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MEASURES OF WATER QUALITY IN MERRIT ISLAND NATIONAL WILDLIFE REFUGE IMPOUNDMENTS AND ADJACENT INDIAN RIVER LAGOON

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ABSTRACT

The goal of this project was to conduct preliminary investigations to determine appropriate sampling strategies to measure the flux of dissolved nutrients (specifically, NH_4^+, NO_3^-, NO_2^-, and PO_4^{3-}) and suspended particulate matter (TSS) between impoundments and the IRL in preparation for an intensive 3-yr monitoring program. In addition to nutrients and TSS, a variety of common water quality indicators were also measured during these preliminary studies. Six impoundments and a single restored marsh selected for study. Over a month long period, water samples were collected weekly at selected impoundment culverts. Water was collected in duplicate as independent grab samples from both the lagoon side and within the perimeter ditch directly adjacent to the culverts. Water quality indicators inside and outside the marsh impoundments were different. Ammonium, salinity, bacteria and chlorophyll-*a* were higher inside the impoundments as expected possibly as a result of the great affect of evaporation on impoundment water. Water quality indicators responded rapidly both inside and outside the impoundments as exemplified by the increase in NH_4^+-N concentrations during a horseshoe crab die-off. Water quality indicators were high variable during the month in which water samples were collected. Because the impoundments are widely spaced it is logistically unrealistic to sample each of the impoundments and associated seagrass beds on a single day, sampling must be stratified to allow patterns of material movement and the annual flux of materials to and from the impoundments to be determined.

MEASURES OF WATER QUALITY IN MERRIT ISLAND NATIONAL WILDLIFE REFUGE IMPOUNDMENTS AND ADJACENT INDIAN RIVER LAGOON

Linda K. Blum

1. INTRODUCTION

In much of the coastal United States, large areas of salt marshes have been impounded to control mosquitoes and sea-level intrusion into agricultural land. At Merritt Island National Wildlife Refuge (MINWR) marsh impoundment began as early as 1956 and was accelerated when NASA funded the mosquito control districts in the late 1950's and early 1960's. Most of the impoundments were completed by 1966. In 1963, NASA transferred management authority for many of the impoundments to the U.S. Fish and Wildlife Service (USFWS). The MINWR wetlands are presently managed by USFWS biologists under a multispecies management program with focused on, but not limited to, fish, wildlife, plant communities, and consumptive and non-consumptive public uses (Epstein, 1995).

To enhance biodiversity and provide better management of the MINWR wetlands restoration of impoundment T-10-K was begun when it was drained in 1969. T-10-K was fully restored (the dikes were removed and the perimeter ditches filled) in 1977 (Leenhouts 1982). Restoration efforts continued when refuge managers began installing culverts to reconnect impoundments to the adjacent lagoons in the 1970's. In addition to enhancing refuge biodiversity and restoring wetland interaction with the lagoons, reconnection of the impoundments has created unique opportunity for scientists to study the response of the lagoon-marsh ecosystem to restoration efforts. Reconnection of the impoundments to the lagoon has restored the flow of materials, both dissolved and particulate, between the marsh impoundments and the lagoon. Although Day (1989) stresses that the flux of materials between estuaries and their adjacent wetlands is a critical process in estuarine ecosystems because of the impact on system biodiversity and production, little is known about how reconnection of impoundments will affect material movement of materials to and from the lagoon and the impoundments.

As a result, SJRWMD, NASA, USFW, and a number of universities have been awarded funding from EPA to examine a variety of questions focused on the response of the impoundments and lagoon to reconnection. One of the primary objectives of the EPA-funded project is to examine material flux between the impoundments and lagoon. The goal of my NASA/ASEE project during summer 1999 was to conduct preliminary investigations to determine appropriate sampling strategies to measure the flux of dissolved nutrients (specifically, NH_4^+, NO_3^-, NO_2^-, and PO_4^{3-}) and suspended particulate matter (TSS) between impoundments and the IRL. In addition to nutrients and TSS, a variety of common water quality indicators were also measured during these preliminary studies.

