height and Sc_o is the temperature dependent Schmidt number for oxygen (Borges et al. 2004). The Schmidt number was found using the formulas presented in Wanninkhof (1992). A conversion factor is built into the equation to take m/s from wind speed to cm/hr for k. Wind velocity at 10 m height was taken from a NOAA buoy located just off of Vaca Key, station VCAF1 (24°42'40" N, 81°6'24" W). The coefficients were calculated with an assumed constant salinity of 34 psu, based on seasonal salinity profiles of these region of FB as presented in Kelble et al. 2007.

Tidal Flushing Rate:

The mean flushing rate of MB was estimated in order to assess the importance of water column oxygen fluxes into/out of MB relative to processes within MB. Onset Hobo® pressure sensor loggers were deployed in a variety of locations both inside and outside of Mystery Basin (Fig. 1) from November 2013 to April 2014. Utilizing the tidal amplitudes determined from these measurements, a mean flushing rate was calculated using equation 3 (Dyer 1973).

Eq 3. $$\tau = \frac{V+P}{P} \cdot T$$

Where τ is the flushing time (hours), V is the volume of water at low tide (L), P is the tidal prism (high tide volume minus low tide volume) and T is the tidal period (hrs). This is the classic tidal prism model that has been outlined and modified by Officer (1976), Dyer (1973) and others. This model was chosen because it provides a relatively simple way to get an estimate for tidal flushing rates. The model assumes that the system is well mixed and that all incoming water during high tide is immediately, uniformly mixed throughout the system. Due to the placement of our oxygen array in the center of MB, this model is most likely an underestimate of the tidal flushing rates at the center of the Basin.

To calculate the MB’s volume at low tide and the tidal prism, Hobo water level data from multiple points within the basin were averaged to compute the mean tidal range. Using this data, along with the known surface area of the basin, all other values were calculated.

Results and Discussion:

In-situ variability in Currents and Water levels:

The Z-pulse current sensor located in the center of the basin measured generally low current speeds, with the average current velocity for the December to April, 2017/2018 period being 3.9 cm/s (Fig. 2). Speeds exceeded 10 to 15 cm/s regularly, but these currents generally lasted from a few hours to less than 2 days (seen in December 2017).

The time-series record of currents revealed a clear tidal signal, with mean directions of 100 (15) and 290 (15) degrees (values in parentheses are ± one standard deviation) during incoming and outgoing tide, respectively (Fig. 2). The dominant tidal flow was approximately in and out over the deepest sill, located to the northwest of the basin (Fig. 1). This finding agrees with previous observations (Hoer 2015) that this deepest sill provides the primary conduit for tidal exchange between Mystery Basin and surrounding waters. Starting in mid-February, there was a pattern of consistent northwest flow out of the basin and a slowing of current speeds. This coincided with a shift in wind direction (towards 100 degrees), which most likely aided in ‘pushing’ water out of the basin across the shallower sills (Fig. 3).

It is known that the central basin area of Florida Bay experiences seasonal water level changes (Lee et al. 2016), however, beginning in January 2018 (Fig. 4) we recorded a large decrease in water level relative to previous PSMSL buoy observations (https://www.psmsl.org) and other previous studies (Fig. 5, e.g. Lee et al. 2016). This water level drop occurred during the known winter/spring dry season and aligned with a shift in the wind field (Fig 3). This same water level drop can be seen in other NOAA Buoys located throughout the bay. Buoys located in the Johnson Key, Peterson Key and Whipray basins all observed a decrease in water level that coincided with our measured drop. The average decrease in water level of these 3 locations was approximately 40 cm. We witnessed a drop of 45 (10) cm within MB. This represents the lowest level the bay has seen over the last 6 years but is still within previously measured, water levels, as seen earlier in the Vaca Key time series (Fig. 5).

In-Situ Oxygen Measurements:

Large daily variations in oxygen concentration throughout the study period were observed (Fig. 6). Peak oxygen concentrations occurred between 1 and 4 pm local time, and minimum oxygen concentrations occurred between 4 and 6 am (Fig. 7). An average daily range of approximately 70 µM was observed. Both Fig. 6 and 7 show a highly variable system with daily changes in oxygen and temperature roughly aligning with day/night cycles. Fig. 6 shows that the system regularly reaches supersaturated conditions during day time-hours and sub-saturated conditions during night-time hours. Over the entire record, MB is on average slightly supersaturated at around 109% (Fig. 6). Daily variability can also be seen by the presence of a 24-hour peak in the power spectra for oxygen concentrations (Fig. 8). The presence of this dominate peak affirms what is seen in the in-situ time record. Water temperature has the same daily variability, with a daily range of 1 to 1.5 °C (Fig. 7). The observed diurnal oxygen fluctuations are likely driven by changes in primary production through daily fluctuations in light levels (Fig. 9). No-sky light levels peak during mid-day (noon to 1 pm), closely aligning with the peak in oxygen levels (Fig. 7). Minimum oxygen levels just before day-break also indicate a system dictated by light levels influencing rates of primary production.

Outside of the daily variations, there was also longer-term variability in the oxygen record. By removing the daily fluctuations in the oxygen and temperature records, through 24 hour averaging of the data (Fig. 10), we are able to see that on time scales longer than one day, oxygen concentrations are negatively correlated with temperature. It can be seen that oxygen concentrations vary as a function of water temperature, with larger concentrations correlating to colder water and vice versa (Fig. 11). This oxygen vs. temperature correlation also indicates that the basin is frequently super-saturated with dissolved oxygen.

Generally, the water column fluctuated between super-saturated during daylight hours and sub-saturated during night hours (Fig. 6). During the month of February, oxygen concentrations and the calculated daily standard deviation (Fig. 6 and Fig. 12) increased. In February the oxygen time series (Fig. 6) becomes less noisy and shows a wider envelope of daily oxygen concentrations. This elevated variability could be due to a change in cloud cover, and thus, available light. Utilizing data collected from the MODIS system on NASA’s terra satellite, we were able to get an estimate of the monthly cloud cover fraction over FB. During the month of February 2018, the average cloud fractional cover over FB dropped to 0.20 from 0.60 during January and 0.35 during December. This data aligns with the findings in a 2002 USGS Florida Bay light report. In their report, Carlson et al. (2002) found that lowest light levels occurred during the months of November, December and January; highest levels occurred during March, April and May. February, then, is a transitional time from low to high light levels. It is possible stable water temperatures (Fig. 6 and 10), currents (Fig. 2), decreased water level (Fig. 4) and elevated light reaching the water’s surface all allowed for elevated daily primary production and respiration, leading to increased daily variability during the month of February. The oxygen time-series signal is mixed, however, revealing the combined effects of primary production and respiration plus air-water gas exchange and SOD.

Sediment Oxygen Demand:

The dark chamber showed very little to no draw down of oxygen, and in fact indicated a slight increase in oxygen (Appendix 1). Over the course of 8 hours there was only a change of 2 µM, which is within the detection limit of the optode sensors themselves. Because of this, and the uptick in oxygen, this data series cannot be used to calculate SOD. Clear chambers, showed a consistent uptick in oxygen concentration as did the water column blank chamber. These values indicate that water column primary production could potentially be a significant source of oxygen to MB. Also possible is the presence of benthic algal mats. Because the basin is so shallow and the water was extremely clear during the SOD deployments, it is possible that benthic algal mats, as evidenced by a slime/biofilm layer located on top of the sediment, could produce some dissolved oxygen. The presence of the mats was indicated by a slimy layer on the sediment surface that could be felt by hand.

