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FINAL REPORT

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"EFFECTS OF MOSQUITO CONTROL WATER MANAGEMENT ON WATER QUALITY, HYDROLOGY AND FISHES INDIGENOUS TO PERIMETER DITCHES OF RIM-MANAGED IMPOUNDMENTS, BREACHED IMPOUNDMENTS AND NATURAL TIDAL CREEKS"

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EXECUTIVE SUMMARY

This project examined the association between certain water quality parameters and the distribution of indigenous mangrove swamp/salt marsh fish species. Of particular interest were associations with hydrogen sulfide, which is thought to be a factor in fish kills in managed impoundments. Project sampling sites were located at a RIM managed mosquito control impoundment (IRC #12), a breached impoundment (Blue Hole - SLC #23) and a natural tidal creek. Sampling was based on lunar and tidal influences. Sampling determined that sulfide levels were within the range reported for other salt marshes and that there is some evidence of an inverse relationship between sulfides and numbers of fish species and individuals captured.

Sulfide levels at the tidal creek site were low relative to the breached and RIM managed impoundments. Fish species and numbers increased as sulfide levels rose except for a negative relaitonship between number of individuals and sulfides at 12 in. depth. The lack of a distinct negative relationship between fish and sulfide levels may be due to the very low concentrations of sulfide detected at this site relative to the other two study sites.

At the breached and RIM managed impoundments, sulfide levels correlated negatively with fish species and numbers. Fish species and numbers declined when center ditch sulfide levels rose in the late summer and fall at both the breached and RIM managed impoundments. Sulfide levels at these sites were an order of magnitude higher than at the tidal creek. However this may not only be due to sulfide concentrations but increased marsh flooding area or renewed estuarine access.

This work again demonstrates the importance of opening culverts based on an equilibrium water level and not on a fixed date. By opening the culverts at the RIM managed impoundment during the fall tide increase and timing the opening for high tide, high sulfide levels in the water column were avoided. In past years, fixed date openings had resulted in rapid dewatering of the marsh surface and subsequent leaching of sulfides from the substrate. Proper management dictates that culverts remain closed until lagoon levels rise, even if this means keeping the impoundments closed for an additional time period.

It is difficult to rely completely on these data due both to the low number of stations examined and the low number of fish captured. However, there is some indication of an inverse relationship between sulfide and numbers of fish species and individuals captured. Results of this study do indicate differences in fish faunas between RIM managed impoundments and breached impoundments or tidal creeks. These studies, however, do not conclusively define the reasons for these differences due to the complex interaction of a wide variey of environmental parameters which must be examined on an experimental basis associated with a long term study of a variety of habitats.

SUMMARY

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TASK 1. COORDINATION WITH ENVIRONMENTAL RESOURCE AGENCIES.

A 3 day workshop entitled "Workshop on Salt Marsh Management and Research" was held on October 25-27 to satisfy Task 1 of this funded project. It included a field trip and 33 presentations on marsh management in Florida and several other coastal states. Attended by over 80 people, the workshop was well received and accomplished its objectives of bringing people up to date on salt marsh research and its management implications. A collection of workshop abstracts was compiled and distributed. Additionally, at the spring meeting of the Florida Anti-Mosquito Association (FAMA), the Board of Directors approved publishing the collection as a bulletin of the Journal of the FAMA. It was published as Bulletin Number 1, 1989 of the journal.

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TASK 2. EFFECTS OF WATER MANAGEMENT ON IMPOUNDMENT PERIMETER DITCH WATER QUALITY,

AND

TASK 3. EFFECTS OF WATER MANAGEMENT ON FISHES INHABITING IMPOUNDMENT PERIMETER DITCHES.

Pore and surface water chemistry and fish populations were monitored at the perimeter ditches of a Rotational Impoundment Management (RIM) managed impoundment (IRC #12), a breached impoundment (SLC #23 - Blue Hole), and in a natural tidal creek.

The temporal pattern of most of the variables measured followed the norm for this area, with salinity increasing with temperature and decreasing with rainfall, and dissolved oxygen varying inversely with temperature. In broad terms, the sulfide patterns (low in early summer, high in the fall), also corresponded with those reported for other marshes.

The RIM managed impoundment had higher salinities, high pH, and higher sulfide concentrations (at 12" and 18") than the breached impoundment or tidal creek. During the closed period, the most important of these was the high salinities observed at the managed impoundment which may have been responsible for some fish mortality. The only way to prevent this would have been to pump more frequently to equalize the salinity of the impoundment waters with that of the lagoon.

However, more individuals were collected in the managed impoundment than at other sites due to the abundance of resident species, which were not captured at the open creek sites. Resident species are those that are more tolerant of a variety of environmental parameters whicn vary widely in impounded wetland habitats (e.g., dissolved oxygen, salinity, water temperature; Gilmore, Peterson, Brockmeyer and Scheidt 1989).

More transient species were captured at the tidal sites compared to both impoundment sites possibly due to (a) better access to these sites from the estuary, (b) more favorable habitat conditions, i.e. lower tolerance to low dissolved oxygen condition, high sulfides, high salinities and high water temperatures. Of particular interest are the captures of menhaden and anchovies in the tidal creek systems as these species are quite sensitive to low dissolved oxygen conditions and other water quality parameters. More mojarras were collected at the natural creek site and more snook and mullet at the breached impoundment but numbers of the latter two species were so low that a major habitat association cannot be determined.

Sulfide levels recorded at the three sites were within the range reported for other salt marshes. Sulfide levels in the top six inches of the substrate were not significantly different between the managed and the breached impoundment, and both were higher than at the creek. At 12", the managed impoundment had higher sulfide concentrations than the breached impoundment but the latter was not significantly different from the tidal creek, whereas at 18" all three stations were significantly different. The only consistent gradient in sulfide concentration with depth was at the creek (18" > 12" > 6").

There were few statistically significant differences in water column physical variables between stations, but salinity and pH were both significantly higher at the managed impoundment than at the tidal creek. Sulfide was significantly higher at the managed impoundment than at the other two sites but water column sulfide levels were always low. The highest water column sulfide levels at the managed impoundment were not associated with culvert opening, but occurred in early summer, just as in the breached impoundment. At the tidal creek, a rise in sulfide levels also started in mid-June, but here the increase was longer-lived and peaked in mid-July.

When sulfide levels rose in the center of the tidal creek, so did fish species and number of individuals although there was a negative relationship between number of individuals and sulfide concentrations at 12" depths. The lack of a distinct negative relationship between fish and sulfide levels may be due to the very low concentrations of sulfide detected at this site relative to the other two study sites.

When sulfide levels in the center ditch at the breached impoundment increased in the late summer and fall, fish species and numbers declined. Sulfide levels at this site were an order of magnitude above the tidal creek site.

When ditch center sulfide levels increased at the RIM managed impoundment after reopening, the fish populations reduced significantly. However, this faunal decline may not only be due to sulfide concentrations but also to renewed estuarine access allowing emigration or increased marsh surface due to tidal waters flooding the marsh to a higher elevation than the mosquito control pumping.

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MANAGEMENT CONSIDERATIONS

This work again demonstrates the importance of opening culverts based on as equilibrium water level and not on a fixed date. By opening the culverts ar the managed impoundment during the fall tide increase and timing the opening for high tide, high sulfide levels in the water column were avoided. In past years, fixed date openings resulted in rapid dewatering of the marsh surface and subsequent leaching of sulfides from the substrate. Proper management dictates that culverts remain closed until lagoon levels rise, even if this means keeping the impoundments closed for an additional time period.

The greatest change in sulfide concentration after culvert opening was observed at 6", where after a small initial increase, sulfide levels dropped considerably by the next low tide. This sulfide was either; 1) oxidized upon exposure of the substrate at low tide and/or 2) drained into the perimeter ditch as tidal waters invaded the marsh at high tide and retreated at low tide. The future fate of the sulfide sequestered in the deeper soil layers is not known. We will continue to monitor this system to see what happens to this sulfide, particularly when the lagoon water levels recede and the marsh surface is exposed for long periods of time.

It is difficult to rely completely on these data due both to the low number of stations examined and the low number of fish captured. However, there is some indication of an inverse relationship between sulfide and numbers of fish species and individuals captured. There is little question that the occurrence of more transient species in the tidally influenced stations is due to better access in addition to any differences in water quality parameters.

The capture of a reasonable number of belonids, (= needlefishes) at the tidal sites and their absence from the RIM managed impoundment No. 12 and previous intensive studies of culverted impoundments, indicates a possible reluctance in these species to migrate through culverts.

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FURTHER STATISTICAL EVALUATION

Consultation by Alan Curtis (IRMCD Research Entomologist) with Dr. Rey and Dr. Gilmore early in the study confirmed that the study's experimental design was appropriate for comparative analysis. At that time, it was decided that a possible avenue of statistical analysis would be the association between measured sulfides and fish abundance. This proved to be an uneventful correlation because sulfides in the water column were not a significant component for comparative analysis.

The project leaders decided that the next best approach for collaborative investigation was the association between plankton and fish gut analysis. This data, collected between 1982-1984 is now being prepared separately for publication. When analyzed jointly, it should reveal some interesting relationships. This statistical analysis will be conducted in 1990 as part of a collaborative scientific publication.

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PRESENTATIONS AND PUBLICATIONS DRAWING ON CZM SPONSORED RESEARCH.

WORKSHOP ON SALT MARSH MANAGEMENT AND RESEARCH. This 3 day workshop (Oct. 25-27) satisfied TASK 1 of this funded project (see page 2). It included a field trip and 33 presentations on marsh management in Florida and several other coastal states. A collection of workshop abstracts was compiled and distributed. This collection was also published as Bulletin Number 1, 1989 of the Journal of the Florida Anti-Mosquito Association.

Workshop presentations directly drawing on CZM sponsored research included:

"Mosquito production in a rotationally managed impoundment compared to other management techniques" by Peter O'Bryan and Douglas Carlson (Indian River MCD).

"Vegetation dynamics in impounded marshes along the Indian River Lagoon" by Jorge Rey, Roy Crossman and John Schaeffer (Florida Medical Entomology Laboratory).

"Subtropical herbaceous marsh, mangrove swamp fish communities" by Grant Gilmore (Harbor Branch Oceanographic Institution, Inc.).

"Physiological observations on common wetland fishes, Snook, Centropomus undecimalis, Sailfin-molly, Poecilia latipinna and Sheepshead minnows, Cyprinodon variegatus" by Mark Peterson (HBOI).

INTERAGENCY COASTAL MANAGEMENT COMMITTEE PRESENTATION (OCTOBER 1988, TALLAHASSEE). This committee presentation by Doug Carlson and Grant Gilmore provided an overview of the entire impoundment management study that DER/CZM has funded, highlighting research findings and how they are being implemented in marsh management practices.

INDIAN RIVER RESEARCH SYMPOSIUM PROCEEDINGS (MARINE RESOURCES COUNCIL, SEPTEMBER 1988, MELBOURNE). Presented at this meeting in September 1988, this paper, entitled: "Salt marsh mitigation: an example of the process of balancing mosquito control, natural resource and development interests" was presented by Peter O'Bryan and co-authored by Doug Carlson and Grant Gilmore. It now has been accepted for publication in Florida Scientist.

FLORIDA ANTI-MOSQUITO ASSOCIATION SHORT COURSES (JAN. 1989, TAMPA). Doug Carlson contributed to a course on "State Management Plans" explaining the current political and scientific/management status of source reduction work in Florida.

JOINT MEETING OF THE MARINE FISHERIES COMMISSION AND THE GULF OF MEXICO FISHERY MANAGEMENT COUNCIL (MARCH 1989, MIAMI). In this meeting familiarizing these two committees with mosquito control practices, Doug Carlson and Peter O'Bryan made presentations on source reduction/impoundment. Doug's presentation dealt with the historical perspectives and current implementation of salt marsh source reduction practices. Peter's presentation focused on impoundment research implications relating to fisheries management.