2. MATERIALS AND METHODS

A. Impoundments: The criteria used in impoundment selection included: proximity to the IRL, presence of culverts installed through the impoundment dike directly to the IRL (i.e., the impoundments were reconnected to the IRL), and hydrologic management regime (Fig. 1). The six impoundments and single restored marsh selected for study vary in size (Fig. 1) and in plant community composition (Table 1).

Although a variety of structural marsh management techniques are used at MINWR, the two most commonly employed methods are wildlife aquatic management (WAM) and open. The combination of these techniques is used by MINWR biologists to maximize biodiversity and ecosystem productivity (M. Epstein, personal communication). The primary objective of the

WAM technique is to create habitat that favors utilization by ducks and wading birds by encouraging the growth of submerged aquatic vegetation, especially *Ruppia martima* an important food source for herbivorous water birds. *R. maritima* growth is promoted by flooding the marsh surface with IRL water for approximately 8-10 months of the year. When the WAM impoundments are flooded, exchange of water with the IRL is limited to times when sufficient rain fall raises the level of the impoundment above that necessary for *R. martima* growth or water level in impoundments falls below the water level in the lagoon and water is flow is from the lagoon into the impoundment. Water flow is from the impoundment to the lagoon during drawdown when the impoundment is allowed to drain allowing for consolidation of the sediment to provide substrate suitable for reestablishment of *R. martima*.

*Figure 1. Black Point impoundments at MINWR.

TABLE 1. Description of impoundments selected for water quality study during summer 1999.

Marsh Impoundment	Management Type	Months Flooded per Year	% Emergent Plant Cover
T-10-J	WAM	8-10	90
T-10-L	WAM/RIM	8-10/4-6	50
T-10-H	Open	2-3	35
T-10-C	Open	2-3	5
T-10-D	WAM/RIM	8-10/4-6	2
T-10-E	WAM	8-10	2

The primary objectives of open impoundment management are to provide estuarine organisms with access to the marsh surface and to allow movement of suspended materials to and from the lagoon. Open management is critical to some commercially and ecologically important fishes such as tarpon, snook, red and black drum, spot, and blue crabs (Gilmore 1999). Furthermore, in many lagoon-marsh systems, overall lagoon production and biodiversity are dependent on the export of particulate organic material from the marshes to the lagoon (Nixon, 1980) while marshes are maintained by import of mineral particles from the lagoon (Day and Templet 1989). The movement of materials (including organisms) to and from the lagoon is accomplished by leaving the culverts open to natural changes in water level so that open impoundments are flooded approximately 2-3 months of year.

TABLE 2. Sampling dates and the direction of water flow in the culverts during preliminary water quality sampling, summer 1999.

Date	Impoundment Sampled	Direction of Water Flow
June 22	T-10-C	no flow
	T-10-D	no flow
	T-10-H	no flow
June 29	T-10-E	to lagoon
	T-10-J	no flow
	T-10-H	to lagoon
	T-10-L	to lagoon
July 6	T-10-C	no flow
	T-10-D	to lagoon
	T-10-H	from lagoon
	T-10-L	to lagoon
July 13	T-10-E	no flow
	T-10-H	no flow
	T-10-J	no flow

B. Sampling: Over a month long period, water samples were collected weekly at selected impoundment culverts. Water was collected in duplicate as independent grab samples from both the lagoon side and within the perimeter ditch directly adjacent to the culverts. Logistical constrains allowed for sampling only 3 or 4 impoundments each week (Table 2). All samples were collected between 0830 and 1130 in clean, 4-L cubitainers and held in ice chests until return to the lab for sample processing.

