INFLUENCE OF TIDAL RESTRICTION ON WATER CHARACTERISTICS IN HUDSON RIVER FRESHWATER TIDAL MARSHES

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Abstract. Dissolved oxygen levels, water levels, and turbidity were measured over several tidal cycles in Hudson River freshwater tidal marshes to determine if tidal restriction was present and whether restriction impacted water characteristics potentially affecting marsh development or fish habitat quality. Restriction was found to be present in two marshes, and the influence of restriction on ebb tide oxygen levels appeared to vary depending on whether water chestnut (*Trapa natans*) cover was extensive. In the marshes without substantial water chestnut cover oxygen levels declined during nighttime ebb tides, but increased during daytime ebb tides. The daytime increases were more pronounced in the restricted marsh. Turbidity was lower in the restricted marsh than the unrestricted marshes. In the marshes with extensive water chestnut cover, oxygen levels declined during all ebb tides measured regardless of diel phase, with more extensive declines recorded for the restricted marsh.

INTRODUCTION

Wetlands provide habitat for a wide variety of species and can exert regional influence on nutrient cycling and hydrological development (Mitsch and Gosselink 2000). The Hudson River estuary contains both saline and freshwater tidal systems from New York City to the federal dam at Troy. Hudson wetlands are utilized by birds, fish, invertebrates, and perhaps amphibians. Juvenile fish find shelter from predators and abundant food in marshes; the availability of these habitats may be important to the success of freshwater and anadromous species in the river (Mihocko et al.).

Hudson wetlands have been extensively modified during the last several hundred years of human activity in the area, both indirectly through land use change in the watershed and more directly through development and hydrological engineering projects along the river. A project with a major influence on the hydrological character of Hudson wetlands was the construction of railway lines on both riverbanks in the late 1800s. Where the railway track crosses wetlands, dikes have been constructed to elevate the track above the water level. The dikes form a permanent barrier between wetland and river; tidal exchange is confined to culverts constructed in the dikes, openings that range in size from pipes of a meter in diameter to box culverts several tens of meters wide. While the culverts were generally constructed to align with naturally occurring tidal creeks, the permanence of the artificial boundary has almost certainly altered hydrological development in these wetlands. The extent and character of these alterations, and any impacts they may have on the capacity of the wetlands for various ecological functions, remain largely unquantified.

One way the installation of dikes and culverts could have a major influence on the ecological function of wetlands is by alteration of the timing or volume of tidal exchange. Tidal exchange is the most regular and generally the largest influence on flushing times in these wetlands, as volumes of run-off from wetlands and tributaries are comparatively small. Elevation is also important, because low elevation marshes have a lower proportion of their total volume exchanged tidally than do higher elevation marshes. Culverts might influence tidal exchange in two ways: 1) exchange volume could be diminished if culvert size is small relative to marsh volume, restricting flow rates enough that the marsh does not fill or empty completely before the tide changes, and 2) ebb tide phase could be prolonged and overall exchange volume diminished if the invert (lowest elevation) of the culvert is higher than the low tide water level. Reduction of tidal exchange volume and prolongation of ebb tide increase flushing times, thus increasing the influence of marsh processes on water characteristics. Respiration by marsh organisms consumes oxygen, so dissolved oxygen concentrations might be expected to be lower in restricted marshes than unrestricted marshes, especially approaching low tide. If dissolved oxygen concentration falls below 5 mg/L, the health of some fish may be endangered. Dissolved oxygen concentrations below 2 mg/L are acutely lethal to these fish. A prolonged ebb tide may also allow more sediment to settle per tidal cycle, potentially influencing geomorphology. Previous casual observations of several Hudson marshes suggested that culverts might be restricting tidal flow in some places. The problem of this study was to identify restricted areas, obtain water level data to demonstrate and characterize restriction, and to determine whether patterns over time (days) in dissolved oxygen levels or turbidity differed between restricted and unrestricted marshes.