AMERICAN MOSQUITO CONTROL ASSOCIATION ANNUAL MEETING (APRIL 1989, BOSTON, MASS). Doug Carlson made a presentation at this meeting entitled: "Current issues in salt marsh management in Florida".

FLORIDA ANTI-MOSQUITO ASSOCIATION ANNUAL MEETING (MAY 1989, ORLANDO). Doug Carlson made a presentation at this meeting entitled: "Salt marsh management in Florida: progress during 1988-89 by the Subcommittee on Managed Marshes".

FLORIDA DEPARTMENT OF NATURAL RESOURCES INTRA-AGENCY MEETING ON MOSQUITO CONTROL (MAY 1989, ST. PETERSBURG). Doug Carlson's invited presentation was on water management for salt marsh mosquito control. This included a summary of CZM sponsored research and a description of the role of the Subcommittee on Managed Marshes.

INDIAN RIVER COUNTY EXCHANGE AND ROTARY CLUB (SUMMER 1989). Doug Carlson made presentations dealing with salt marsh mosquito biology and control. This presentation also summarized CZM sponsored research.

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT GOVERNING BOARD (SEPTEMBER 1989, PALATKA). Doug Carlson participated in a presentation to the SJRWMD Governing Board briefly explaining improvements in salt marsh management and the importance of SJRWMD's continued support of the SWIM program as it relates to salt marsh management. DER/CZM's support of impoundment research was recognized.

At the request of Mr. John Minton, Governing Board Chairman, Doug Carlson will make an expanded slide presentation to the Governing Board on impoundment management on December 13. The management implications of DER sponsored impoundment research will be the crux of this presentation.

COMPARISON OF PORE AND SURFACE WATER CHEMISTRY AND FISH POPULATIONS BETWEEN THE PERIMETER DITCHES OF A MANAGED IMPOUNDMENT AND A BREACHED IMPOUNDMENT AND A NATURAL TIDAL CREEK.

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December 15, 1989

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SUMMARY

Pore and surface water chemistry, and fish populations were monitored at the perimeter ditches of an open (IRC #12) and a breached (Blue Hole) impoundment, and in a natural tidal creek.

The temporal patterns of most of the variables measured followed the norm for this area, with salinity increasing with temperature and decreasing with rainfall, and dissolved oxygen varying inversely with temperature. In broad terms, the sulfide patterns (low in early summer, high in the fall), also corresponded with those reported for other marshes.

The managed impoundment had higher salinities, higher pH, and higher sulfide concentrations (at 12' and 18") than the other two sites. During the closed period, the most important of these was the high salinities observed at IRC #12, which may have been responsible for some fish mortality. The only way to prevent this would have been to pump more frequently to equalize the salinity of the impoundment waters with that of the lagoon.

Sulfide levels recorded at our sites were within the range reported for other salt marshes. Sulfide levels in the top six inches of the substrate were not significantly different between the managed and the breached impoundment, and both were higher than at the creek. At 12", IRC #12 had higher sulfide concentrations than Blue Hole, but the latter was not significantly different from the tidal creek, whereas at 18" all three stations were significantly different. The only consistent gradient in sulfide concentration with depth was at the creek (18" > 12" > 6").

There were few statistically significant differences in water column physical variables between stations, but salinity and pH were marginally significant (both higher at IRC #12 than at the creek). Sulfide, was significantly higher at IRC #12 than at the other two sites, but water column sulfide levels were always low.

The highest water column sulfide levels at IRC #12 were not associated with culvert opening, but occurred in early summer, just as in Blue Hole. At the creek, a rise in sulfide levels also started in mid-June, but here the increased was longer-lived and peaked in mid-July. Probably the most important factors in preventing high water column sulfide concentrations at IRC #12 were the fact that the culverts were not opened until the lagoon water levels had undergone their normal fall rise, and the fact that the culverts were opened at high tide. This observation mitigates against setting fixed impoundment opening dates. A more prudent course of action is to open impoundments when the lagoon water levels are high, and at high tide, even if this

means keeping the impoundments closed for a couple of extra weeks.

The greatest change in sulfide concentration after culvert opening was observed at 6", where after a small initial increase, sulfide levels dropped considerably by the next low tide. This sulfide was either (1) oxidized upon exposure of the substrate at low tide and/or (2) it was drained into the perimeter ditch as tidal waters invaded the marsh at high tide and then retreated at low tide. The future fate of the sulfide sequestered in the deeper soil layers is not known. We will continue to monitor this system to see what happens to this sulfide, particularly when the lagoon water levels recede and the marsh surface is exposed for long periods of time.

INTRODUCTION

Even though a great deal of research effort has been dedicated to problems relating to salt marsh mosquito control impoundments, we still lack concrete information on several aspects of the impoundment problem. One of these is the dynamics of perimeter ditch waters, particularly during the "reopening" period after summer closure. The perimeter ditch merits special consideration because it represents the immediate connection between the impounded marsh and the lagoon, and because it is the only refugium for aquatic organisms during periods of receding and low water levels.

Numerous fish kills have been observed in perimeter ditches during the weeks immediately following reopening of the culverts in the fall. Various explanations have been proposed for this phenomenon, including low D.O. levels, high hydrogen sulfide levels (or high acidity resulting from oxidation of reduced sulphur compounds), and preferential draining of the top, oxygenated, water layer in the ditch, leaving fish stranded in lower, oxygen-poor layers. Alternating periods of marsh flooding and draining have been shown to generate sulfides which can leach into the perimeter ditches and generate stressful conditions both in their reduced state, or upon oxidation (Abel et al. 1987, Carlson et al. 1983). Furthermore, the construction of dikes has also been shown to contribute to this phenomenon (Gaviria et al. 1986).

Another aspect of the impoundment problem that needs further attention is the evaluation of differences, in terms of habitat quality, of RIM-managed impoundments and impoundments with breached dikes. Although dike-breaching has been promoted as possible mitigation for marsh-related work, its advantages relative to RIM management have not been evaluated, particularly in light of the fact that breaching a dike results in the loss of mosquito control capabilities, and thus may force the use of pesticides for that purpose.

This study attempts to investigate some of the questions addressed above by investigating the patterns of certain physical variables in impoundment perimeter ditches and the surrounding pore waters. Data was collected at various stations within a RIM-managed impoundment, an impoundment with a breached dike, and a natural tidal creek.

STUDY SITES

Three sites were selected for this study; two impoundments (IRC #12 and Blue Hole) and a natural tidal creek. IRC #12 is a 128.4 ha impoundment on the barrier island side of the Indian River lagoon at the Indian River-St. Lucie county line (Figures 1A & 2). The impoundment is connected to the lagoon via two 76.2 cm diameter culverts with risers, and two 45.7 cm diameter culverts with flapgates. During this study, the impoundment was managed according to the RIM protocol; it was closed and flooded for mosquito control on June 8, 1989, and re-opened on September 18, 1989. Blue Hole (Figures 1B & 2) is located approximately 1.5 km south of IRC #12 and 1.5 km north of the tidal creek. It covers an area of 743.5 ha, and is connected all year to the lagoon via a 76.2 cm diameter culvert with no control structures, and through a breach on the dike on the northeast side of the impoundment. At each impoundment, two pore water sampling stations were established on the banks of the perimeter ditch, and one in the center of the ditch, whereas at the tidal creek site, two stations were established on both creek banks and one in the center of the creek. Additional stations were established to sample the water column in the center of the ditches or creek at all three sites.

METHODS

Field Samplers.

Pore water samples were collected biweekly at depths of 6, 12, and 18 inches, not more than 1 hour before or after high tide. The samplers were modified versions of those described by Zimmermann et al. (1978). The samplers consist of 1.91 cm diameter PVC pipes sealed inside 3.81 cm PVC pipes with a filtering piece at one end and PVC plugs at the other (Figure 3). Two bulkhead fittings on the top plugs are connected to 0.318 cm diameter tubing for sample removal and for purging air from the assembly by pumping in nitrogen gas. All joints are sealed with silicone cement and, where appropriate, with rubber or silicone seals. The total length of each sampler varies depending on its application.

Each filtering piece consists of a 1.27 cm diameter PVC pipe 11.1 cm long with 20 1.59 cm diameter holes on the walls. This pipe is covered with 150μ macro-filter screening and is enclosed within a 1.91 cm diameter PVC pipe which screws into the bottom of the samplers. The whole filtering assemblage is covered with #2 plastic screening. We tested different combinations of polyethylene and teflon filters of smaller mesh sizes and found that they clogged very rapidly and did not permit the extraction of enough sample volume for our analyses.

The water column samplers were identical to the above, but were suspended in a float so that samples were always collected 15-20 cm below the surface.

Sample Collection.

Field samples were collected at biweekly intervals, at high tide, and no more than 2 days removed from the full and new moons. Approximately 18 hours before sample collection, the nine samplers at each station were purged using a Nalgene Mity Vac to pressurize the system and bring the pore water to the surface via the sampler tubing. Originally, we intended to purge the samplers two hours prior to sampling, but this short period did not allow enough water to filter in for our analyses. Even with 18 hours, some samples sometimes did not contain enough water to conduct all of the analyses; in those cases, water for the sulfide analysis was fixed first, and other determinations were performed depending upon the water volume left.

The actual samples were removed by pumping in nitrogen gas through the sampler's gas intake valve (Figure 3) to completely purge the system of oxygen. The samples were collected directly into 50 ml serum bottles that were filled with nitrogen gas and vacuum sealed with rubber caps. This was done with a plastic tubing and needle arrangement so that the seal was no broken, and the sample was not exposed to air. From the serum bottles, 10 ml of pore water were removed for sulfide analysis with 20 ml syringes which contained 10 ml of freshly-prepared SAOB and which were wrapped in aluminum foil and kept in a cooler. After collection, each syringe was again wrapped with aluminum foil and returned to the cooler. Thus, there was no exposure to oxygen during the sample extraction and fixing process.

The water remaining in the serum bottles was the used to obtain measurements of dissolved oxygen and temperature (YSI Model 51B meter), pH (Gallenkamp pH Stick), and salinity (AO temperature compensated refractometer).

In the laboratory, sulfide determinations were made not more than three hours after collection using an Orion EA940 Ion Analyzer with a Model 94-16 Silver/Sulfide electrode, a Model 90-02 double junction reference electrode, and an Orion Automatic Temperature Compensator (ATC) probe. Prior to analysis, the machine was calibrated (3-point) using commercially prepared standards (Orion Sulfide Standards). Standards covering the range of concentrations normally encountered in our samples were also run after every 4 samples.

Data Analysis.

All data analyses were performed using SAS (SAS Institute, Cary N.C.) on a Microvax II computer. ANOVAS were performed with the GLM procedure of SAS, and the Waller-Duncan a-posteriori test was used to examine individual differences for significant ANOVA terms. If significant interactions were discovered in multiway and nested ANOVAS, the interacting terms were analyzed separately using one-way analyses.

RESULTS

Water Levels and Precipitation.

The summer of 1989 was relatively dry, and rainfall was sporadic throughout the season (Figure 4). The highest consistent precipitation occurred after August, but average rainfall was way below normal for summer and fall.

At IRC #12, water levels were influenced principally by pumping and precipitation (Figure 5). In the impoundment, water levels were raised when the impoundment was closed and pumped in June and then steadily dropped until August, when additional pumping and high precipitation again raised the water level. After the second pumping, water levels did not drop as fast as before due to higher rainfall. Likewise, levels did not drop sharply when the impoundment was opened in September because this event took place after water levels in the lagoon had undergone their normal fall rise (Figures 4 & 5).

Temporal Patterns.