C. Water Quality Measures: In the field, the direction of water flow was determined visually (Table 2). Measurements of dissolved oxygen (DO), salinity, and water temperature were made (Table 3). Immediately upon return to the laboratory sample pH was determined in each cubitainer and subsamples for determination of bacterial abundance were preserved in 2% formaldehyde (Table 3). Within 4 h or less of return to the laboratory, samples were filtered for determination of NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, TSS, particulate organic matter (POM), mineral matter, and chlorophyll-*a* (chl-*a*) (Table 3). Samples for nutrient analysis were preserved by filtration through 0.45 μm pore size Gelman supor membrane filters. Filtered nutrient samples were frozen until analysis, which occurred with 9 days or less from sample collection (Table 3). Samples for TSS, POM, mineral matter and chl-*a* were filtered collected on Whatman GF/C filters and processed immediately upon collection (Table 3).

Table 3. Major Water Quality Measures and Method of Analysis

VARIABLE	DECSCRIPTION	APPROVED METHOD
Total suspended solids	gravimeteric	EPA 160.2
Organic and mineral particulates	gravimeteric	EPA 160.4
NO_2^- and NO_3^-	Cd reduction	EPA 353.1 & EPA353.2
NH_4^+	Phenol hypochlorite	EPA 351
ortho-PO_4^{3-}		EPA 365.1 & EPA 365.2
salinity		
Chlorophyll-*a*	acetone-DMSO extraction	SM10200H
Bacteria	Direct microscopic count	Hobbie et. al. 1977
pH	Orion pH meter	
Dissolved oxygen	YSI DO meter	
Water temperature	YSI meters	