METHODS

Site identification

We surveyed several sites with water depth measurements and observations at low tide to determine whether tidal exchange was potentially restricted by high inverts. From north to south, these sites are: Mill Creek marsh (just south of Mill Creek swamp reserve), Hudson North marsh, Mandara South, Matambeson, Astor Cove, and Suckley Cove (Figure 1). At Hudson North marsh and Astor Cove, water levels at exchange points were at least 30 cm deeper than the minimum depth necessary to allow flow throughout the tidal range (MLLW- MHHW). At Mill Creek and Mandara South, invert depth was near 10 cm above low tide level. The water level observation at Mill Creek was taken at a near-spring low tide, 9:15 8/2/00; only 25 tides annually were predicted to be as low or lower, and the lowest tide of the year was predicted to be less than 10 cm lower (International Marine 2000). Therefore it appears the marsh just north of Mill Creek is never restricted.

A previous report documented restriction in the north sector of Manitou marsh (Lawler, Matusky and Skelly 1993), and inspection at low tide suggested restriction was occurring at Matambeson marsh and Suckley Cove, so these three sites were chosen for more detailed measurement. Matambeson is 2.3 ha in area (Kiviat); vegetation is mainly emergent but also includes intertidal and open-water areas with minimal water chestnut cover. Suckley Cove is 11 ha in size (Kiviat); it has mainly intertidal vegetation and open water, with some emergent marsh at fringes. Water chestnut cover is extensive in open water areas. Three unrestricted sites were chosen as reference sites: Tivoli North and South Bays, and Mandara South marsh. Tivoli North Bays is 110.2 ha in area, has mainly emergent marsh vegetation, and low water chestnut cover (Mihocko et al. in press). Tivoli South Bays is 120 ha in area and has little emergent vegetation; water chestnut cover is high (Kiviat). Mandara South was chosen because its size (1.8 ha, Kiviat), topography, and vegetation type were closely similar to Matambeson marsh.

Field Measurements

All measurements were taken inside marshes just in front of the culvert opening. In Tivoli North and South Bays, Mandara South, and Matambeson marshes, water level, dissolved oxygen, temperature, and turbidity measurements were taken at 5-minute intervals over a 66-hour period (17:00 8/4/00-12:15 8/7/00) with YSI Model 6000 sondes. The tidal cycle was 4.5 days past spring tide at the start of the measurement interval. In Mandara South and Matambeson marshes the sampling interval was 15 minutes. Data from Tivoli North and South Bays are courtesy of Chuck Nieder (HRNERR), and were taken at 30-minute intervals. In Suckley Cove, dissolved oxygen measurements were taken at 2-minute intervals with an oxygen meter and recorded over a 25-hour period (16:47 8/2/00-17:00 8/3/00) with a Campbell data logger. The tidal cycle was 1.5 days past spring tide at the start of the measurement interval. In Manitou Marsh, water level data were recorded from staff measurements and dissolved oxygen measurements taken with an oxygen meter during an ebb tide on 7/20/00, with low tide at 21:00. Low tide river water level was projected to be 36 cm above the lowest spring tide predicted in 2000.

RESULTS AND DISCUSSION

Restriction occurred in two of the marshes measured, Matambeson and Suckley Cove, while Mandara South, Tivoli North and South Bays and the North and South sectors of Manitou marsh all appear to be unrestricted. The pattern of dissolved oxygen level variation during ebb tide in the marshes we measured appears to be influenced substantially by diel phase, tidal restriction, and extent of water chestnut cover.

Marshes with low water chestnut cover

Mandara S. marsh, Matambeson marsh, and Tivoli N. Bay all had low water chestnut cover, and all displayed similar patterns of dissolved oxygen level variation over time. In all marshes, dissolved oxygen measurements were constant at the river value (near 7 mg/L) during hours when the marshes experienced flood tide; because of the position of the instruments at the marsh-side opening of the culverts, water very recently removed from the river covered the sensors during the flood current (Figs. 3, 4, 6). In the unrestricted marshes with low water chestnut coverage, dissolved oxygen levels declined continuously during nighttime ebb tides to reach a low between 3.5 and 4.5 mg/L, but declined to a low near 5 mg/L and then began to increase to near the river value during daytime ebb tides (Fig. 4). The trends and values observed for dissolved oxygen in Tivoli N Bay and in Mandara S. marsh were nearly identical, despite the large size difference between the marshes (Fig. 4).