Air-Sea Gas Exchange:

The air-sea gas exchange time series data indicate a trend of out-gassing of oxygen during daytime supersaturated conditions (Fig. 13). Diffusion into the basin during nighttime sub-saturated conditions also occurred. There was an increase in variability in air-sea gas exchange during the month of February (Fig. 13). This is being driven by the increased variability of MB in-situ oxygen concentrations (Fig 6.). Overall there was net out-gassing of oxygen over the course of this study. The average oxygen flux out of the basin through the water surface was 3.0×10^{-3} mol/m^2 hr (Fig. 13). Across the full surface area of the basin (4.2×10^6 m^2) this represents a net basin-wide export of 1.2×10^4 mol/hr.

Tidal Basin Water Flushing Rates

HOBO sensors deployed from November 2013 until April 2014 at positions HOBO 1, 2, 3, 4 and 5 (Fig. 1) were used to estimate the average tidal range in the basin, which was found to be approximately 0.25 m and the average depth during this year (2013-14) was 1.82 m.

Using the calculated values for the tidal prism model, a range of flushing rates were calculated in Table 1. It can be seen that flushing for the basin can range from 4 to 7 days. Under both of these conditions, flushing rates of MB are multiple days, indicating that the large daily fluctuations in oxygen concentrations recorded are being driven by processes inside of the basin, because flushing rates are occurring on time-scales longer than the daily variability.

Month	**Max Flushing**	**Min Flushing**
November (13)	6.3	4.3
December (13)	7.0	3.2
January (14)	6.3	2.5
February (14)	7.0	3.8
March (14)	7.5	3.3
April (14)	5.8	4.0

Table 1: Monthly maximum and minimum daily flushing rates for Mystery Basin. All values represent number of days. Numbers in parentheses in the month’s column are the years the data was collected.

Oxygen Budget Calculations

The oxygen budget in the basin can be expressed (eq 4) as:

$$V\frac{dC}{dt} = A(\sum R) - A\big(k(Cw -* C_0)\big) + (Q_{in}C_{out} - Q_{out}C_{in})$$

1 2 3 4

Eq 4: Oxygen budget equation for Mystery Basin. 1 is the oxygen rate of change within the basin, 2 is net respiration, 3 is air-sea gas exchange, and 4 is advective flow in and out of the basin. A is surface area of MB, V is volume and Q is water transport into/out of MB.

Equation 4 includes terms for each of the processes to be considered in our budget calculations. Rates of each process were either determined from our field measurements, previous studies, or calculated from data available from NOAA weather buoys as described above.

In-situ water column oxygen measurements from the center of the basin were used to calculate term 1 (oxygen rate of change within the Basin). The dissolved oxygen varied heavily on a day-night cycle (Fig. 6 and 7) indicating a system largely under the influence of primary production due to daily changes in sunlight. Calculated air-sea gas exchange rates were used for term 3. In-situ measurements of SOD could not be derived, but SOD of the system will be accounted for in the net respiration variable (Term 2). Term 4, representing advective fluxes into and out of the bay, was also set to zero. This was done because advective fluxes should have little impact on MB. If the system were to have major inputs from advective sources, we would expect to see the time-series oxygen record vary on a tidal time frame (oxygen fluctuations in phase with tidal fluctuations). This is because tidal fluctuation (which are the dominant source of water movement in MB as indicated in Fig. 2) would transport oxygen rich or depleted water into/out of the basin, having an impact on the oxygen budget. In our record we observed oxygen values varying on a day-night cycle and not a tidal one. This indicates that any advective sources are minor since no tidal oxygen signal is detected in the oxygen time series. Another reason for excluding this term is that our flushing rates are on the order of multiple days. This represents a significantly longer time scale than any tidally driven advective flux into or out of the basin, which would be on the order of hours, again making this term have a minor impact on the larger oxygen budget. This is because any tidal flow would become well mixed throughout MB before being exchanged out of the basin.

Utilizing eq 4, we are able to solve for a $*\sum R$ value that includes unaccounted oxygen sources and sinks, creating a combined time series record in MB. This $*\sum R$ value encompasses $\sum R$ along with oxygen sources and sinks other than air-water gas exchange. By subtracting out our spatially-scaled air-sea gas exchange values from the rate of total oxygen change, we can solve for the $*\sum R$ value that includes these unknown sources and sinks (Fig. 14). $*\sum R$ values closely follow the main short- and long-term patterns observed in the in-situ MB oxygen concentrations, with an average value of $2.1\text{x}10^{-3}$ mol/m^2 hr. There are daily fluctuations of the $*\sum R$ values, peaking in the afternoon (with higher daylight and water temperature) and reaching a minimum just before daybreak (with lower sunlight and water temperature). The average day time production was $1.03\text{x}10^{-2}$ mol/m^2 hr and night time respiration was $-1.04\text{x}10^{-2}$ mol/m^2 hr. This could indicate that the main contributor to this value is $\sum R$ (Fig. 14) due to clear production during the day and respiration during the night. The value of $*\sum R$ does tend to be centered around zero (Fig. 15), indicating that night time respiration demands are mostly met by daytime production of oxygen. Variance in the $*\sum R$ record increases in February as weather conditions become calmer, temperatures stabilize and cloud cover decreases.

In order to quantify $*\sum R$ it helps to understand how this system compares to other oceanic and coastal environments. In a coastal shelf environment off of Louisiana, it was found that phytoplankton community respiration rates ranged from $4.0\text{x}10^{-4}$ mol/m^3 hr at the surface to

2.0×10^{-4} mol/m^3 hr at the bottom (Murrell et al. 2013). In the upper parts of Plum Island Estuary, MA, max community respiration rates were found at 1.4×10^{-2} mol/m^3 hr (Vallino et al. 2005). MB's single daytime production and nighttime respiration values are a comparable magnitude to an estuarine system's community respiration. Overall, though, MB's net respiration values are smaller than those recorded in the estuary, but still larger than a more open ocean environment. Near-by basins with more seagrass beds could potentially have net respiration values more directly comparable to the Plum Island Estuary.

Contributors to $^*\sum R$

Our calculated $^*\sum R$ is a general term encompassing all primary production, respiration and other sources and sinks except for air-sea gas exchange. However, we can make estimates for the contributions that sponges and seagrasses, two dominant components of the benthos prevalent throughout FB, have on $^*\sum R$.

While few sponges remained in MB after a 99% loss caused by hypoxia resulting from a large-scale phytoplankton bloom in 2013-14 (Hoer 2015), benthic surveys conducted prior to 2013 measured 3.6×10^{6} L of sponge biomass within the basin (Hoer et al 2019). High sponge biomass at hardground environments has been typical throughout Florida Bay before the occurrence of large-scale bloom conditions, with values ranging from 100 to 300 g dry wt/m^2 (Peterson et al. 2006). In order to quantify oxygen utilization by sponge respiration within MB pre-2013, we use *Spheciospongia vesparium* as a model sponge within MB. *S. vesparium* accounted for almost half, 1.9×10^{6} L, of the total sponge wet biomass within MB, making it the predominate species that was present before the 2013-14 die off (Hoer 2015). We assume that *S. vesparium's* pumping and respiration rates can be applied across the full biomass of sponges found within MB based on previous studies by Weisz et al (2008) that showed reasonably similar rates among other commonly found species. They found that *S. vesparium* has a pumping rate of approximately 0.18 L/s per L of sponge tissue. The entirety of MB contains 3.6×10^6 L of sponge biomass, thus representing a total pumping rate of 6.5×10^5 L/s or 2.3×10^9 L/hr. *S. vesparium* oxygen uptake measured by Hoer et al. (2018) yielded an average respiration loss of 12.6 (7.1) µM based on measurements of the difference in oxygen concentration between the ambient water column and the ex-current water released by the sponge. Multiplying the Weisz et al. (2008) pumping rates times the oxygen removal measured by Hoer et al. (2018) yields a calculated oxygen respiration rate of 2.95×10^4 (1.65×10^4) mol/hr for the full biomass of sponges that existed in MB prior to the 2013-14 bloom. Across the total benthic area of MB (4.2×10^6 m^2) this represents an average oxygen draw down of 7.0×10^{-3} (3.0×10^{-3}) mol/m^2hr. Sponges, therefore, could have represented a significant pre-bloom oxygen loss term within Mystery Basin. This loss term should be considered in other central Florida Bay basins that still contain significant sponge populations.