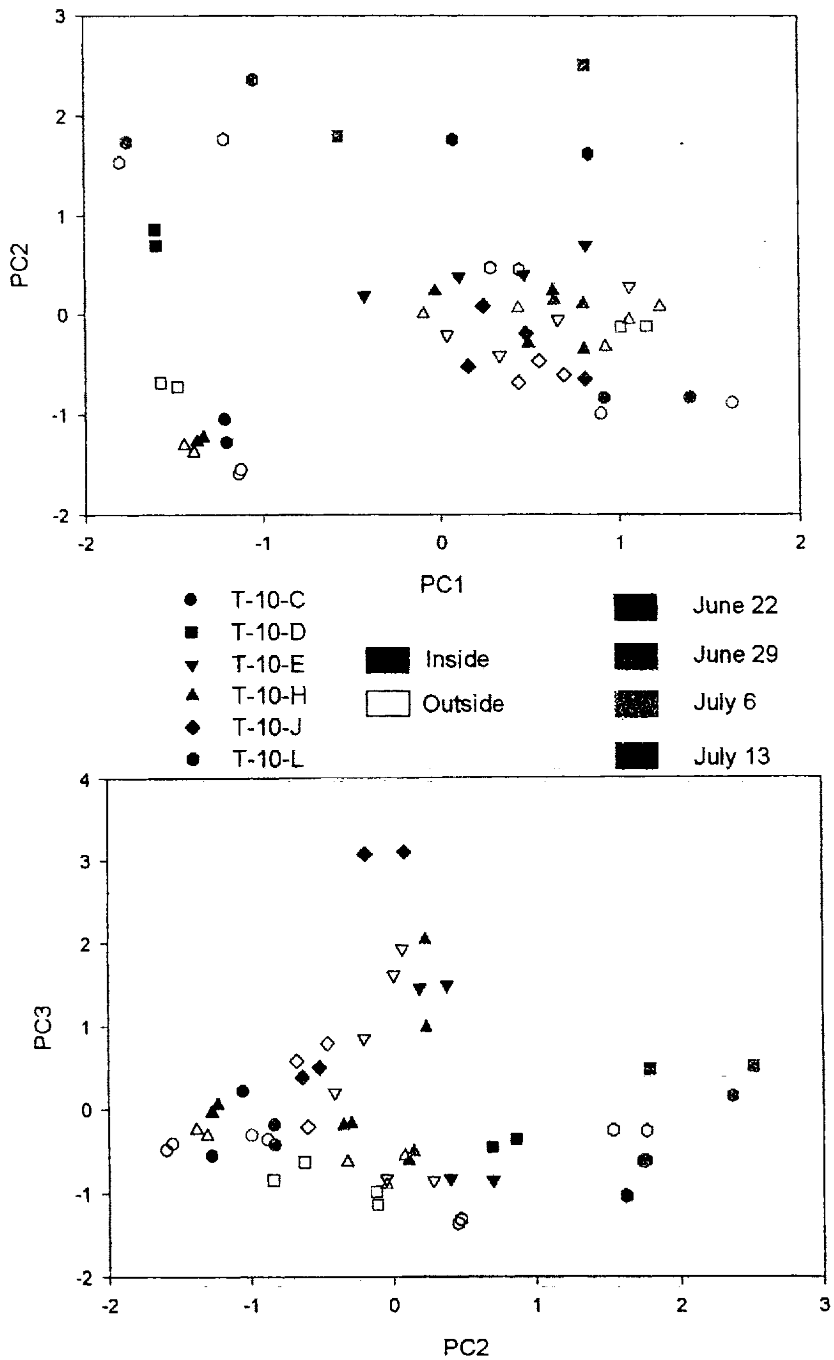
3. RESULTS

A. Impoundment Comparisons: Examination of the entire water quality indicator data set by PCA showed that PC1, PC2 and PC3 accounted for 36.2%, 18.5%, and 14.9%, respectively, of the variance in the data set or a total variance of 69.6%. A clear pattern was observed when PC1 (comprised of TSS, POM and mineral particles) and PC2 (comprised of chlorophyll-*a* and bacterial abundance) and PC2 and PC3 (comprised of NH_4^+-N) were compared to one another (Fig. 2). Water samples collected inside the impoundment consistently separated from those collected outside the impoundment. This pattern was confirmed to be statistically significant by one-way ANOVA of inside vs. outside values for salinity, pH, ammonium, bacterial abundance, and chlorophyll-*a* ($\alpha = 0.05$). Values for each of these variables were always lower outside the impoundment than they were inside the impoundment. There were no significant correlations among any of the water quality variables measured ($\alpha = 0.05$).

In addition to the inside vs. outside pattern, the PC2 vs. PC3 comparison revealed that those samples collected on July 13 (blue symbols) separated along PC3 (the nitrogen component) from all other sampling times (Fig. 2 bottom panel). On July 13, we observed a significant increase in the number of dead *Limulus polyphemus* (horseshoe crab) around the impoundment culverts. Horseshoe crab carcasses were abundant both inside and outside the impoundments where samples were collected. Decay of the crab carcasses was the likely cause of the 2- to 12-fold increase in NH_4^+-N concentrations measured at T-10-E, T-10-H, and T-10-J observed for the July 13 samples.