Matambeson marsh was observed to be restricted. In comparison to Tivoli N. Bays and Mandara N. marsh, the water level curve for Matambeson had a smaller amplitude, and ebb tide phases were prolonged by an average of 29%, or 2 hours 4 minutes (Figure 2). As the low tide water levels recorded at the time of sampling were above mean low water level, it can be expected that substantial restriction occur in this marsh throughout the spring-neap and seasonal tidal ranges. The ebb tide pattern of variation of dissolved oxygen in this marsh differed markedly from that observed in the unrestricted marshes described above: during nighttime ebb tides oxygen declined similarly, but during daytime ebb tides dissolved oxygen increased to supersaturated values up to 18 mg/L (Fig. 3). The turbidity levels recorded in Mandara S. (unrestricted) were on average twice as high as those in Matambeson (restricted). The Matambeson turbidity data showed peaks with the onset of flood tides and declines during ebb tides, while the Mandara data exhibited no discernable pattern relative to tidal phase (Figs. 9 and 10).

The trend of dissolved oxygen decreasing during nighttime ebb tides in all observed marshes lacking substantial water chestnut cover is likely due to oxygen consumption through respiration, while the trend of oxygen levels increasing during daytime ebb tides likely occurs because photosynthetic production of oxygen by submerged aquatic vegetation (SAVs) outweighs respiratory consumption. Submerged aquatic vegetation was observed at all marshes but not surveyed. Interestingly, the supersaturated [DO] values in the unrestricted marsh were likely also due to photosynthesis by SAVs, as the high spike occurred on a sunny day and the lower spike occurred on a cloudy day (Fig. 3). The productivity of submerged aquatic vegetation is often light-limited; the much lower turbidity observed in the restricted marsh may have allowed SAVs to photosynthesize at a higher rate, and if the low turbidity is characteristic it may also have facilitated more extensive SAV establishment over time.

The north and south sectors of Manitou marsh also lacked substantial water chestnut cover, but [DO] variation over time cannot be substantially compared to the other marshes as water level and [DO] data were only taken for one ebb tide to test for restriction. The water level curves for the north and south sectors of Manitou marsh were nearly identical, and 42 cm water remained in the culverts at low tide (Fig. 7). As the lowest spring low tide height projected for 2000 was 36 cm lower than the projected level of low tide on the day sampled, restriction is not expected in either sector of Manitou at any time during the tidal cycle. In Manitou North oxygen levels declined from 7 mg/L at high tide to 5.4 mg/L at low tide, while in Manitou South [DO] increased from 7.3 mg/L to 8.9 mg/L, then began decreasing (Fig. 8).

Marshes with substantial water chestnut cover

In the marshes where substantial water chestnut cover occurred, Tivoli South Bays and Suckley Cove, [DO] declined during ebb tides regardless of daylight. Tivoli South Bays was unrestricted, and [DO] declined to a low of 3 mg/L during ebb tides, then increased back to river values during the beginning of the flood tide (Fig. 6). Suckley Cove was observed to be restricted; no water level data were obtained, but observation at low tide clearly indicated the bottom of the culvert was above the river water level (Fig. 5). The periods of low oxygen observed in Suckley cove were longer than those observed in Tivoli South Bays (Fig. 6), a pattern consistent with the prolonged ebb phase expected to result from restriction. Ebb tide hypoxia has been previously documented to occur in water chestnut beds (unpublished data*); the patterns observed in these marshes indicate that this phenomenon and tidal phase are the dominant factors controlling oxygen level when substantial water chestnut cover is present.

It is possible that the prolonged periods of low oxygen observed in Suckley Cove might be dangerous to some fish. Culverts with inverts near or above the river low tide mark contain little water at low tide, when hypoxia is most severe in the marshes with extensive water chestnut cover, and it is unknown whether fish can successfully traverse the culverts in this condition.

A final interesting feature observed in all the diked marshes visited in this study was a deep pool in the marshes just before the culvert opening, apparently worn away by the high velocity of tidal flows through the culvert. At the Mill Creek marsh, which had the smallest culvert opening, this pool may have been near ten feet deep. This suggests restriction may impact the spatial pattern of sediment deposition in these marshes and perhaps bears further investigation.