CENTER STATIONS. At the creek and ditch center stations, dissolved oxygen showed an increasing trend starting in September at all three sites (Figures 6A - 6C). At the tidal creek and IRC #12, D.O. levels were relatively stable from June to September, whereas at Blue Hole, there was a sharp decrease in late August, before levels started to rise in late September (Figure 6C). Likewise, salinity was fairly stable from June to August, and then decreased significantly in late August (Figures 6D - 6F). A steep rise in salinity evident in the 6" samples at IRC #12 in mid September was not mirrored at the other stations.

Patterns in pH at the tidal creek and Blue Hole were similar (Figures 6G & 6H). A both sites, pH was high during early June, decreased during June, peaked in August, and then decreased again until early September (the last decrease was not evident at 12" in Blue Hole). At IRC #12, however, pH showed an increasing trend until mid October, and then declined sharply (Figure 6I).

Even though sulfide levels under the ditch at IRC #12 were an order of magnitude higher than under the creek center, the temporal patterns at the two stations were similar. At both stations, sulfide levels were relatively stable from June through August, at which time sulfide levels at 12" and 18" began to show irregular peaks (Figures 7B & 7C). At Blue Hole, the 18" samples had relatively even sulfide levels throughout the period covered here, the 12" samples showed a minor peak in mid-June and then remained close to 0, while the 6" samples increased from June to mid-August, with a major peak in late July-early August, and declined after September (Figure 7A).

BANK STATIONS. Although there were significant differences in some physical variables between stations at the same site (see below), we have plotted the means of each site-depth combination for the two bank stations at each site to identify the major patterns observed in each; these plots are shown in Figures 8A-8I.). The dissolved oxygen patterns at the bank stations were similar to those at the center stations, except for a sharper increase at IRC #12 starting in October. Likewise, salinity patterns at the Blue Hole ditch bank stations (Figure 8C) were similar to the ditch center; at IRC #12, average salinity showed an increasing trend from June to August (mid-July for the 18" samples), then decreased until mid-September (Figure 8D). At the creek, salinity decreased steadily from mid June until November (Figure 8I). pH at Blue Hole fluctuated irregularly throughout the study (Figure 8B). At IRC #12, pH patterns at the bank stations were, again, similar to those under the ditch, with pH remaining relatively stable throughout the summer, and a peak in late October (Figure 8F). At the creek, pH also remained relatively stable, except for an anomalous point (pH < 4.0) recorded on June 7 at 6", and a slight drop in mid August (Figure 8H).

Sulfide levels followed similar patterns at all three stations (Figure 9). There was a general increasing trend from July until late September with more or less pronounced drops after that, and with major peaks occurring in mid September. The 18' samples at the creek and IRC #12 also showed peaks in mid June followed by sharp declines during late June - early July. A secondary increasing trend was apparent after mid October, except for the 12" samples at Blue Hole and the tidal creek.

WATER COLUMN. As expected, water column temperatures followed similar patterns at the three sites (Figure 10B). Likewise, salinity values through time were similar at Blue Hole and the tidal creek (Figure 10A) but at IRC #12, salinity increased from June until early August, when high precipitation (Figure 4) and pumping (Figure 5) lowered the salinity there (Figure 10A). Dissolved oxygen increased irregularly at the three sites from June until August at which time levels declined until September, and then increased steadily thereafter (Figure 10C). pH at the two impoundments fluctuated up and down until mid August, and then increased and remained relatively high until mid September. At the creek, pH levels reached their lowest point in mid-July, rose sharply during August, and then declined somewhat in late August-early September (Figure 10D). Sulfide levels in the water column were low in all samples included in this report (Figure 10E). The highest levels were recorded in June at the two impoundments and in July at the creek. Minor peaks were also observed in mid August at the creek and in mid September at the impoundments.

Relationships Between Variables.

Dissolved oxygen was correlated with water temperature at the three sites, whereas salinity was correlated with depth at the two impoundments, but not at the tidal creek (Table 1). Sulfide was positively correlated with depth at Blue Hole and at the tidal creek and negatively correlated with salinity at IRC #12 and at the creek, while at the latter, it was also negatively correlated with pH. pH was correlated with salinity at the tidal creek and inversely correlated with depth at Blue Hole.

Between-site Comparisons.

There were significant between-site differences in pore water temperature, salinity, pH, and sulfide when compared by sample depth (Table 2). Temperature at the two impoundments was higher that at the creek except for the 12" samples, where differences between IRC #12 and the creek were not significant. At 6" and 12" depths, salinities at IRC #12 were higher than at Blue Hole and the tidal creek but there were no significant differences between sites at 18". pH at IRC #12 was higher than at the tidal creek, and at 18", also higher than at Blue Hole. Likewise, sulfide concentrations were higher at IRC #12 than at Blue Hole and the creek except at 6" where the two impoundments were not significantly different. In the water column, the only significant difference was in sulfide concentration, which was higher at IRC #12 than at Blue Hole and the creek (Table 3).

Within-site Comparisons.

Tables 4 - 6 show the results of two-way analyses of variance for differences in pore water physical variables between stations an depths within each site. At Blue Hole, there were no site or depth differences in temperature and D.O., but there were significant differences for salinity, pH and sulfide (Table 4). Salinity was lower at the North station than at the Ditch and South, and lower at 6" than at 12 and 18, whereas pH was lower at the South station than at the Ditch, and lower at 18" than at 6. Sulfide was lowest at the South station, followed by the North and then the Ditch station, and lower at 12" than at 18.

The interaction terms for the above three variables, however, were significant. For salinity, the interaction results from the fact that at 6", the South station had higher values than the North, at 12" both the South and Ditch stations had higher salinities than North, whereas at 18" the Ditch was higher than the North and South stations (Table 7). For pH, the interaction term is significant because the Ditch had significantly higher pH that the North and South stations at 12", but not at 6" or 18". Sulfide, on the other hand, was higher in the Ditch than in the other two stations at 6", but at 12" the North station had higher sulfide concentrations, and at 18" there were no significant differences (Table 7).

The patterns at IRC # 12 were simpler (Table 5): For salinity, there were significant effects of station (North > Ditch), and depth (6" > 18") whereas for sulfide, only the effect of station was significant (C > N = S). No significant effects of station or depth were evident for temperature, salinity, or D.O., nor were any of the interaction terms significant.

At the tidal creek, there were no differences in pH or D.O. between stations and depth (Table 6). Temperature was higher at the Center station than at the East station, whereas salinity was lower at the East station than at the other two. Overall, sulfide concentrations were higher at the East and West stations than at the Center, and higher in samples taken at 18" than in those taken at 12" which in turn had higher concentrations than those taken at 6" (Table 6). A significant interaction between site and depth was evident for sulfide, and resulted from the fact that at 12" and 18" the East and West stations had significantly higher concentrations that the center, but at 6" there were no significant differences between East and Center (Table 7).

<u>Sulfide Levels During Culvert Opening</u>.

There was little change in the sulfide levels at the bank stations after the culverts were opened at IRC #12 (Figure 11). In the ditch stations the patterns were different for the three depths: at 6", sulfide levels rose slightly after opening, and decreased sharply by the next low tide (Figure 11A). At 12", levels showed slight declines after opening, and by the next low tide (Figure 11B), whereas at 18", there was an initial decline but by the next low tide sulfide levels were higher than before the culverts were opened (Figure 11C). Sulfide levels in the water column never rose above 4 ppm, and have remained low to this date.

DISCUSSION

The temporal patterns of most of the variables measured followed the norm for this area, with salinity increasing with temperature and decreasing with rainfall, and dissolved oxygen varying inversely with temperature. In broad terms, the sulfide patterns (low in early summer, high in the fall, Figures 7 & 9) also correspond with those reported for other marshes. Howarth <u>et al</u>. (1983) found similar seasonal patterns in a New England salt marsh, and attribute the pattern in part to high rates of sulfide oxidation by <u>Spartina</u> roots in June, and decreased oxidation rates in September due to senescence of the plants. The kinetics of reducing and oxidizing activity underneath mangrove roots, however, may be totally different (Carlson <u>et al</u>. 1983).

There were significant differences in pore water physical variables between the perimeter ditch of the managed impoundment, the perimeter ditch of the breached impoundment, and the tidal creek. The managed impoundment had higher salinities, higher pH, and higher sulfide concentrations (at 12' and 18") than the other two sites (Table 2). During the closed period, the most important of these was the high salinities observed at IRC #12, which may have caused some fish mortality (see below). The fact that 1989 was an extremely dry year was in part responsible for this phenomenon, and the only solution would have been to pump more frequently to equalize the salinity of the impoundment waters with that of the lagoon.

A large range of salt marsh pore water sulfide levels has been reported in the literature (Howarth and Teal 1982, Howarth et al. 1983, Carlson et al. 1983, Gardner et al. 1988, and others) so it is not surprising to find our values well within that range. Likewise, differences between our stations, even within the same site, are not surprising since wide variability in sulfide concentrations of salt marsh pore waters have often been reported (Gardner et al. 1988).

Sulfide levels in the top six inches of the substrate were not significantly different between the managed and the breached impoundment, and both were higher than at the creek. At 12", IRC #12 had higher sulfide concentrations than Blue Hole, but the latter was not significantly different from the tidal creek, whereas at 18" all three stations were significantly different. Thus, it appears, as one would expect, that there is a relationship between the magnitude of tidal exchange, and the depth distribution of sulfide, but the only consistent gradient in sulfide concentration with depth was at the creek (18" > 12" > 6", Table 4). Howarth et al. (1983), found that in dense sediments (large proportion of sand), there were pronounced gradients in sulfide concentration with depth, but in less dense sediments (little sand, high organic content), such as the ones in our sites (Rey et al. 1990), no such gradients were evident.

There were few statistically significant ($p \leq 0.05$) differences in water column physical variables between stations (Table 3), but salinity and pH were marginally significant (both higher at IRC #12 than at the creek). Sulfide, was significantly higher at IRC #12 than at the other two sites, but water column sulfide levels were always low. Since there is little information on the levels of sulfide required to cause toxic effects on fish, it is impossible to conclude that these low levels were innocuous, but it should be noted that Abel et al. (1987) found that comparable levels elicited an emersion response in Rivulus marmoratus. It is interesting to note that the highest sulfide levels at IRC #12 were not associated with culvert opening, but occurred in early summer, just as in Blue Hole (Figure 10E). At the creek, a rise in sulfide levels also started in mid-June, but here the increased was longer-lived and peaked in mid-July (Figure 10E).

Probably the most important factors in preventing higher water column sulfide concentrations at IRC #12 were the fact that the culverts were not opened until the lagoon water levels had undergone their normal fall rise, and the fact that the culverts were opened at high tide. Thus, there was not a precipitous drop in impoundment water levels as the impounded waters rushed out into a low lagoon; instead, lagoon waters first flowed into the impoundment, and then gradually receded with the low tide. This observation mitigates against setting fixed impoundment opening dates. A more prudent course of action is to open impoundments when the lagoon water levels are high, and at high tide, even if this means keeping the impoundments closed for a couple of extra weeks.

Note that a small peak evident at IRC #12 around the time that the culverts were opened also occurred at Blue Hole, and thus, can not be attributed with certainty to opening of the culverts. The greatest change in sulfide concentration after culvert opening was observed at 6", where after a small initial increase, sulfide levels dropped considerably by the next low tide (Figure 11A). This sulfide was either (1) oxidized upon exposure of the substrate at low tide and/or (2) it was drained into the perimeter ditch as tidal waters invaded the marsh at high tide and then retreated at low tide (King et al. 1982, Gardner et al. 1988). Both of these alternatives are reasonable since the 6" layer would be the first to be exposed to oxidizing conditions, and is also likely to leach into the perimeter ditch under fluctuating water levels, particularly at our stations, which were immediately adjoining the perimeter ditches or the tidal creek (Yelverton and Hackney, 1986). Evidence for alternative (1) would be a decrease in the pH of the 6" layer and possibly, of the water column as sulfide oxidation products such as pyrite and H_2SO_4 accumulate (King et al. 1982), whereas evidence for alternative (2) would be a significant increase in sulfide concentration of the water column; neither of the above, however, are evident in our data. A likely scenario is that some of the sulfide in the surface layer was diluted with the high tide, and washed out into the perimeter ditch, and into the lagoon as the tide receded. If any sulfide oxidation products that were created during this process were also diluted and washed out with the tide, then a decrease in pH and an increase in water column sulfide may not have occurred. The future fate of the sulfide sequestered in the deeper soil layers is not known. We will continue to monitor this system to see what happens to this sulfide, particularly when the lagoon water levels recede and the marsh surface is exposed for long periods of time.