In contrast to the respiration by sponges, seagrass beds pose a potential source of oxygen into the FB water column. Yarbro and Carlson (2008) conducted seagrass oxygen flux measurements throughout FB, specifically in Rabbit Key basin. Rabbit Key is situated 5 km north of MB and should contain a similar seagrass community as MB. In their results, Yarbro and Carlson (2008) found that, on average, seagrass beds in Rabbit Key produced 8.3×10^{-4} (7.1×10^{-4}) mol/m^2 hr oxygen. This is much smaller than the calculated daytime $^*\sum R$, suggesting that there are other sources of oxygen in the basin. Due to a loss of sponges, more of the benthic area is now covered by macro-algae. It is possible that these species along with phytoplankton (as evidence by blank SOD chamber) could be contributing more to the $^*\sum R$ variation seen in this study.

Implications for Greater Florida Bay:

Episodic events like phytoplankton blooms, seagrass die-offs and storms, including hurricanes, will disrupt ∑R through changes in the phytoplankton community and/or through reduction of light penetration through the water column. Phytoplankton blooms are known to greatly reduce light penetration through the water column (e.g. Lorenzen 1972 and Kelble et al. 2005, Philips et al. 1995) and sediment resuspension during storm events regularly reduces light penetration in Florida Bay (Philips et al. 1995). Since it appears that ∑R is the main force behind daily oxygen fluctuations in MB, changes to the benthic community could have lasting effects on this short time scale. Longer variability in oxygen dynamics seemed to be heavily controlled by atmospheric conditions, with dramatic changes in water temperature perfectly mirroring changes in atmospheric temperature, suggesting that MB’s longer time-scale dynamics are impacted by climate change (Fig. 16). Changes in long term dynamics will occur slowly with time or by larger scale atmospheric cycles (such as el Niño/la Niña), but rapid changes in the day to day dynamics of MB could occur quickly after a major event. Elevated turbidity or biomass loss should lead to quick changes in daily oxygen levels. This change could be short, lasting until turbidity is reduced, or longer if biomass levels are needed to return to a certain level. More research will be needed to understand what the larger impacts of these day to day changes could be, but it does appear that continued bloom, storm and die-off events will have an immediate impact on oxygen dynamics of MB and FB. More oxygen, salinity and turbidity measurements in different FB basins that contain varying amounts of seagrass beds, sponges and bottom sediment types would aid in the understating of just how productive FB is and how these environmental pressures will change that.

Conclusion:

Time series measurements of oxygen within a model FB basin revealed a system with strong daily fluctuations in concentrations. This daily variability appears to be driven by $\sum R$, with daily production leading to supersaturated waters and out gassing of oxygen, and nightly respiration leading to undersaturated waters and diffusion of oxygen into the basin. Longer term fluctuations appear to be controlled by alterations in water temperatures due to changes in atmospheric conditions. Variance in oxygen levels changed based on light availability, cloud cover, and stability of basin currents and temperature.

While Florida Bay continues to experience wide-scale ecosystem changes, it is important that we understand what impacts these alterations could have on short and long-time scales. Modifications to benthic communities within MB would have a quick and potentially significant effect on MB oxygen dynamics, however, the longer-term impacts of such events are still unclear.

Figures:

Figure 1 Satellite image of Mystery Basin and surrounding basins. HOBO1 is the center of the basin and the location of one of the Onset pressure sensors and the in-situ sensor array. The other HOBO pressure sensor locations are shown as well, numbering 1 to 14. Red arrow indicates predominant direction of water exchange in and out of MB.

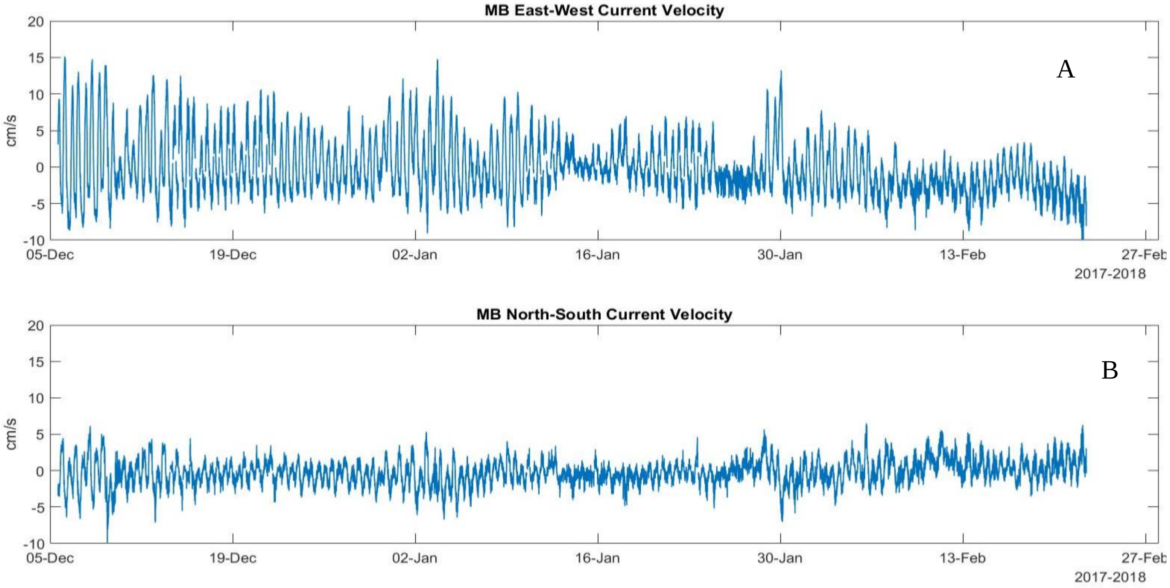


Figure 2 Component current speeds and directions taken at HOBO 1 site. A: East/West Current and B: North/South Current (cm/s). Due to equipment malfunction, there was some loss of current data in December and January.