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*study documenting ebb tide hypoxia in water chestnut beds done by Institute for Ecosystem Studies; not yet published http://www.hrwa.org/pages/bigmap_new.html (original Hudson map image)

Appendix

TABLE 1. Summary of major factors influencing ebb tide [DO] trends in observed marshes

	With water chestnut	Without water chestnut
Restricted	ebb tides prolonged, [DO] ↓ during all ebbs hypoxic 63% of time observed hyperoxic 1% of time observed	ebb tides prolonged [DO] ↓ during night ebbs, ↑ during day ebbs hypoxic 2% of time observed hyperoxic 16% of time observed
Unrestricted	ebb tides normal duration [DO] ↓ during all ebbs hypoxic 38% of time observed hyperoxic 0% of time observed	ebb tides normal duration [DO] ↓ during night ebbs, ↑ during day ebbs hypoxic 13-25% of time observed hyperoxic 0% of time observed

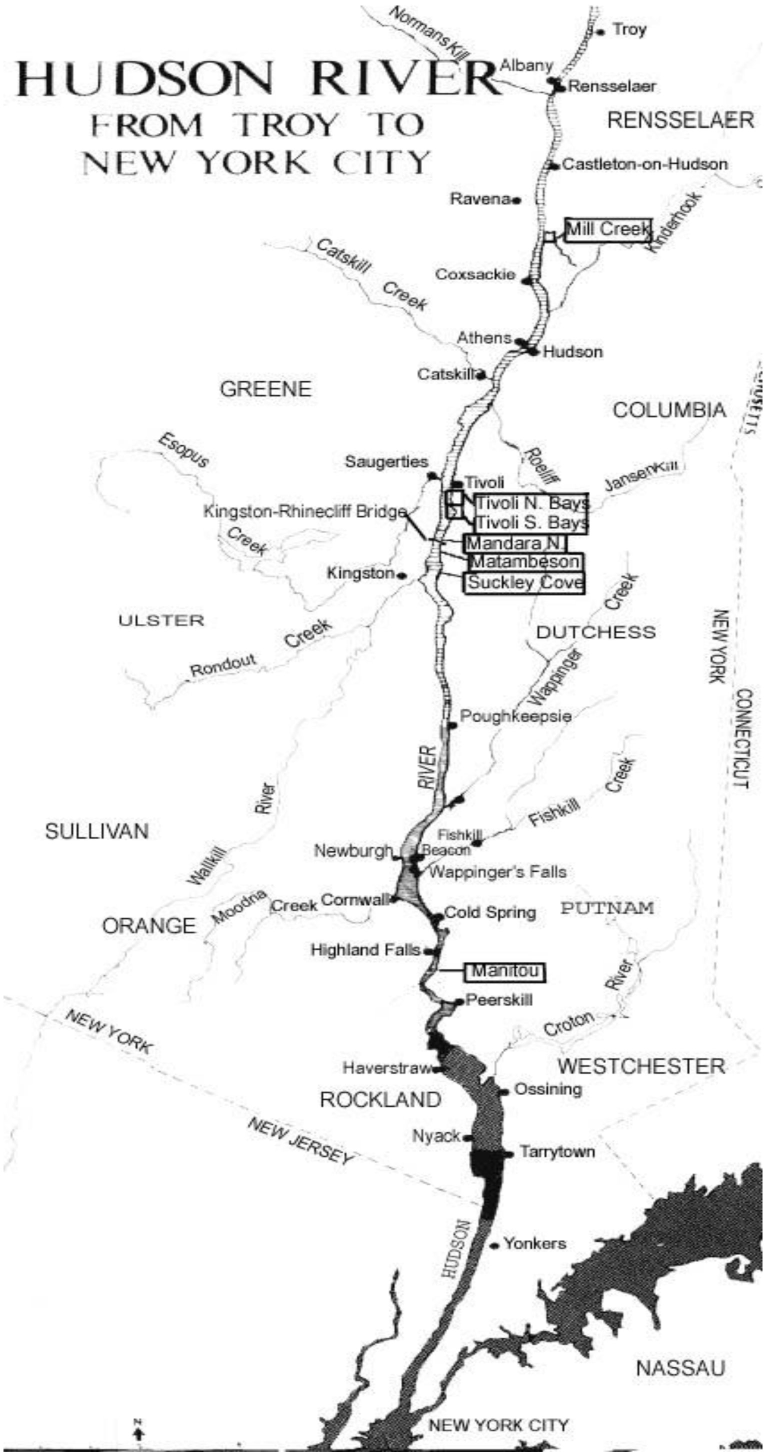

FIGURE 1. Map of Hudson River from Troy to New York City, showing location of study marshes.