LITERATURE CITED

Abel, D. C., C. C. Koenig, and W. P. Davis. 1987. Emersion in the mangrove forest fish Rivulus marmoratus: a unique response to hydrogen sulfide. Env. Biol. Fishes 18: 67-72.

Carlson, P. R., L. A Yabro, C. F. Zimmermann, and J. R. Montgomery. 1983. Pore water chemistry of an overwash mangrove island. Fla. Scientist 46: 239-249.

Gardner, L. R., T. C. Wolaver, and M. Mitchell. 1988. Spatial variation in the sulfur chemistry of salt marsh sediments at North Inlet, South Carolina. J. Marine Research 46: 815-836.

Gaviria M., J. I., H. R. Schmittou, and J. H. Grover. 1986. Acid sulfate soils: Identification, formation, and implications for aquaculture. J. Aqua. Trop. 1: 99-109.

Howarth, R. W. and J. M. Teal. 1979. Sulfate reduction in a New England salt marsh. Limnol. Oceanogr. 24: 999-101

Howarth, R. W., A. Giblin, J. Gale, B. J. Peterson, and G. W. Luther III. 1983. Reduced sulfur compounds in the pore waters of a New England salt marsh. Env. Biogeochem. Ecol. Bull. 35: 135-152.

King, G. M., M. J. Klug, R. G. Wiegert, A. G. Chalmers. 1982. Relation of soil water movement and sulfide concentration to Spartina alterniflora production in a Georgia salt marsh. Science 218: 61-63.

Rey, J. R., J. Shaffer, and R. A. Crossman. 1989. Salt marsh and mangrove forest soils in impounded wetlands. J. Fl. Anti-mosquito Association. in press.

Yelverton, G. F., and C. T. Hackney. 1986. Flux of dissolved organic carbon and pore water through the substrate of a Spartina alterniflora marsh in North Carolina. Est. Coastal and Shelf Sci. 22: 255-267.

Zimmermann, C. F., M. T. Price, and J. R. Montgomery. 1978. A comparison of ceramic and Teflon in situ samplers for nutrient pore water determinations. Est. Coastal. Mar. Sci. 7: 93-97.

FIGURE LEGENDS

FIGURE 1. Maps of IRC #12 and Blue Hole showing the location of the sampling stations (denoted by the arrows and circles).

FIGURE 2. Relative location of the study sites. IR = IRC #12, BH = Blue Hole, TC = tidal creek.

FIGURE 3. Schematic diagram of the pore water samplers.

FIGURE 4. Rainfall recorded at the Florida Medical Entomology Laboratory during the study. Data points represent the amount of rainfall recorded between samples.

FIGURE 5. Plot of water levels at IRC #12 showing the timing of pumping events and culvert opening.

FIGURE 6. Physical variables at the ditch and creek centers pore water sampling stations.

FIGURE 7. Pore water sulfide concentrations at the ditch and creek center stations.

FIGURE 8. Physical variables at the creek and ditch bank pore water sampling stations. Values plotted are the means of the observations at the two stations in each site.

FIGURE 9. Sulfide concentrations at the creek and ditch bank pore water sampling stations. Values plotted are the means of the observations at the two stations in each site. Values for IRC #12 are plotted along the right Y-axis while those for Blue Hole and the tidal creek along the left.

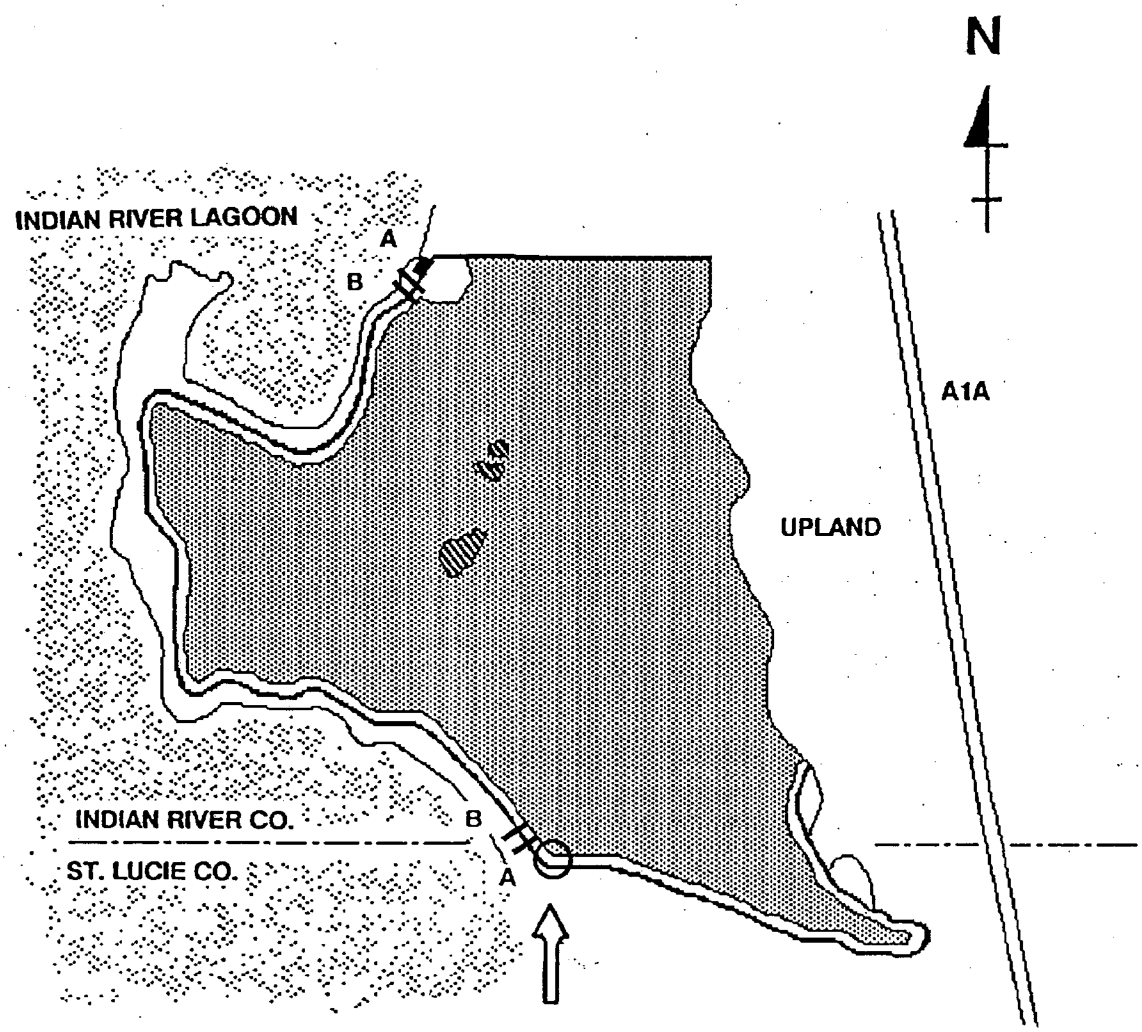
FIGURE 10. Physical variables at the water column sampling stations.

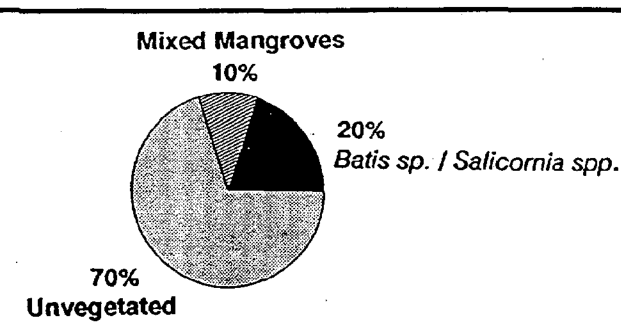
FIGURE 11. Sulfide levels at IRC #12 during culvert opening. PRE = samples collected immediately before opening, POST = immediately after opening, LOW = next low tide, HIGH = next high tide.