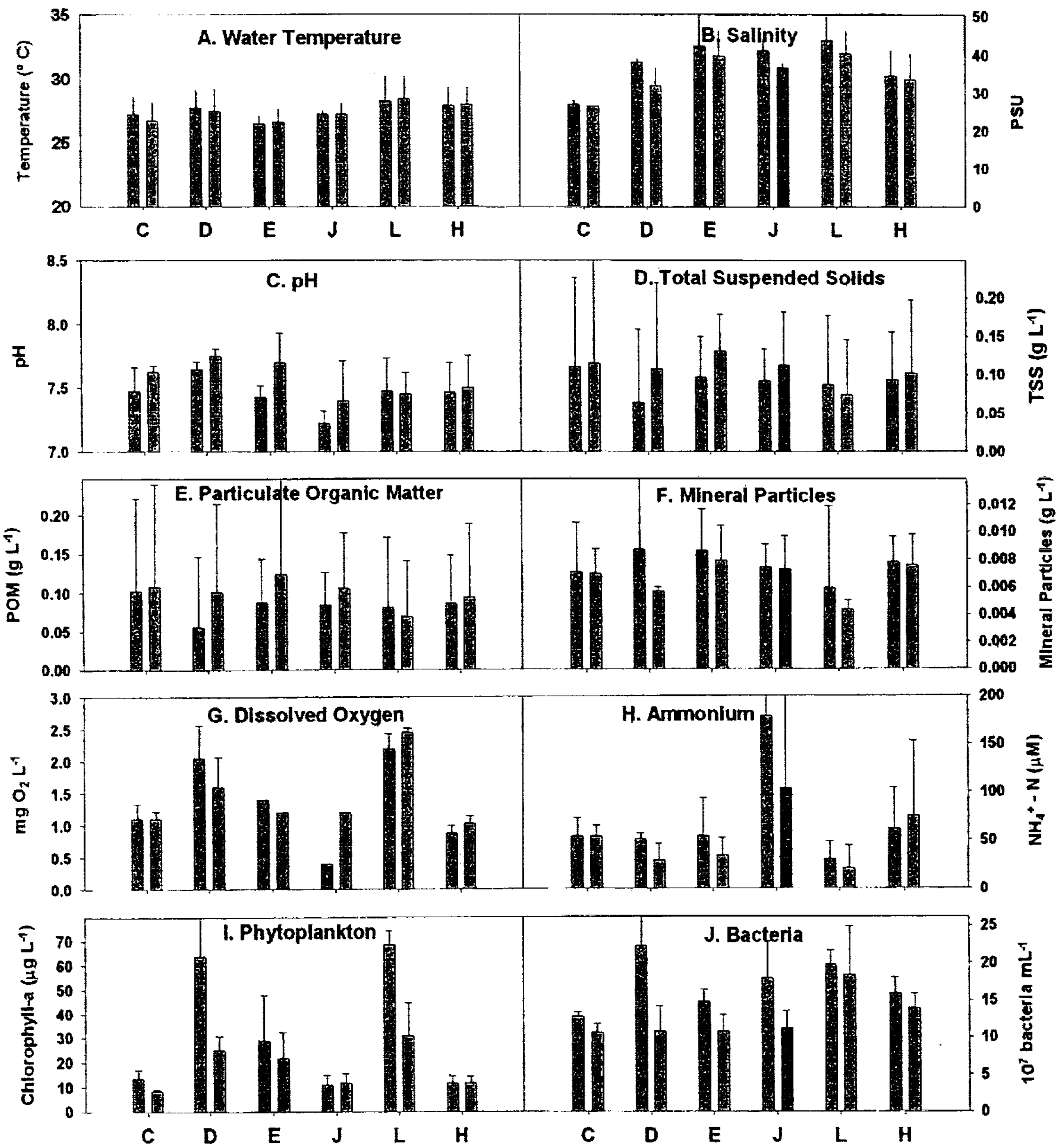
A second PCA was done without the July 13 data to ascertain if these high N samples were the underlying cause of the patterns obtained when the entire data set was subjected to PCA. The results of the second PCA without the July13 data were nearly identical to the first analysis, which included the July 13 data (data not shown). The variables comprising PC1, PC2, and PC3 for the second analysis were identical to those in when all the data were analyzed. For the second PCA, the variance explained by the first 3 PCs was even greater (PC1=38.3%, PC2=23.2%, PC3=13.2%, total = 74.7%) than that explained when all the data were used. In contrast to the first PCA, the inside vs. outside separation was the only obvious pattern seen when PC1 vs. PC2 or PC2 vs. PC3 were compared.

*Figure 2. Results of principal component analysis using all data for collected on all dates (top panel) and without data from July 13, 1999.