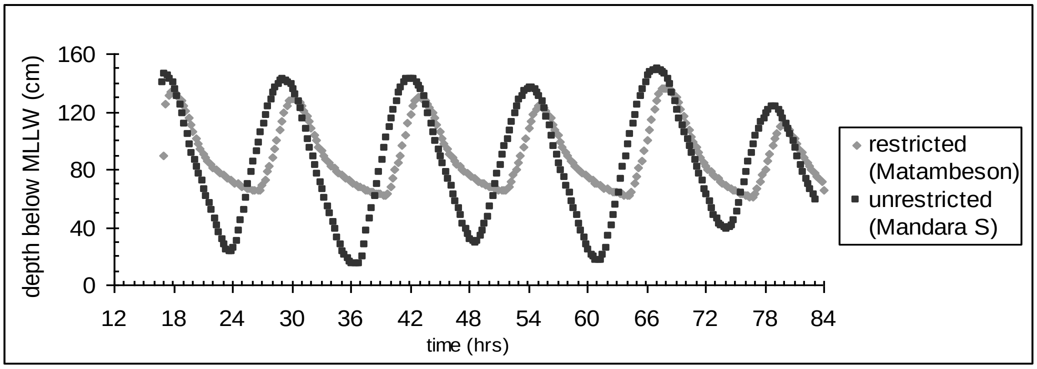

FIGURE 2. Water depth measurements at 15 minute intervals in Matambeson marsh (restricted) and Mandara S. marsh (unrestricted), referenced to mean low low water height. 17:00 8/4/00 - 12:00 8/7/00

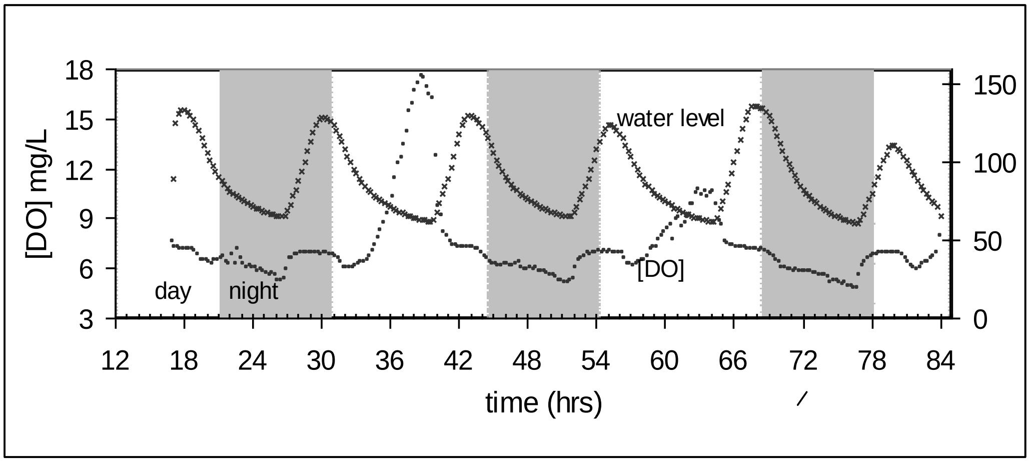

FIGURE 3. [DO] and water depth measurements (referenced to MLLW) at 15 minute intervals at Matambeson marsh (restricted site). Water level curve included for reference to tidal phase. 17:00 8/4/00 - 12:00 8/7/00