A

12

COUNTY LINE





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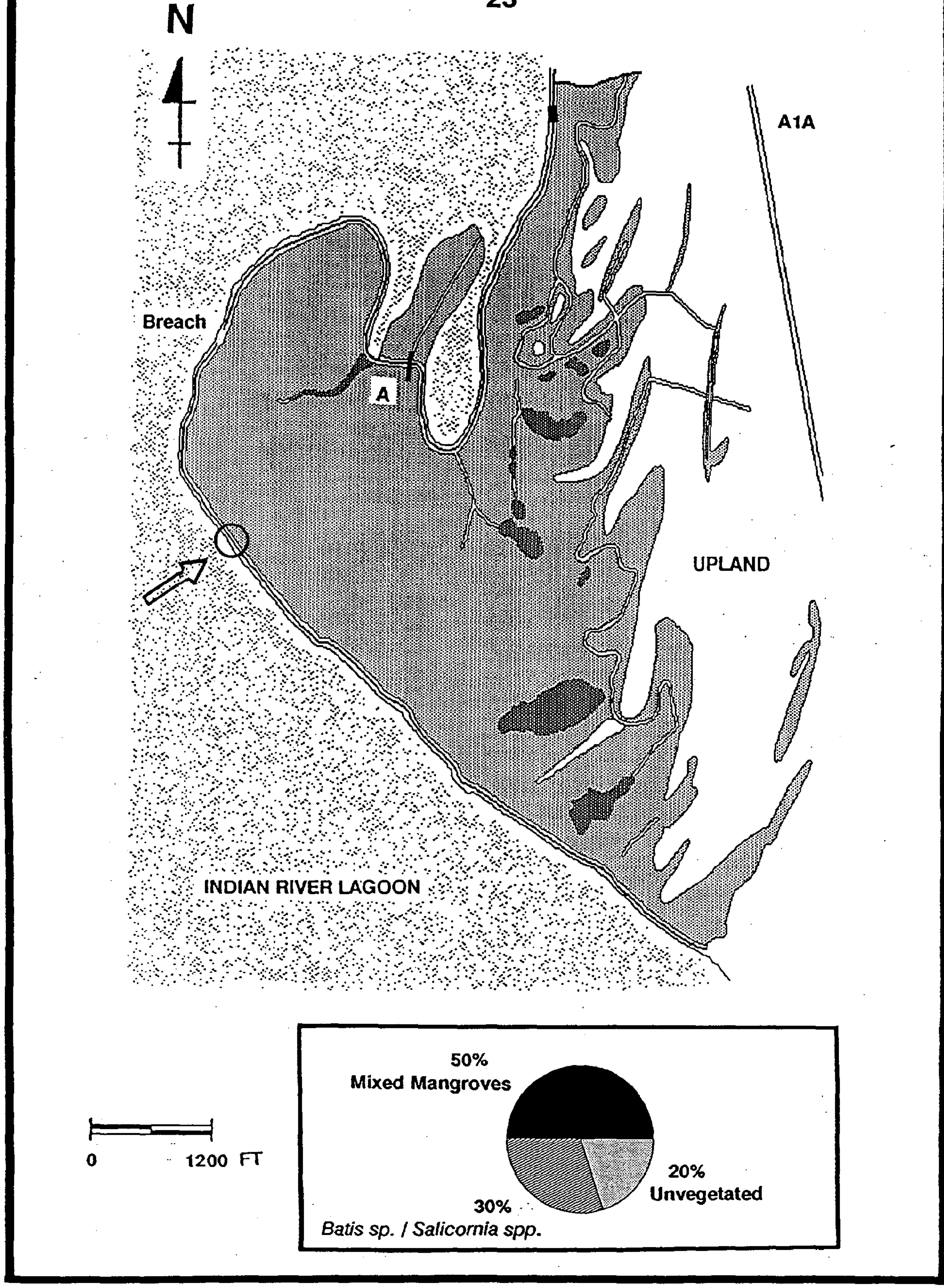
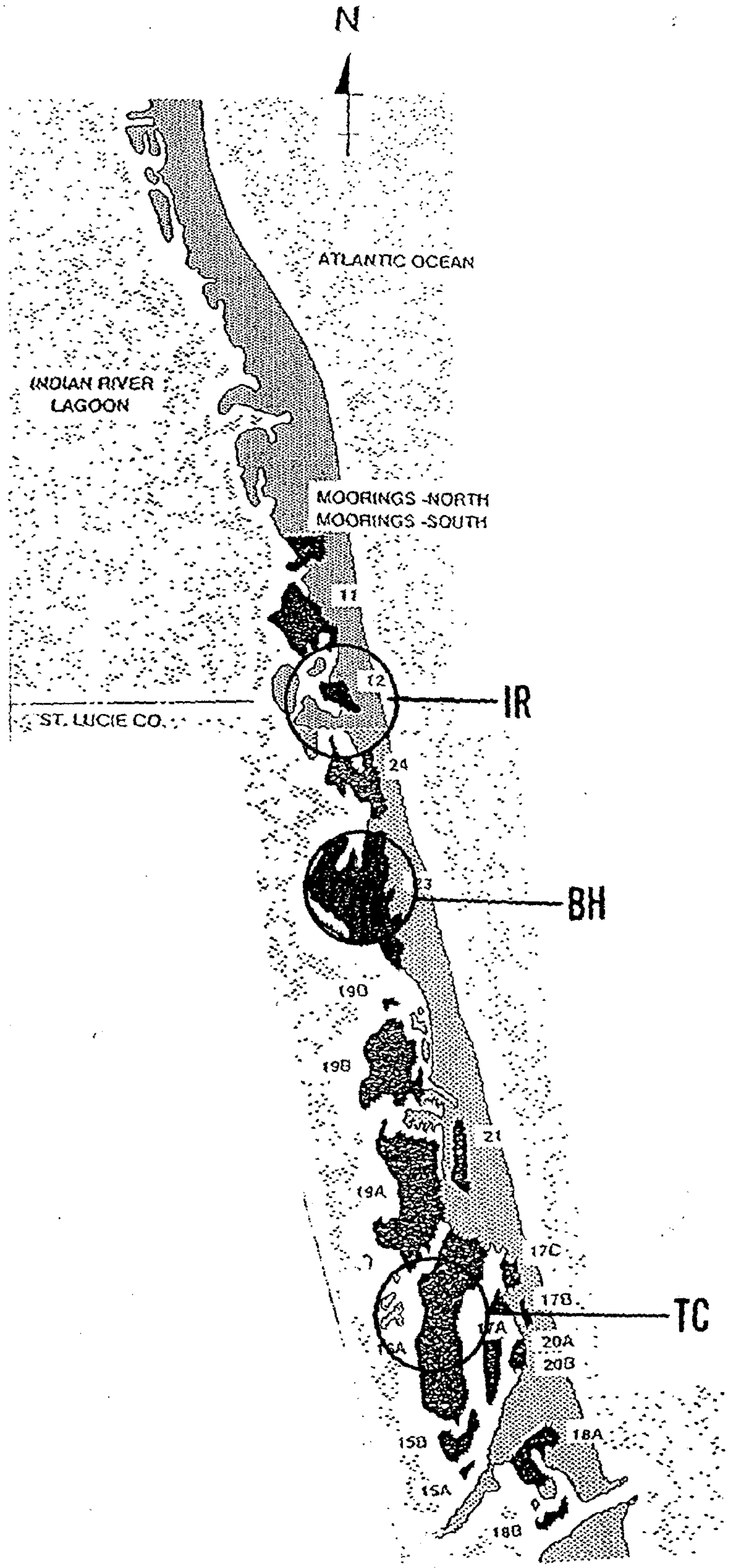

N
A1A
Breach
A
UPLAND
INDIAN RIVER LAGOON
0
1200 FT
50%
Mixed Mangroves
20%
Unvegetated
30%
Batis sp. / Salicornia spp.

INDIAN RIVER COUNTY
SOUTH

2



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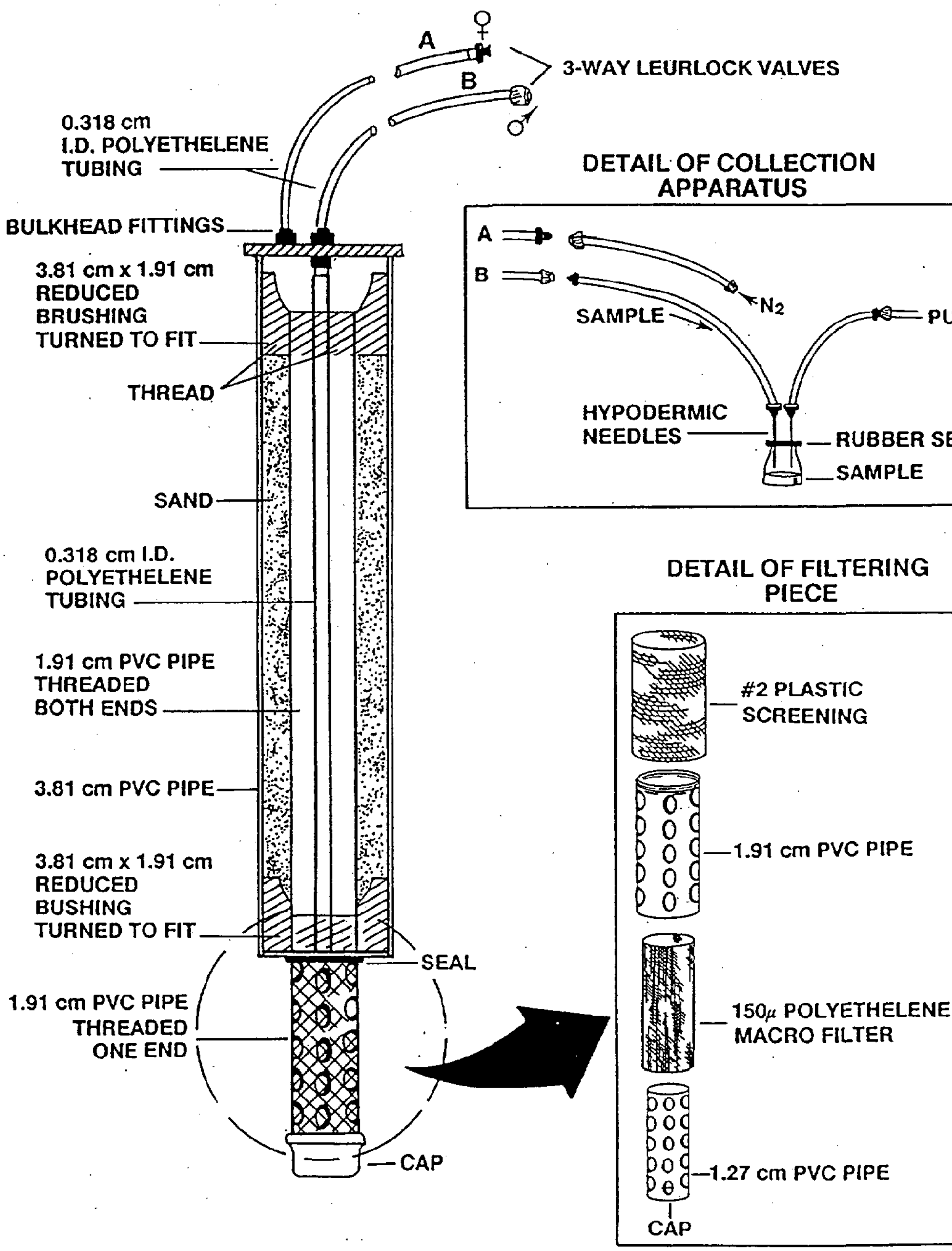

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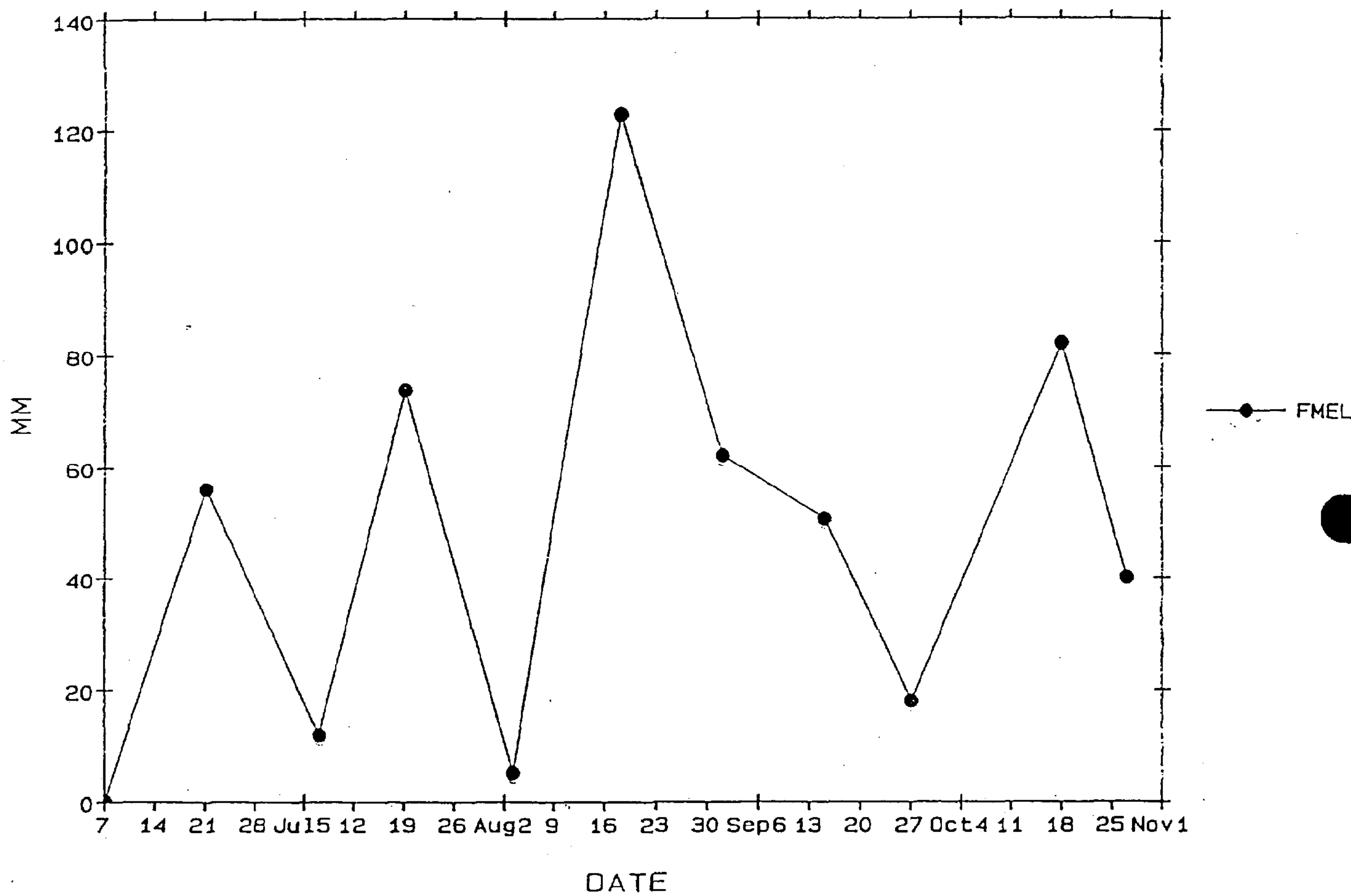