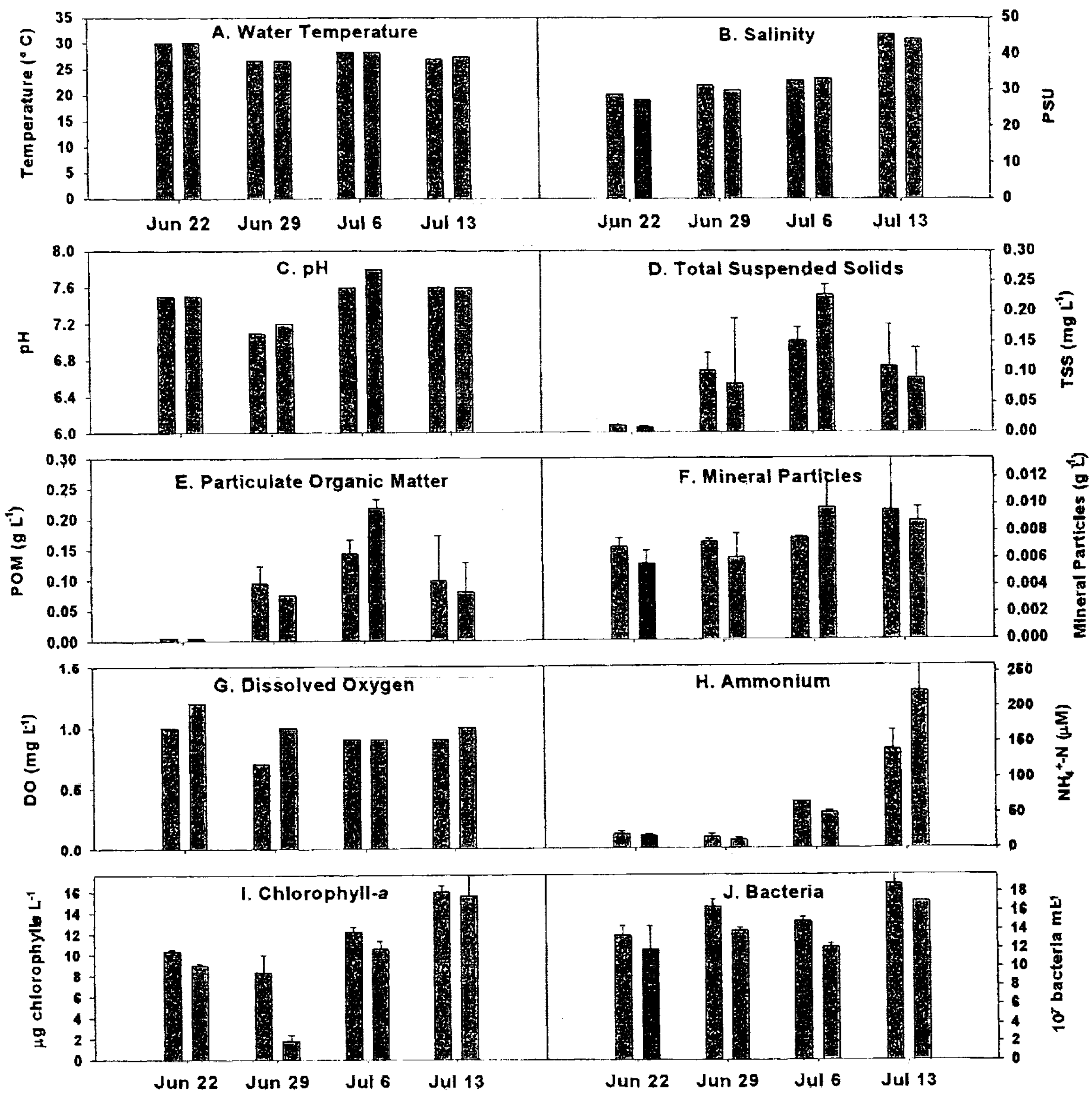
No clear patterns are evident among the impoundments (Fig. 3). This is not surprising given the limited nature of the current data set.

*FIGURE 3. Mean concentrations (μM) of NH_4^+ for all samples collected from each of the impoundments during summer 1999 in panel (a) where n = 2 for all impoundments except T-10-H where n = 4) and (b) where n = 2 for T-10-C, T-10-D, T-10-L, n = 1 for T-10-E and T-10-J, and n = 3 for T-10-H. Green bars = inside the impoundment. Blue bars = outside the impoundment.