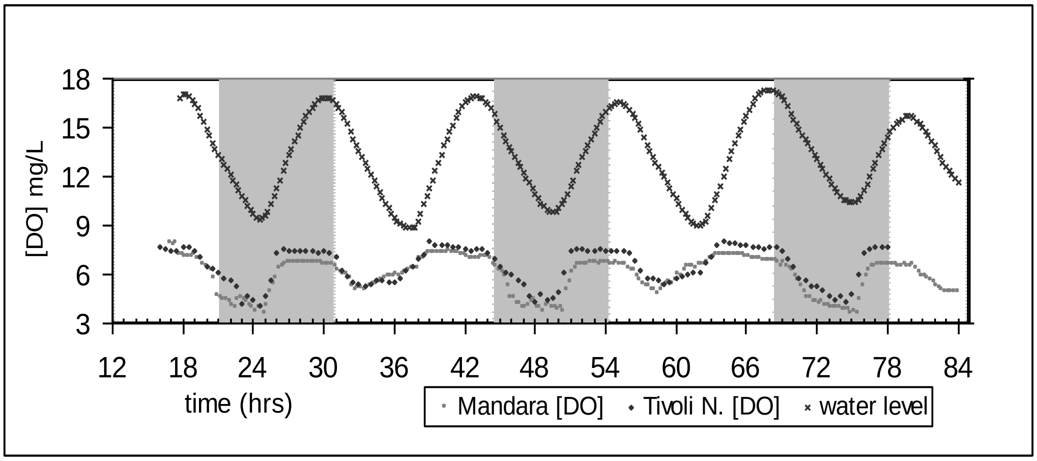

FIGURE 4. [DO] over time for Mandara S. and Tivoli N. Bays (unrestricted sites), with water level curve from Mandara S. to show tidal phase. Sites are near enough that tidal cycling is within 15 minutes. 17:00 8/4/00 - 12:00 8/7/00.

FIGURE 5. Looking into Suckley Cove culvert at low tide; the invert is above the river water level.