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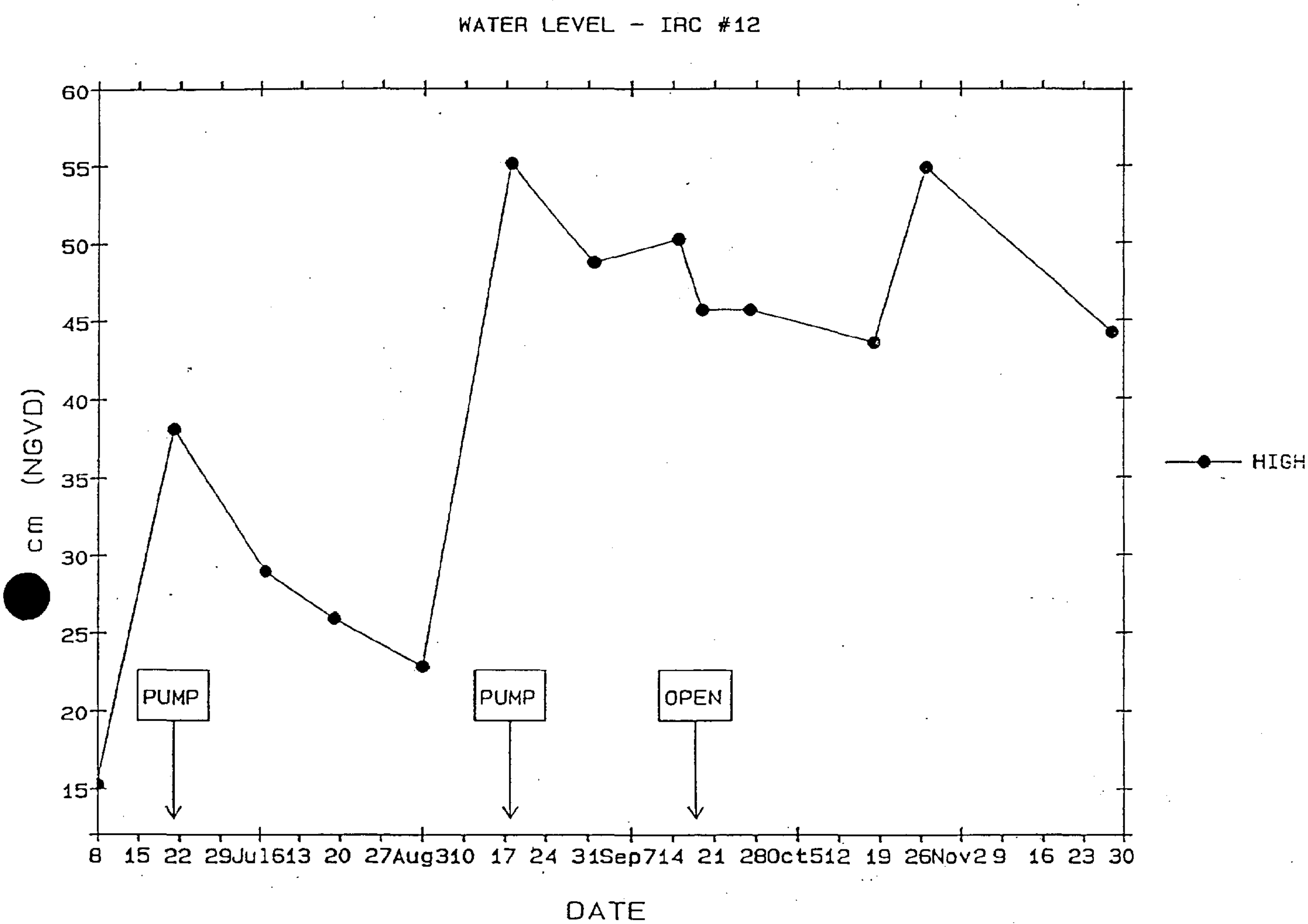
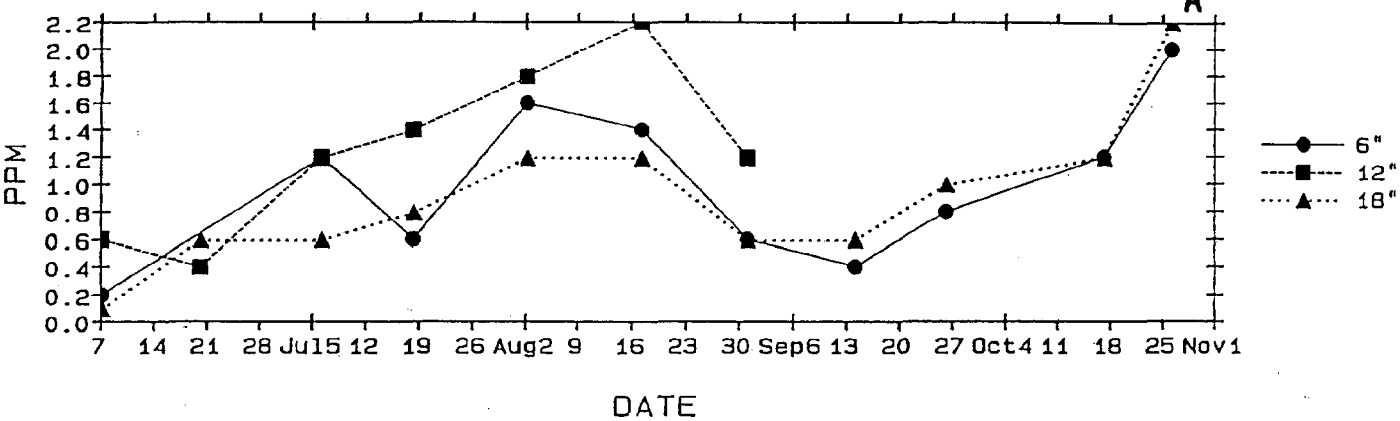

WATER LEVEL - IRC #12
cm (NGVD)
60
55
50
45
40
35
30
25
20
15
PUMP
PUMP
OPEN
8 15 22 29Jul613 20 27Aug310 17 24 31Sep714 21 28Oct512 19 26Nov2 9 16 23 30
DATE
HIGH

6

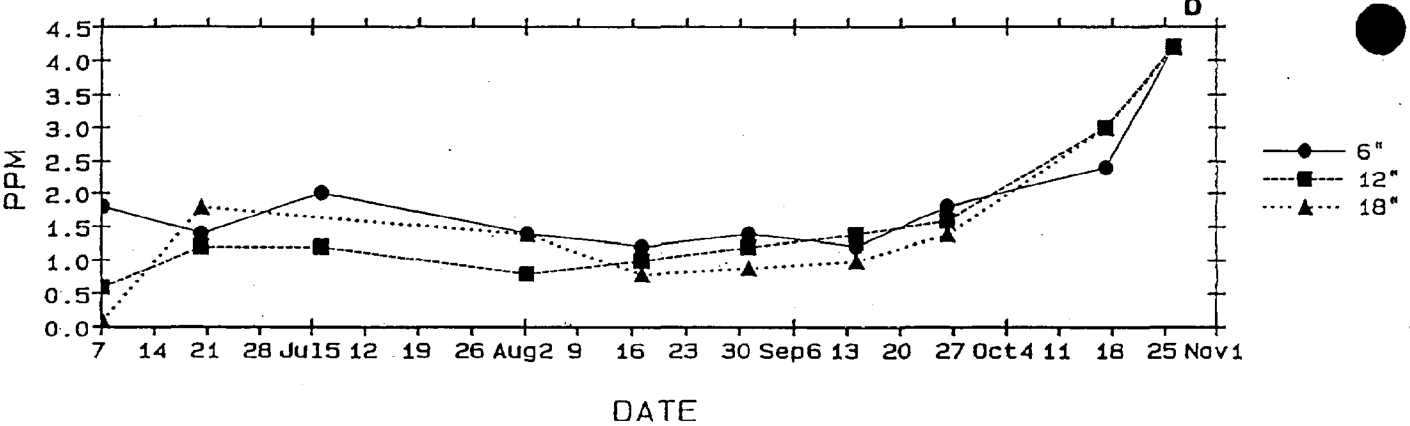
BLUE HOLE DITCH - DO

A

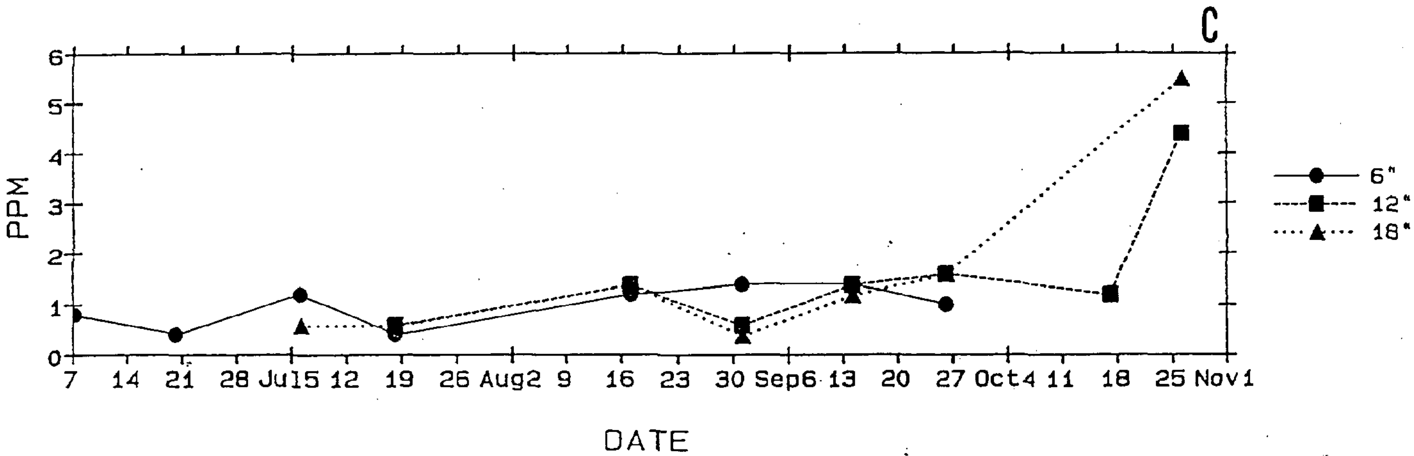


TIDAL CREEK CENTER - D.O.