B. Temporal variation among samples: Impoundment T-10-H was the only site where samples were collected each of the weeks of the experiment. Water quality measures were highly variable across the times sampled at T-10-H (Fig. 4). The only consistent pattern during these 4 weeks was that chlorophyll-a, and bacterial abundance were significantly different ($\alpha = 0.05$) and always greater inside the impoundment than outside the impoundment. No significant correlations were detected among the variables measured for impoundment T-10-H.

*FIGURE 4. Temporal variation of water quality indicators for T-10-H on the four sampling dates. Green bars = inside the impoundment. Blue bars = outside the impoundment.



4. DISCUSSION AND RECOMMENDATIONS

The primary objective of the work completed in summer 1999 was to determine an appropriate water quality sampling scheme for work to be conducted with EPA funding in 1999-2001. One of the primary concerns was and is the feasibility of sampling 7 impoundments and the associated seagrass beds in the IRL within a time frame to allow for direct comparison among impoundments. This concern is based on the EPA-funded project's long-term goal to compare the effect of WAM and open water management on the impoundments, which requires knowledge of both the annual flux and the patterns of material (particulate and dissolved) movement between the IRL and the impoundments. An additional goal of the EPA-funded work is to determine what effect material flux from the impoundments has on seagrass beds adjacent to the impoundment culverts. Ideally the impoundments and the seagrass beds should be sampled on the same day to minimize temporal variation for comparison of flux patterns. However, based on the preliminary work completed this summer, sampling 7 impoundments would require approximately 5 hours. Sampling the adjacent seagrass beds would require additional time – probably another 4 hours. An additional limitation is that imposed by sample processing time and the time between collection and stabilization of the samples once they have been returned to the laboratory. Further constraints on sampling include diel variation in biological activity, especially photosynthesis by phytoplankton and SAV in shallow impoundment water, which can have a profound effect on water chemistry over the course of a single day. To minimize diel variation, samples should be collected at similar times of the day and within several hour of one another. Clearly, it will not be possible to collect samples at the impoundment culverts and over the seagrass beds and process those samples within a single day.

The following sampling scheme is suggested as a way to capture both the patterns of materials loading among the impoundments and the annual materials flux between the individual impoundments and the IRL as well as the water quality over adjacent seagrass beds.

A. Weekly Impoundment Sampling: Independent impoundment samples (inside and outside) should be collected in duplicate on the same day of each week, at the same time of day at the selected culverts for each of WAM and open impoundments selected for the EPA-funded study (6 impoundments, described in Table 1) or a total of 24 water samples. T-10-K, a restored marsh that has no culverts, will serve as a control marsh. For this marsh, independent water samples should be collected in duplicate at two locations in shallow lagoon water (4 water samples). It is critical that sampling time, water temperature, and dissolved oxygen content are noted in the field log because the values of these water quality indicators are highly variable on diel cycles. At all sites, but especially at T-10-K where sampling will need to be conducted from a small boat, great care must be taken to avoid disturbing the sediments to prevent abnormally high values for all water quality indicators.

B. Monthly Seagrass Bed Sampling: The relatively large volume of the IRL water as compared to the impoundments suggest that alterations in water quality indicators are likely to occur on a longer time scales than in the impoundments as a result of dilution and mixing. However, D. Scheidt (Blum & Scheidt, 1999) found that water overlying a seagrass bed 150 m from an impoundment culvert responded to the rapid drawdown of the impoundment within one day. The EPA-funded project study impoundments are not subjected to rapid drawdown like those examined by Scheidt where large differences in hydraulic head created rapid mixing between impoundment and lagoon water. Unless rapid draw down of WAM impoundments is planned or an extreme storm tide or rainfall event occurs creating large head differences, monitoring of water quality over seagrass beds can occur less frequently than weekly sampling at impoundment culverts. A better integrated indicator of the effect of water quality on the seagrass beds will be obtained from monitoring seagrass distribution and production (Virnstein 1990, 1995). Thus, in association with ongoing water quality sampling in the IRL, water overlying seagrass beds near to each to the impoundments and T-10-K should be sampled once each month. A minimum of triplicate, independent grab samples should be collected over each bed along a transect centered on the impoundment culvert (to the extent possible) and be oriented parallel to the impoundment dike (21 water samples). To allow for direct comparison with impoundment sampling, seagrass and impoundment water quality should be sampled within one day of one another.