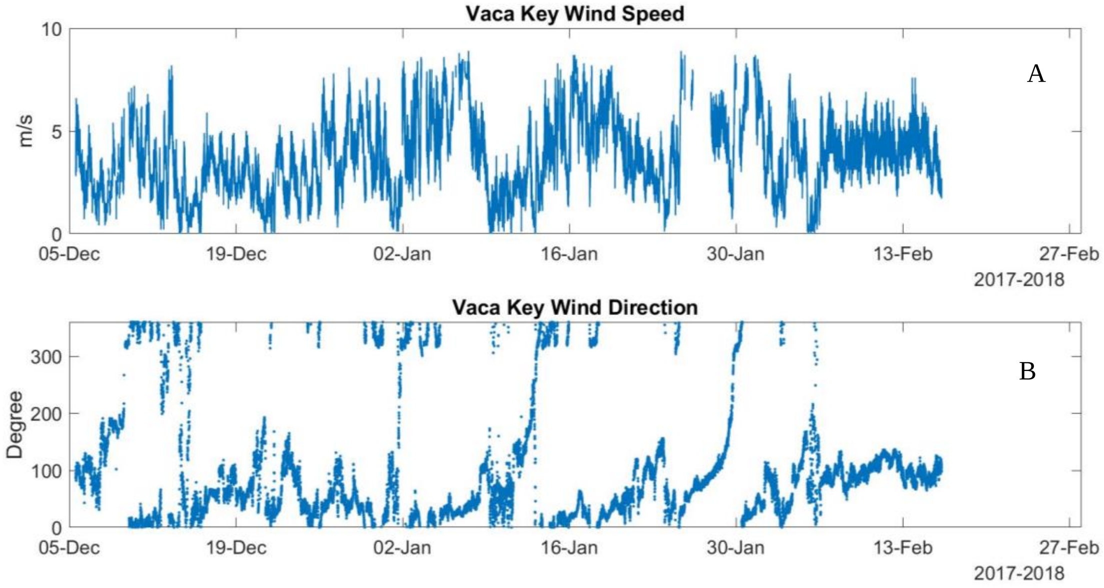


Figure 3 A: Vaca Key NOAA weather buoy wind speed in m/s and B: meteorological direction (where the wind is blowing from). Data downloaded from www.ndbc.noaa.gov. A clear directional shift and speed stabilization can be seen during February.

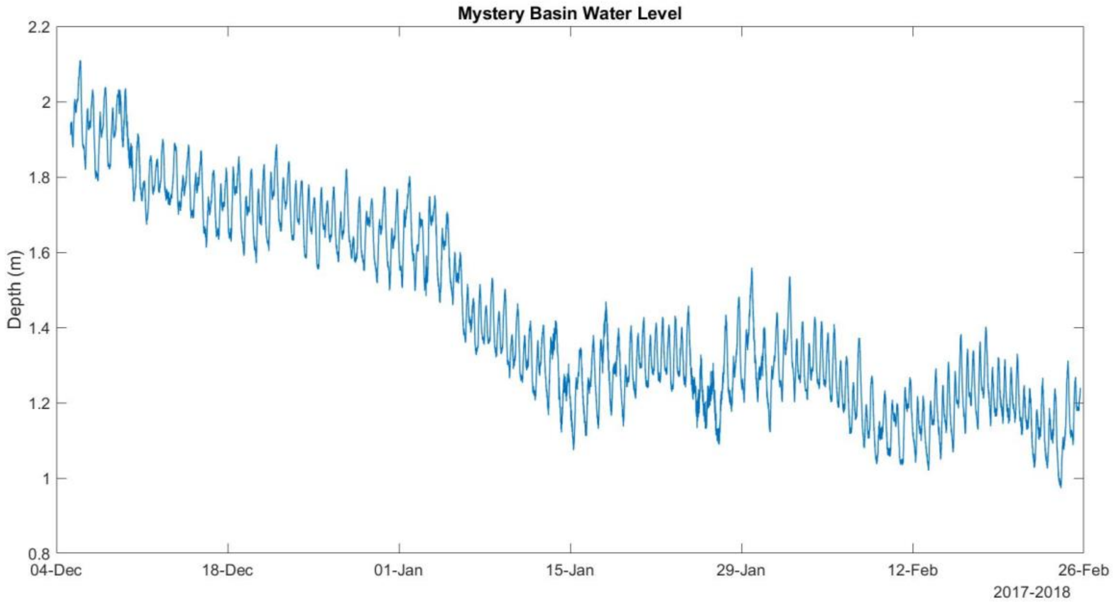


Figure 4 Water level taken from HOBO 1 site. Water level dropped significantly over a 2-month period, falling from 1.9 to 1.2 meters in depth. All gaps in data in January and end of February are due to equipment malfunction (when line breaks into signal points).

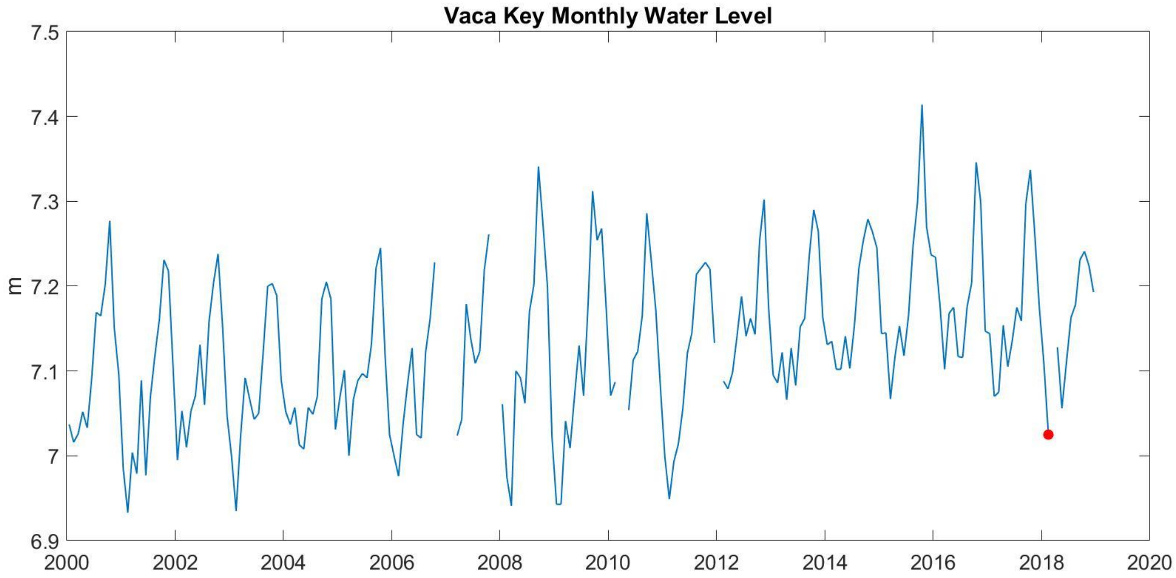


Figure 5 Monthly average water level (in meters; m) for Vaca Key since 2000 (x axis is year). Red dot corresponds to low water level recorded during February of 2018. This was lowest recorded water level for last 6 year but still within water levels recorded at this station. Data downloaded from PSMSL (https://www.psmsl.org/data/)

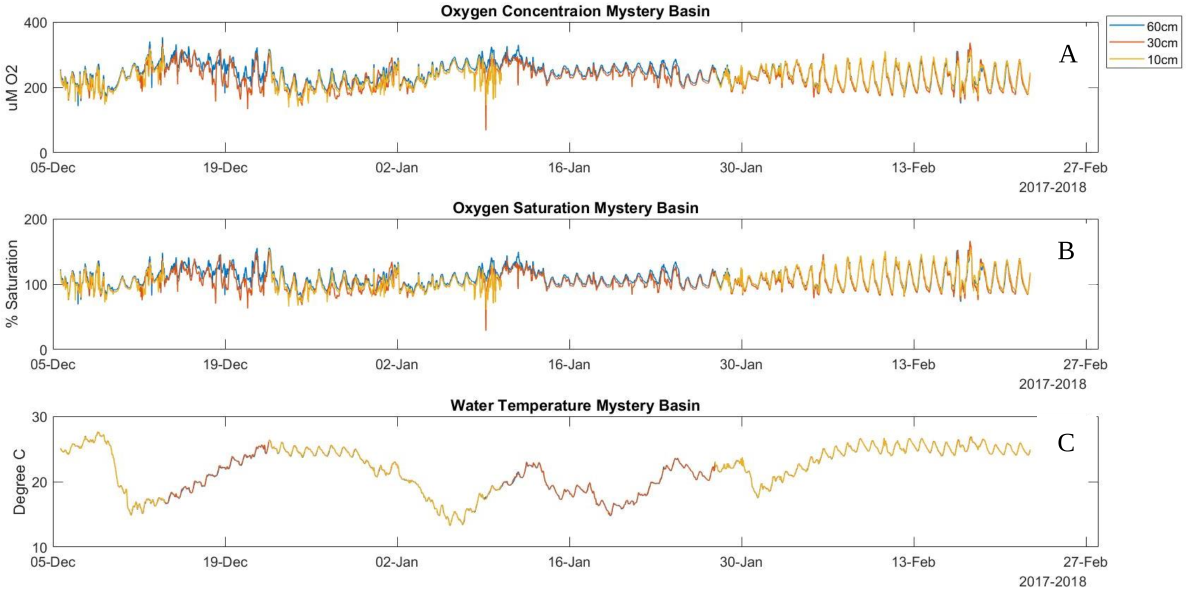


Figure 6 A: In-situ oxygen concentration at various depths within MB in µM B: Oxygen percent saturation values in MB and C: In-situ water temperature values in MB in ºC. All values are averaged to every 10 minutes. There was some loss of data in January leading to some sensors dropping out of the record.