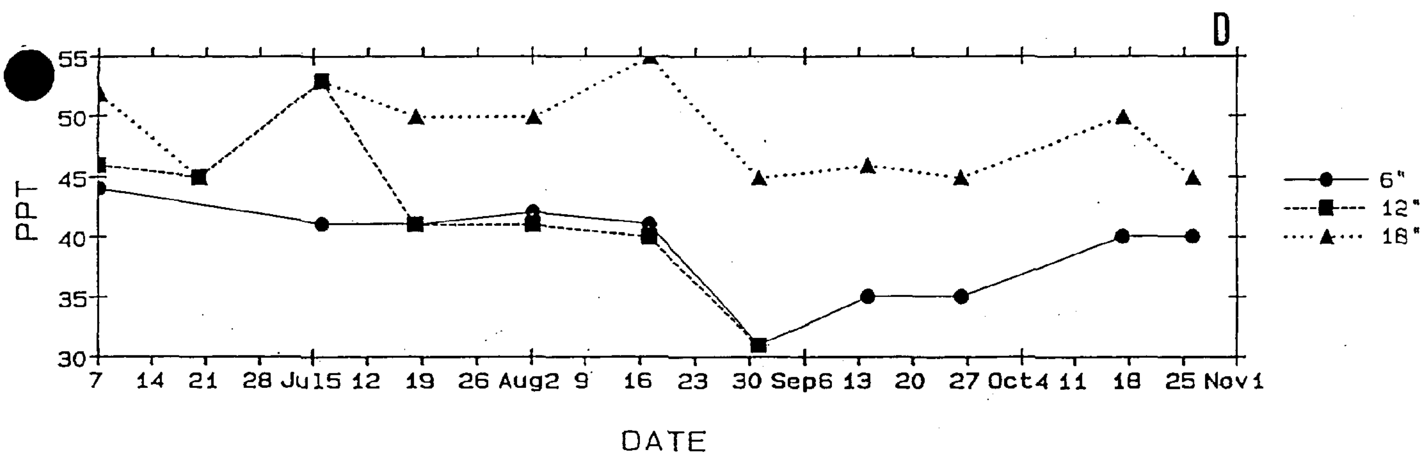
B



IRC #12 DITCH - DO



BLUE HOLE DITCH - SALINITY



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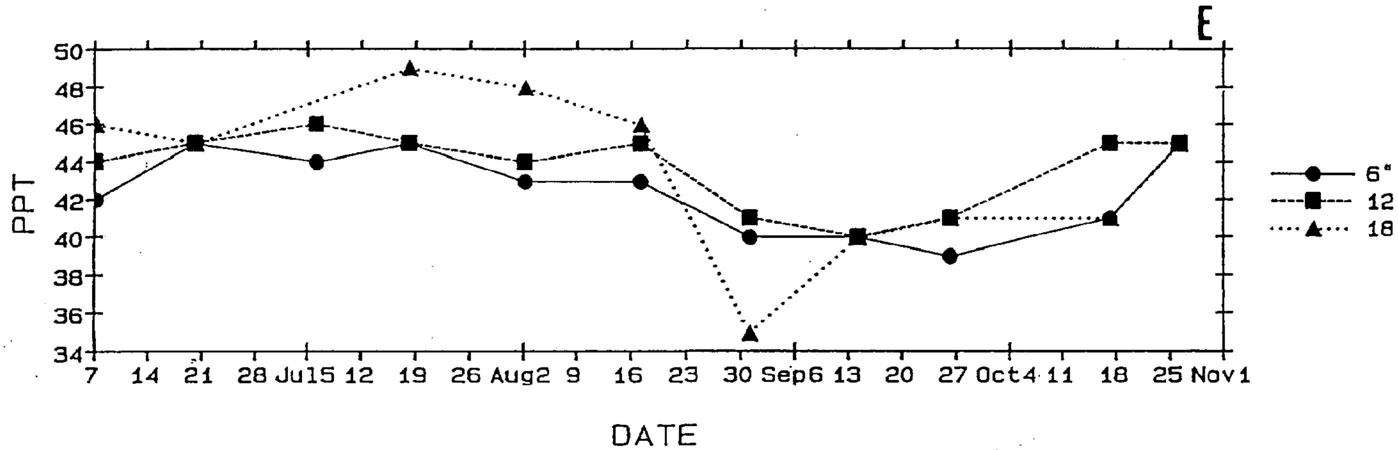

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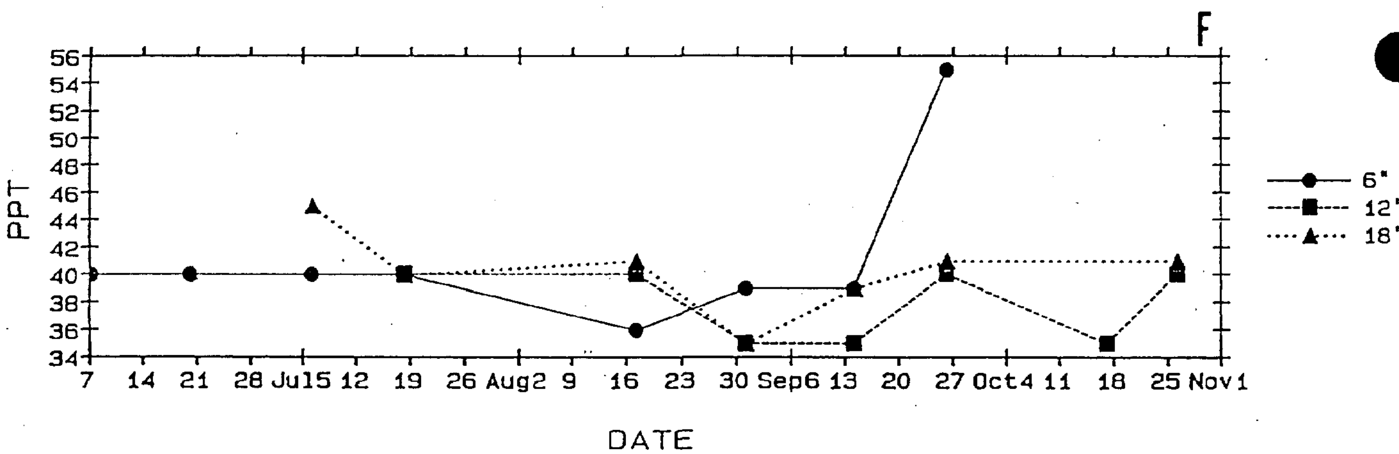
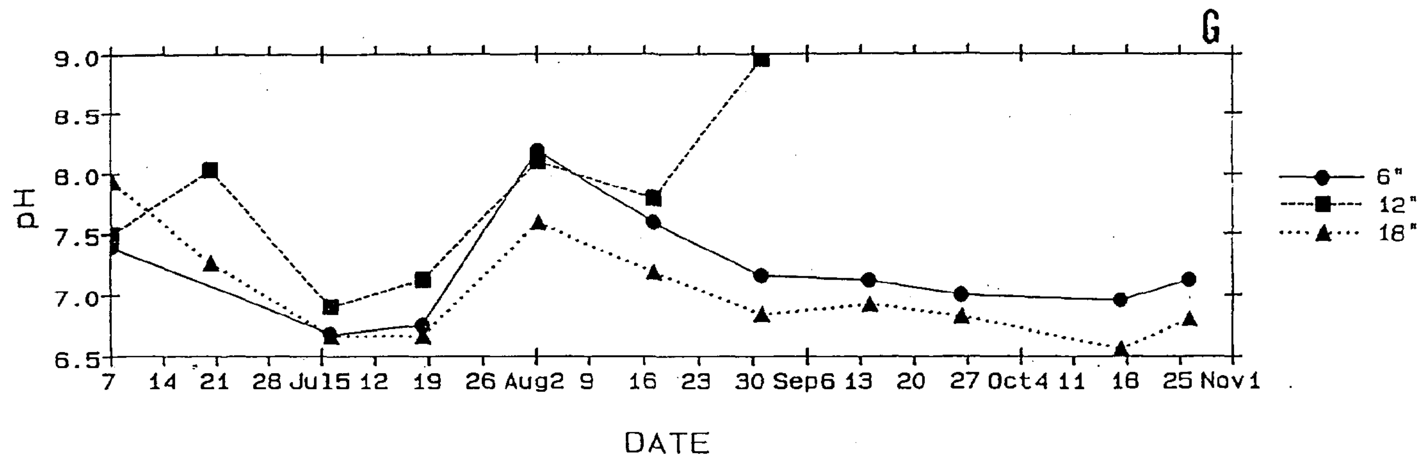


BLUE HOLE DITCH - pH



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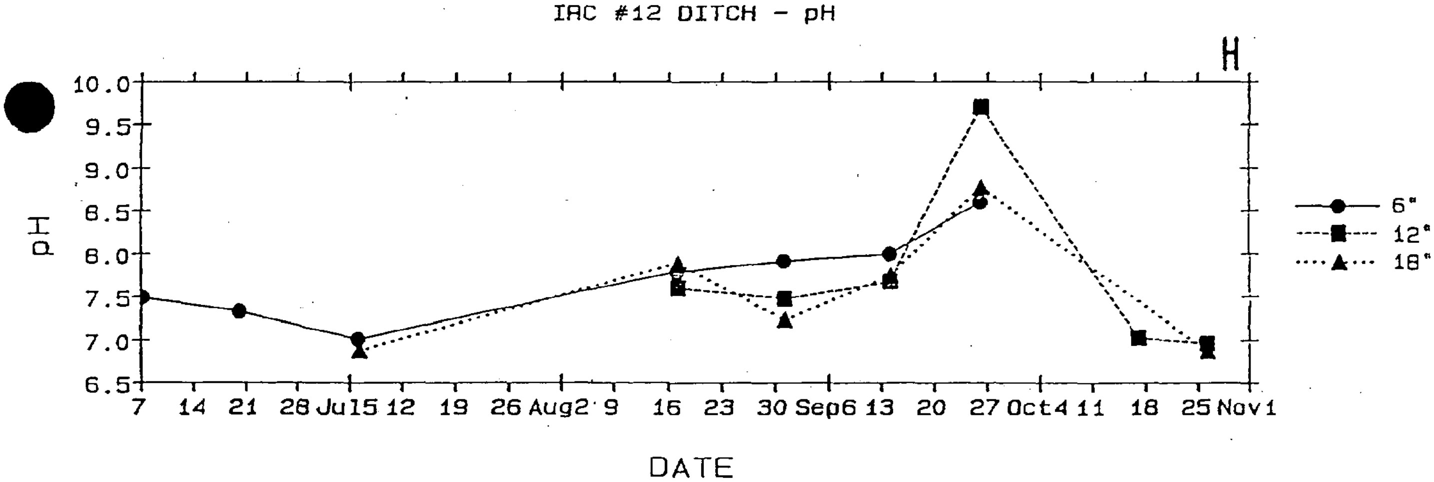