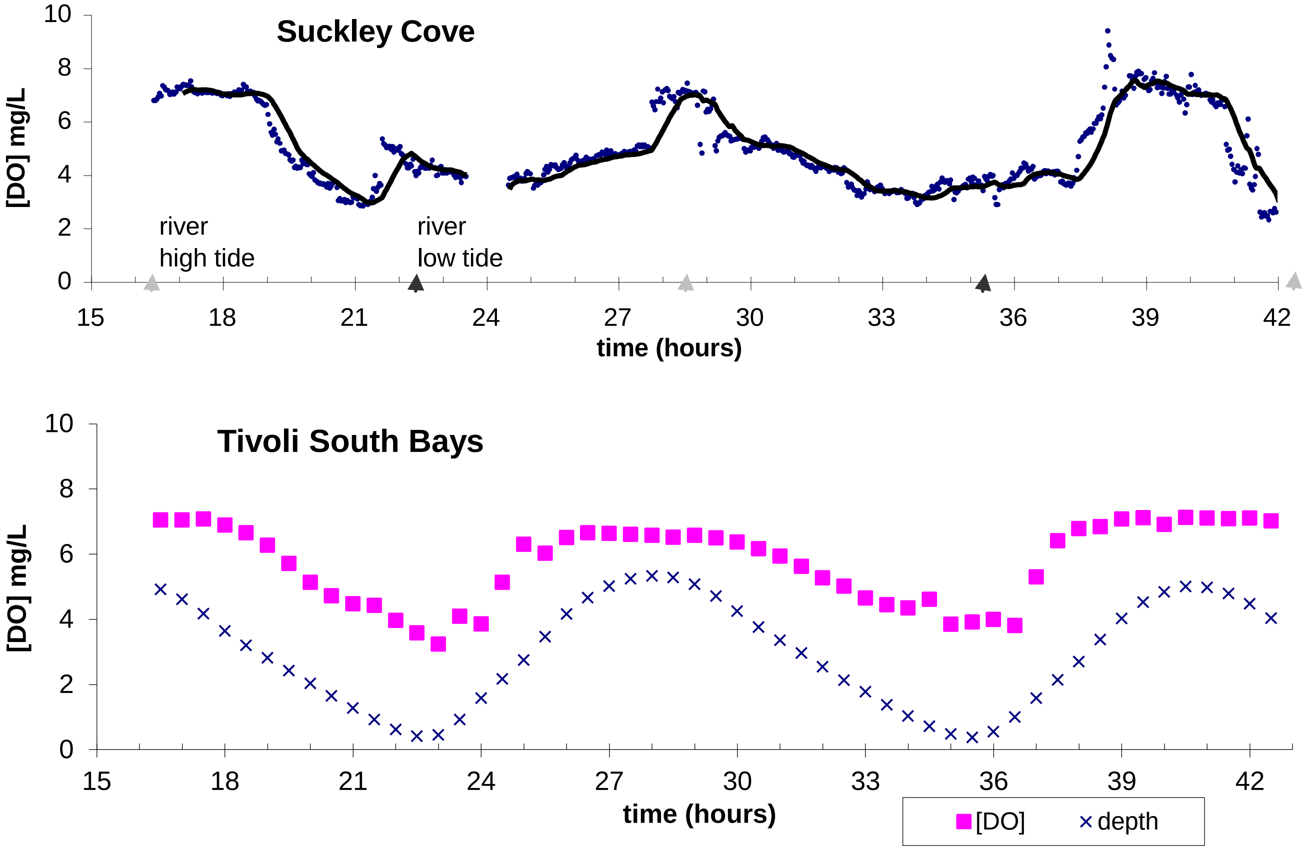

FIGURE 6. Top graph shows [DO] data (2 minute intervals with running average line) from restricted site Suckley Cove. On x-axis, dark triangles designate times of river low tides, and light triangles designate times of river high tides. Lower graph shows [DO] data and water depth data from unrestricted site Tivoli South Bays.

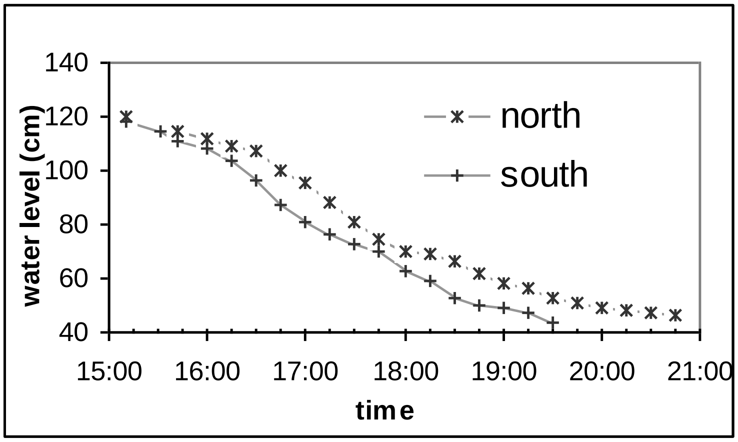

FIGURE 7. Water depth measurements taken at 15 minute intervals during ebb tide in Manitou marsh north and south sectors, 15:00 - 21:00 7/20/00, with line of best fit.

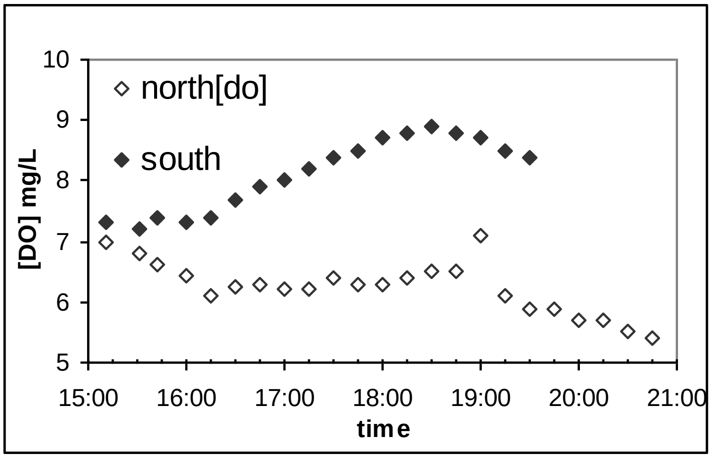

FIGURE 8. Dissolved oxygen measurements taken at 15 minute intervals in Manitou marsh north and south sectors, 15:00 - 21:00 7/20/00.