C. Intensive spatial sampling:

1. Perpendicular to impoundment dikes through the culverts. Work by D. Scheidt (Blum & Scheidt, 1999) found that a transect extending from 50 m inside the impoundment culvert to 150 m into the lagoon showed a detectable gradient in water quality characteristics when the impoundment was closed and a steeper gradient at least 96 h after rapid drawdown. Water was collected on the marsh surface about 50 m from the culvert, in the perimeter ditch and in the lagoon at the culvert mouth, and 150 m from the culvert. In both WAM and open impoundments, perpendicular transects similar to those used by Scheidt should be sampled to determine if there is a gradient in water quality indicators from the marsh surface, to the perimeter ditch, through the culvert, to nearest seagrass bed. Collecting additional samples 50 and 100 m from the culvert into the lagoon is also recommended to better define any gradients that might exist. If independent, duplicate samples are collect at each interval along the transect, a total of 12 water samples per impoundment would result from sampling in this manner. Ideally, WAM-managed impoundments would be sampled prior to culvert closure, one month after closure, just prior to drawdown, and daily during drawdown. Open impoundments should be sampled at times coincident with sampling of the WAM impoundments to determine if gradients occur when water exchange is allowed to occur freely between the impoundment and the lagoon. Similarly, T-10-K should be sampled from the intertidal region to 150-m off-shore.

2. Parallel to impoundment dikes in the perimeter ditch and lagoon. During the preliminary sampling conducted this summer (1999), impoundment (inside) and IRL (outside) water were collected at the ends of culverts installed through impoundment perimeter dikes. Sampling in this way provides the most conservative estimate of differences in the water quality indicators: differences would have been minimized between the impoundment and the lagoon, particularly when water was flowing through the culverts. Greater differences in water quality indicators are likely to occur away from the culverts. To determine if this assumption is true, at least once during the first year of the EPA-funded project each impoundment should be sampled along a transect centered on the culverts and extending perpendicular to the impoundment dikes. Duplicate, independent grab samples should be collected along the lagoon shoreline and in the perimeter ditch at 50-m intervals over a total distance of 400 m (i.e. 200 m in each direction from the culvert). This intensive sampling will generate 108 water samples from the six impounded marshes and 18 water samples from the restored marsh. These transects would be sampled at the same time as the perpendicular transects. Because of the logistical limitations associated with sampling both types of transects, it may be necessary to establish impoundment pairs that would be sampled on the same day. For example, T-10-D might be paired with T-10-J, T-10-E with T-10-H, and T-10-C with T-10-L so that the entire set of impoundments would be sampled over a 3-day period.

4. CONCLUSIONS

Water quality indicators inside and outside the marsh impoundments were different. Ammonium, salinity, bacteria and chlorophyll-*a* were higher inside the impoundments as expected possibly as a result of the great affect of evaporation on impoundment water. Water quality indicators responded rapidly both inside and outside the impoundments as exemplified by the increase in NH_4^+-N concentrations during a horseshoe crab die-off. Water quality indicators were high variable during the month in which water samples were collected. Because the impoundments are widely spaced it is logistically unrealistic to sample each of the impoundments and associated seagrass beds on a single day, sampling must be stratified to allow patterns of material movement and the annual flux of materials to and from the impoundments to be determined.

Figures 1-4 of the original document are in color. To obtain a copy of this report in color, please contact Dr. Linda Blum at LKB2e@virginia.edu or (804) 924-0560.

5. REFERENCES

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