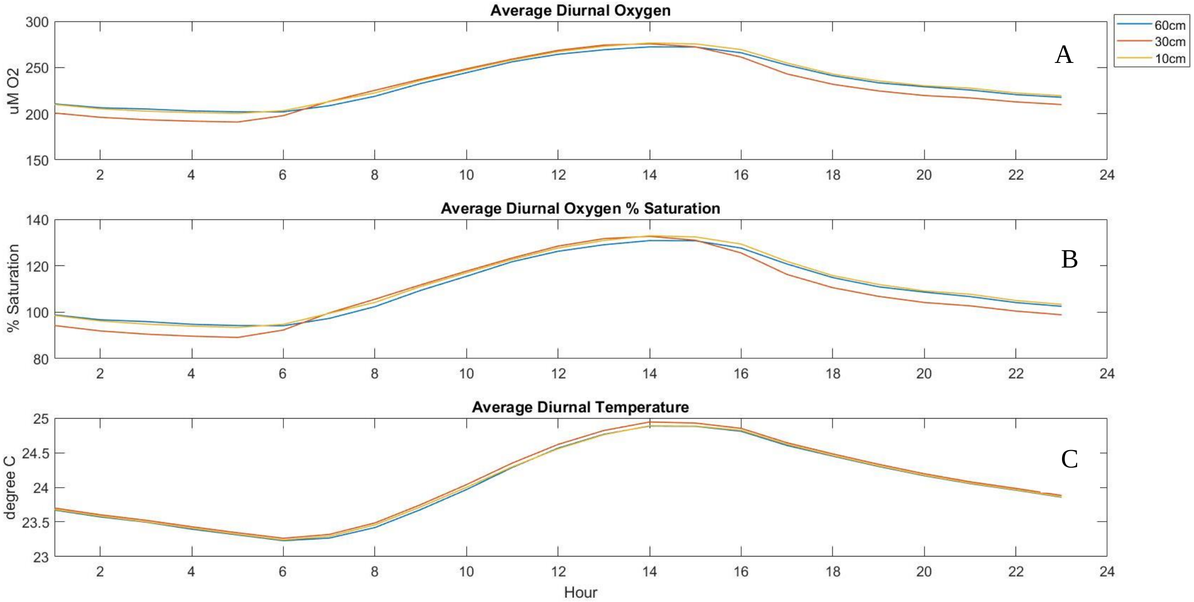


Figure 7 Daily average in-situ values for A: Oxygen concentration in µM, B: Oxygen percent saturation and C: Water temperature in ºC. Hours starts at 0 and ends at 23. Daily peaks for both measurements occur at 1-4 pm and minimums at 5-7 am. Temperatures are within less than 0.1 ºC.

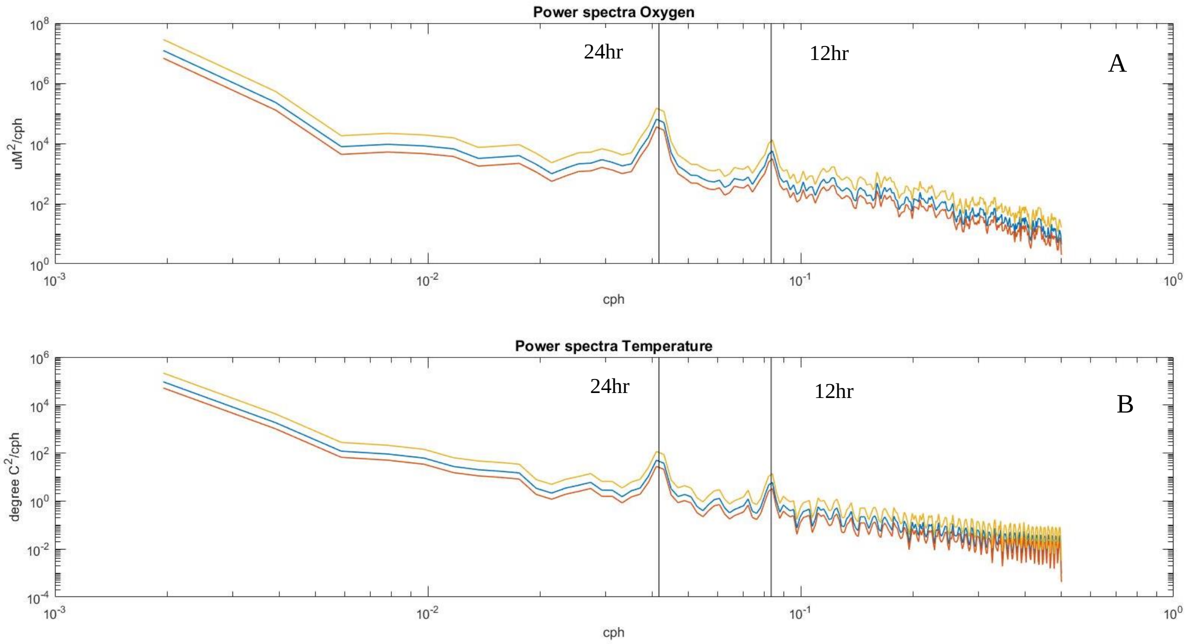


Figure 8 A: In-situ depth averaged power spectra of oxygen concentrations. B: in-situ depth averaged power spectra of temperature values. Principal peaks occur around 24 and 12 hours. Blue line is power spectra, yellow and red are 95% confidence level.

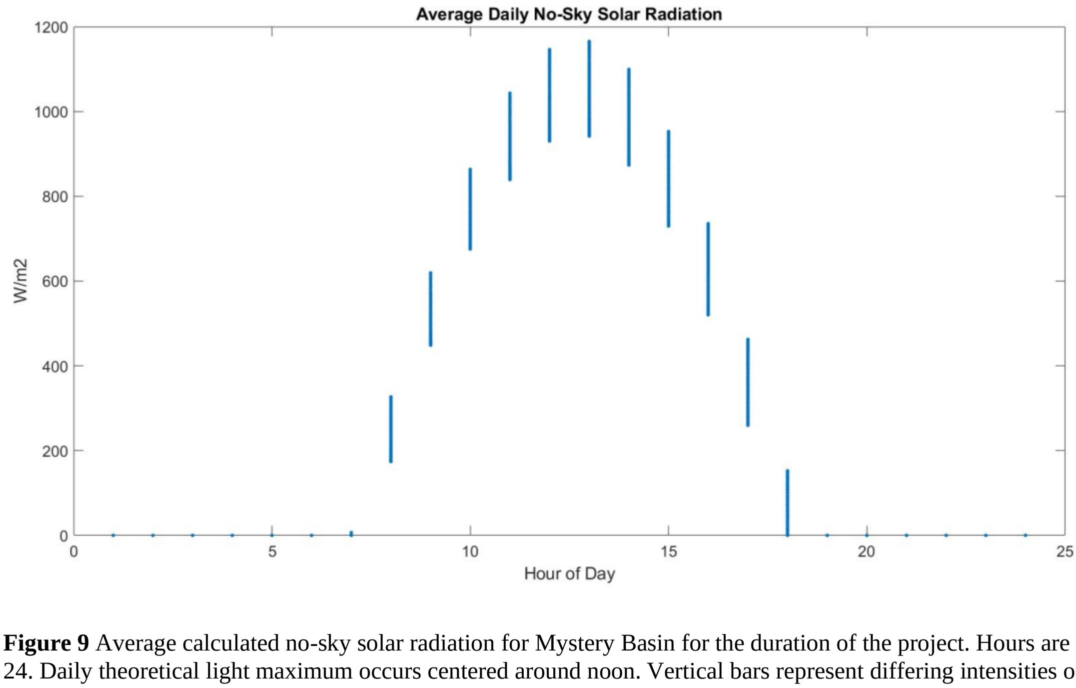


Figure 9 Average calculated no-sky solar radiation for Mystery Basin for the duration of the project. Hours are from 1 to 24. Daily theoretical light maximum occurs centered around noon. Vertical bars represent differing intensities of radiation throughout the 4- month period of the project. Calculated using SORADNA1 function in matlab, from SEA-MAT toolbox.

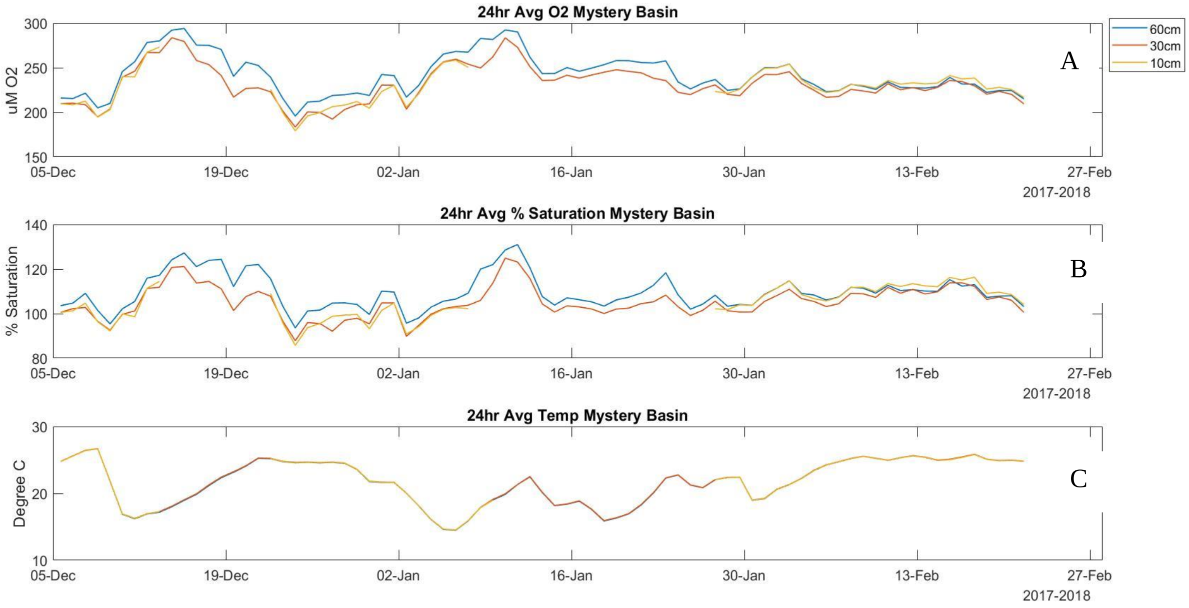


Figure 10 Daily fluctuations removed data for A: in-situ oxygen, B: oxygen percent saturation and C: in-situ temperature. Data is daily average values for each record (24 hour average).

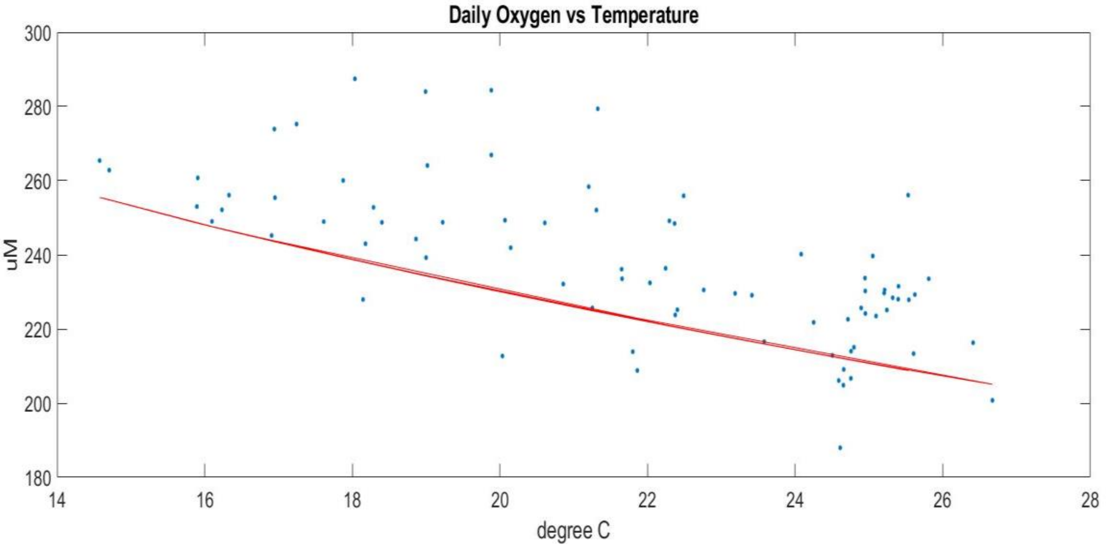


Figure 11 Depth averaged in-situ oxygen concentrations vs water temperature. Blue dots signify oxygen vs. temperature. Red line is theoretical concentrations of oxygen at saturation at the given temperature.

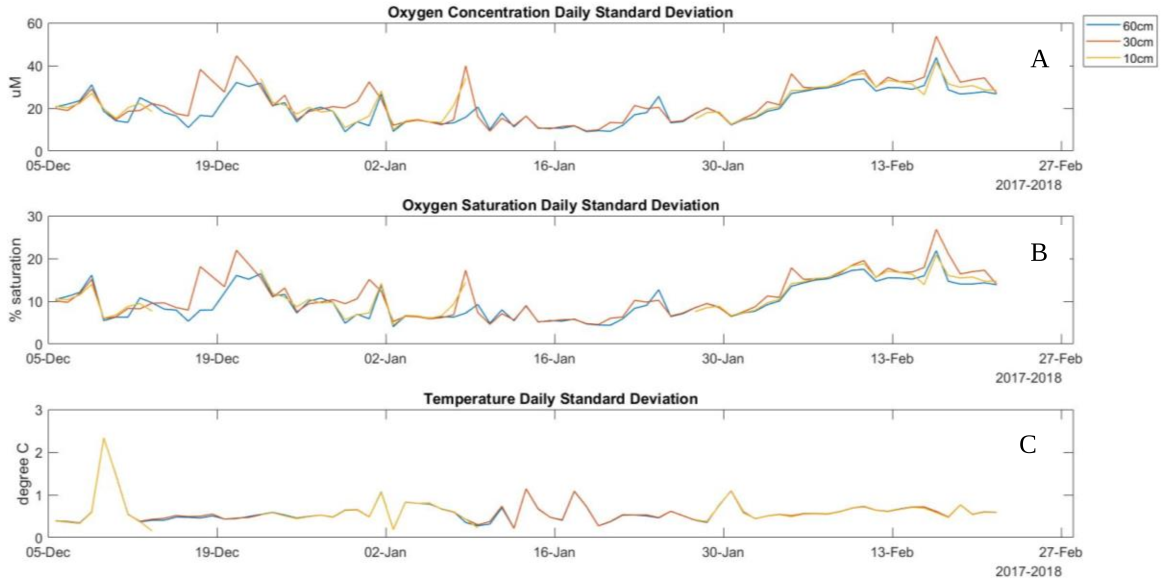


Figure 12 Daily standard deviation of A: in-situ oxygen concentrations, B: oxygen percent saturation and C: in-situ temperature values. February shows a greater deviation with respect to oxygen but not temperature.

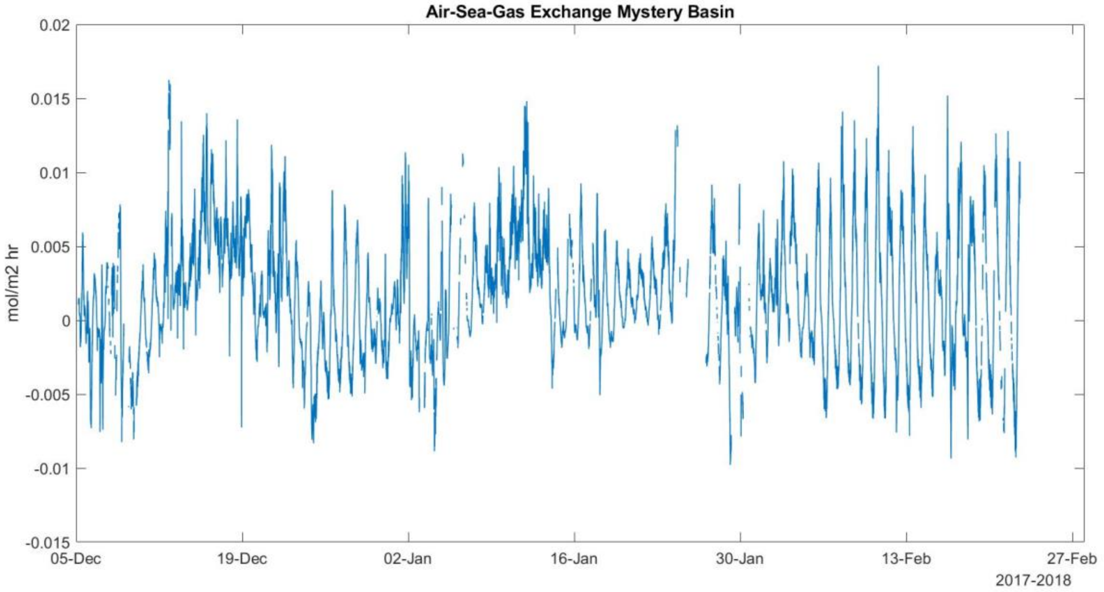


Figure 13 Calculated Air-Sea gas exchange values in mol/m^2 hr. Positive values represent outgassing of oxygen, while negative values represent diffusion of oxygen into the basin. Small gaps in data are due to gaps in NOAA Vaca Key wind data.

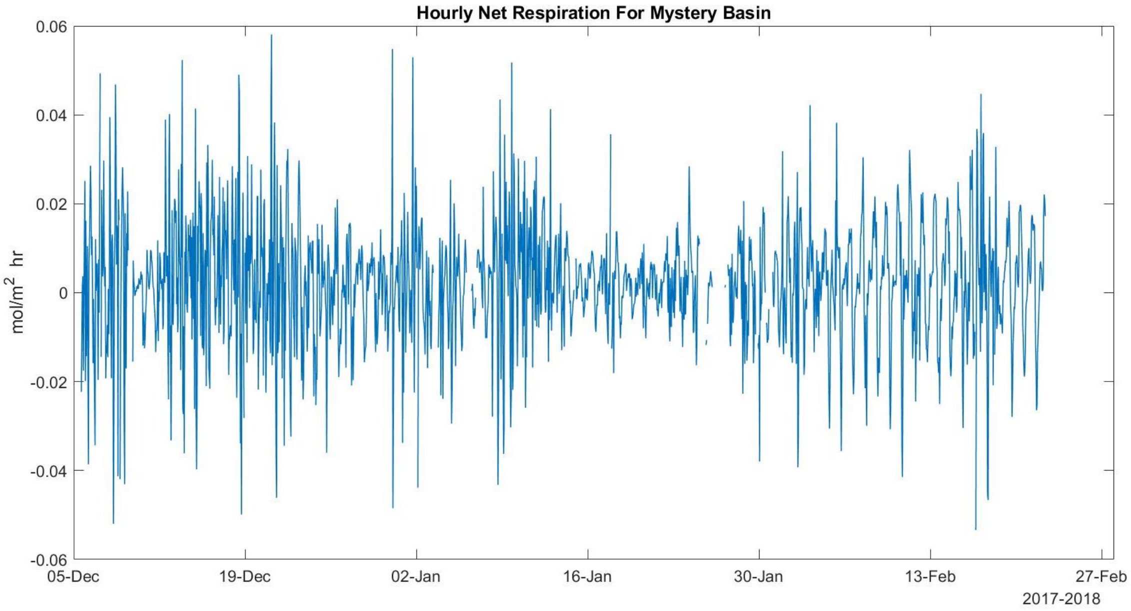


Figure 14 Calculated NPP from eq 4 in mol/m^2 hr. Positive values represent excess production of oxygen. Negative values are net consumption of oxygen. Values line up with super and sub saturation of oxygen.

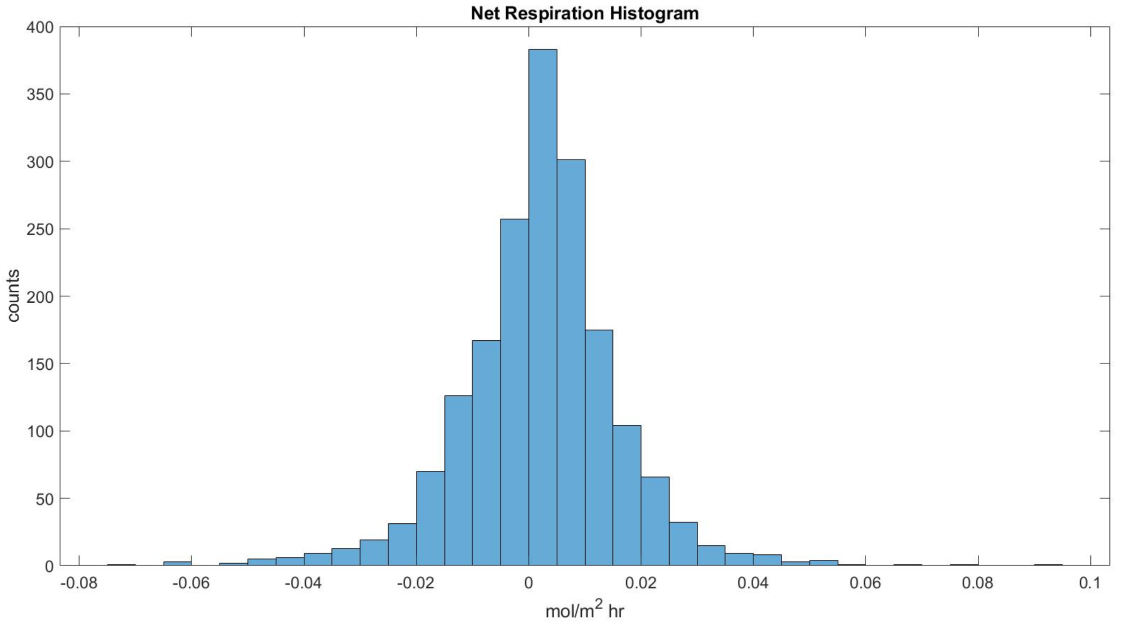


Figure 15: Distribution of Net respiration values for Mystery Basin. Y axis represents number of counts for corresponding respiration values.

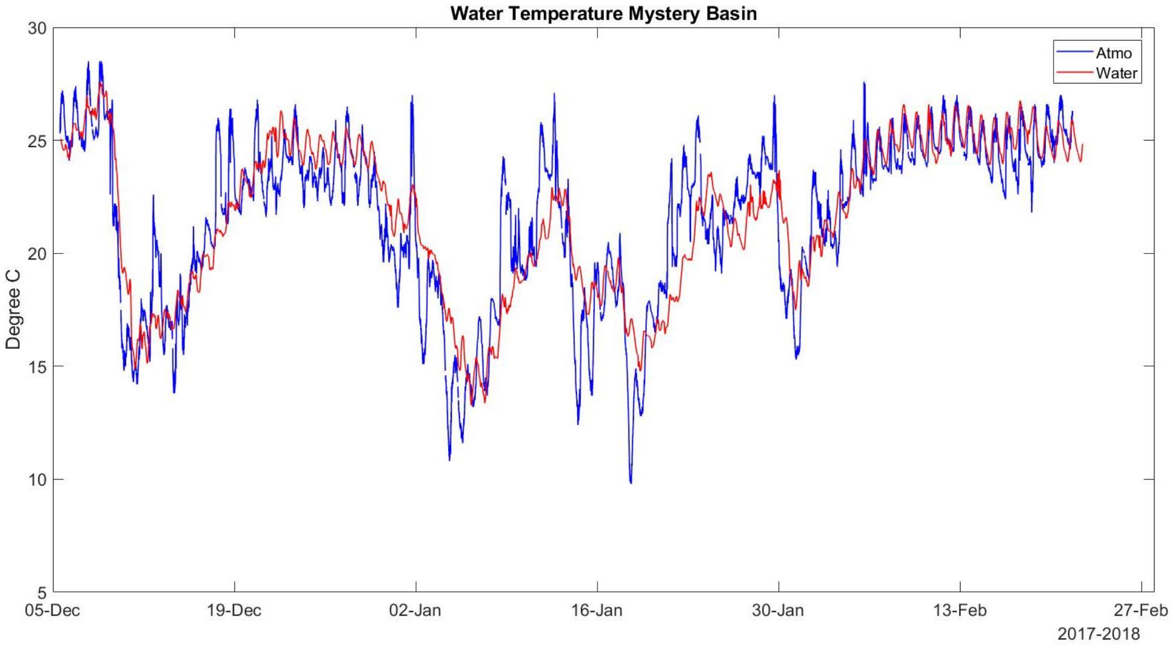
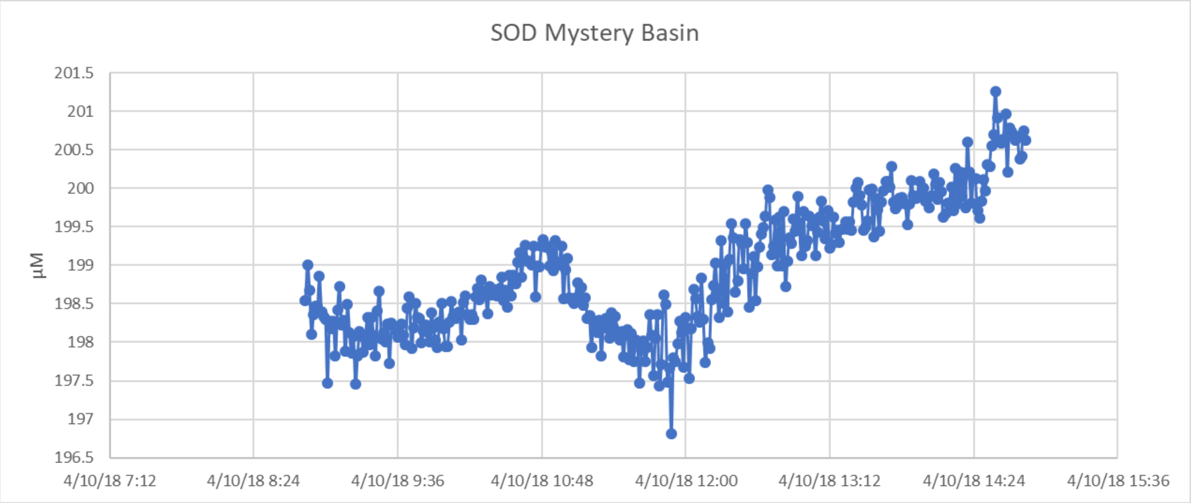


Figure 16: Vaca Kay atmospheric temperature (in blue) vs Mystery Basin water temperature (in red).

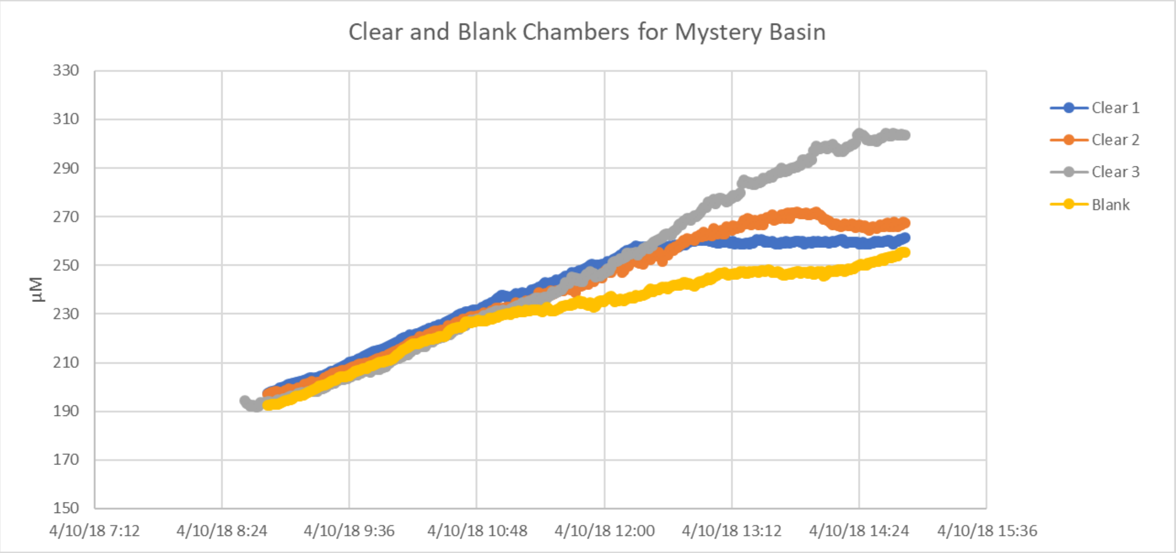
APPENDIX 1: SOD RAW VALUES

SOD values were excluded from the calculations due to increase in oxygen within the dark chambers. All deployments were at the center of MB.

Dark chamber SOD value.



Clear and Blank chamber values.



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