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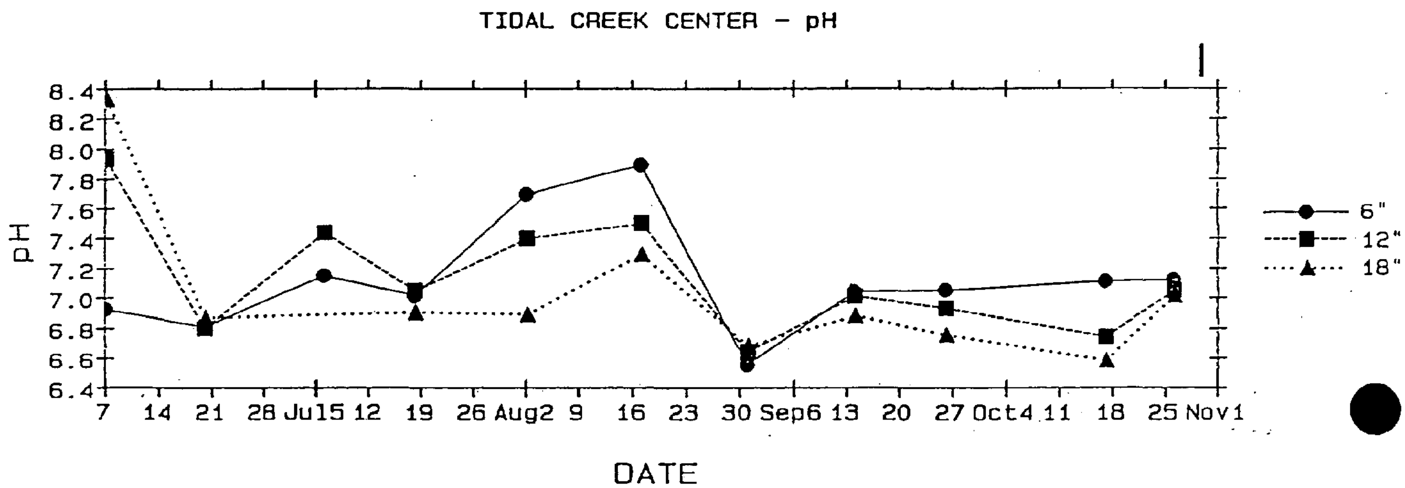
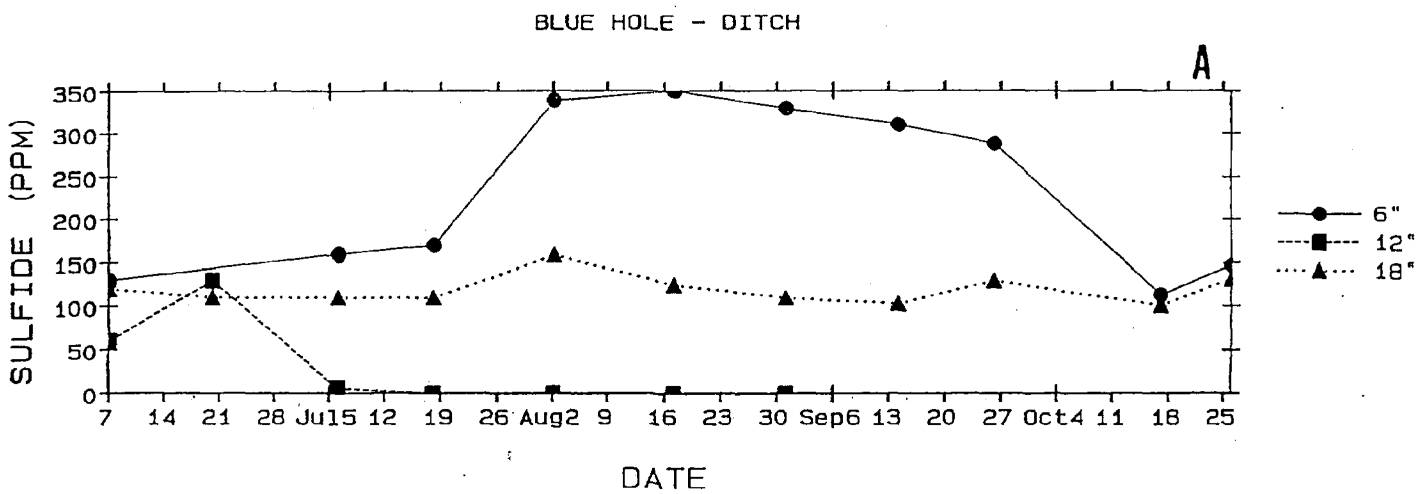
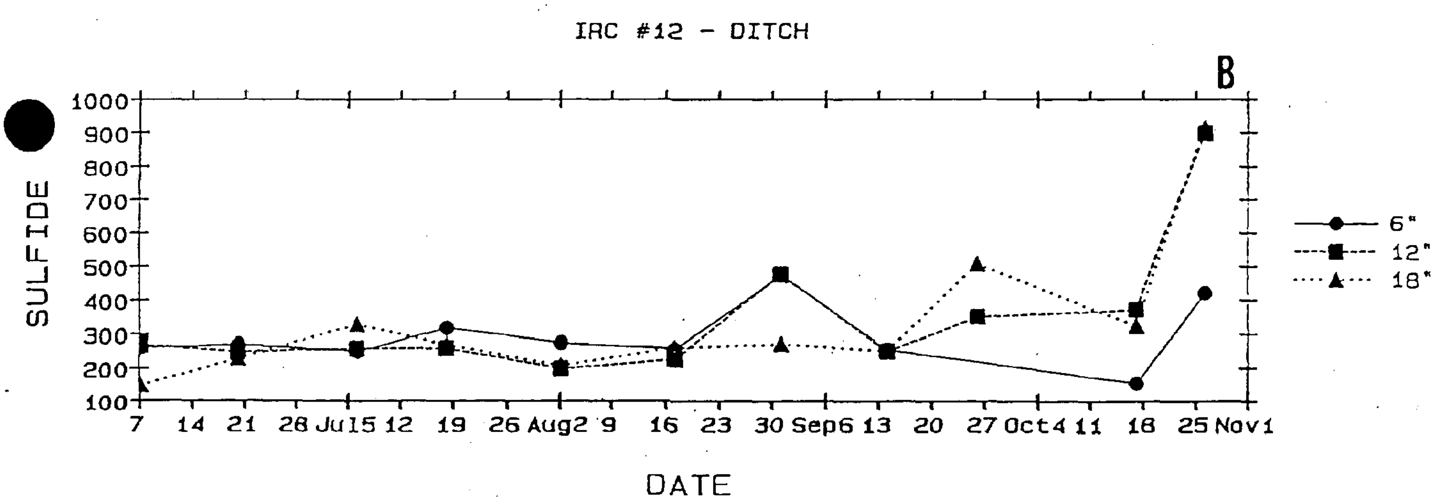
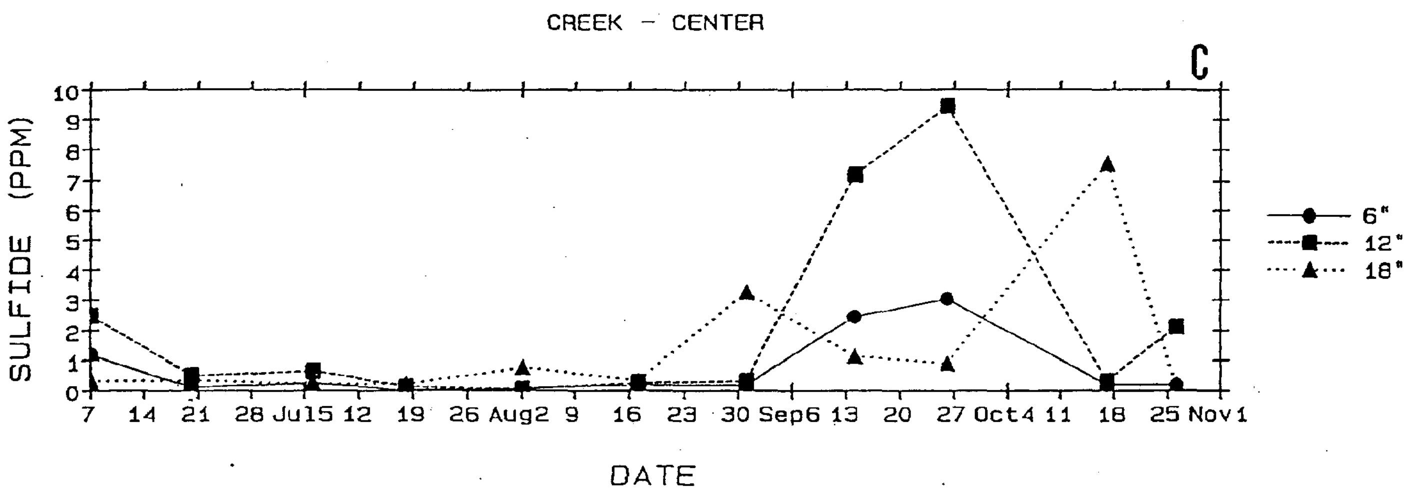
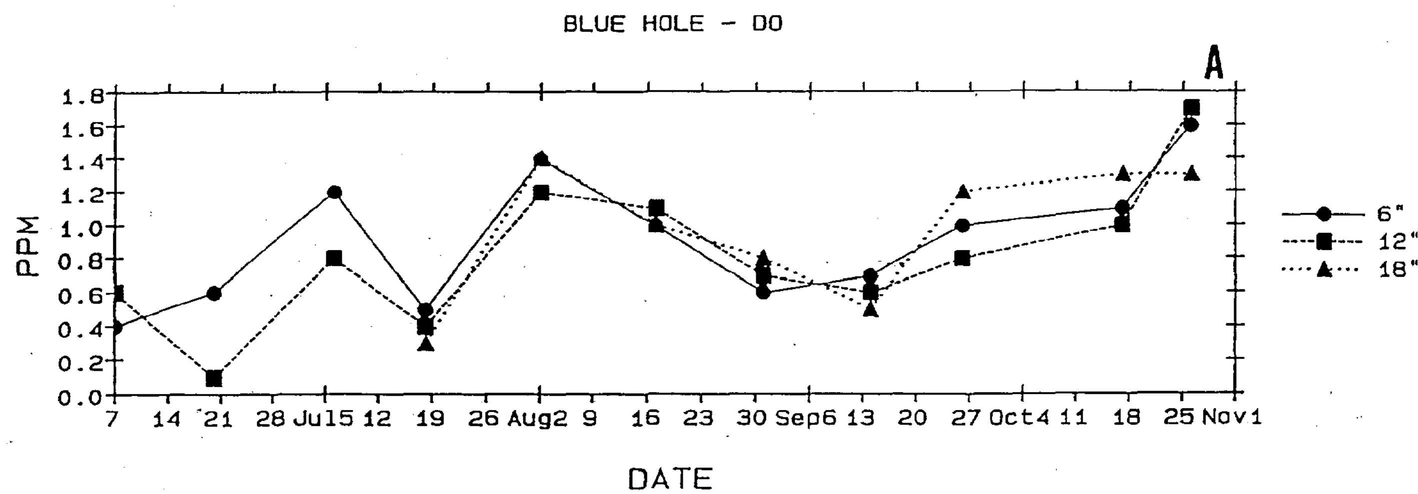

TIDAL CREEK CENTER - pH
pH
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"

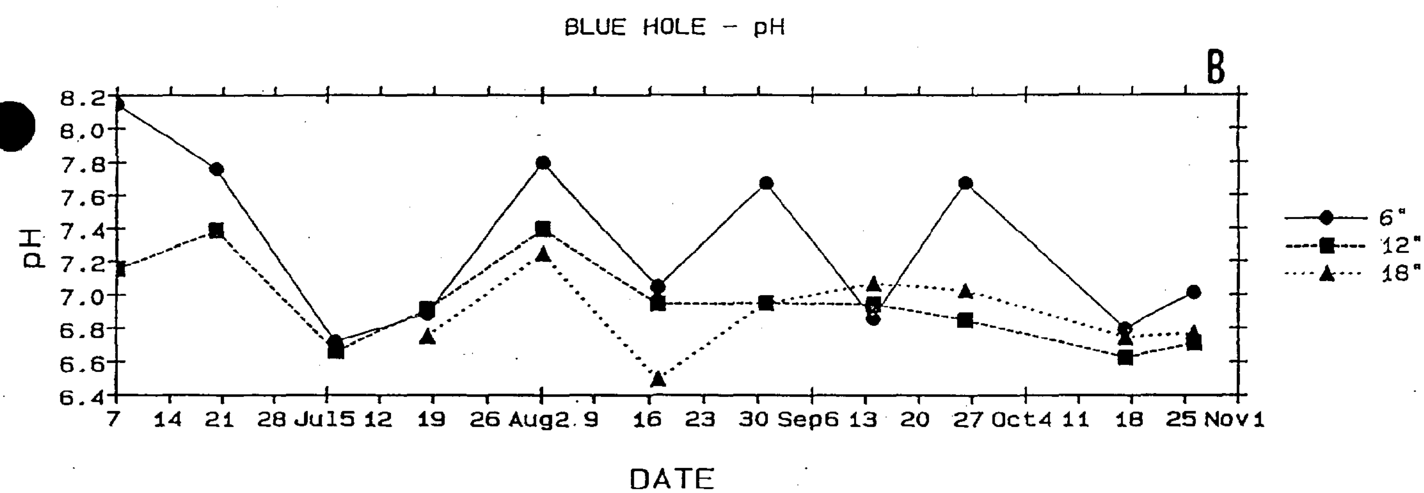

BLUE HOLE - DITCH
A
SULFIDE (PPM)
350
300
250
200
150
100
50
0
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25
DATE
6"
12"
18"

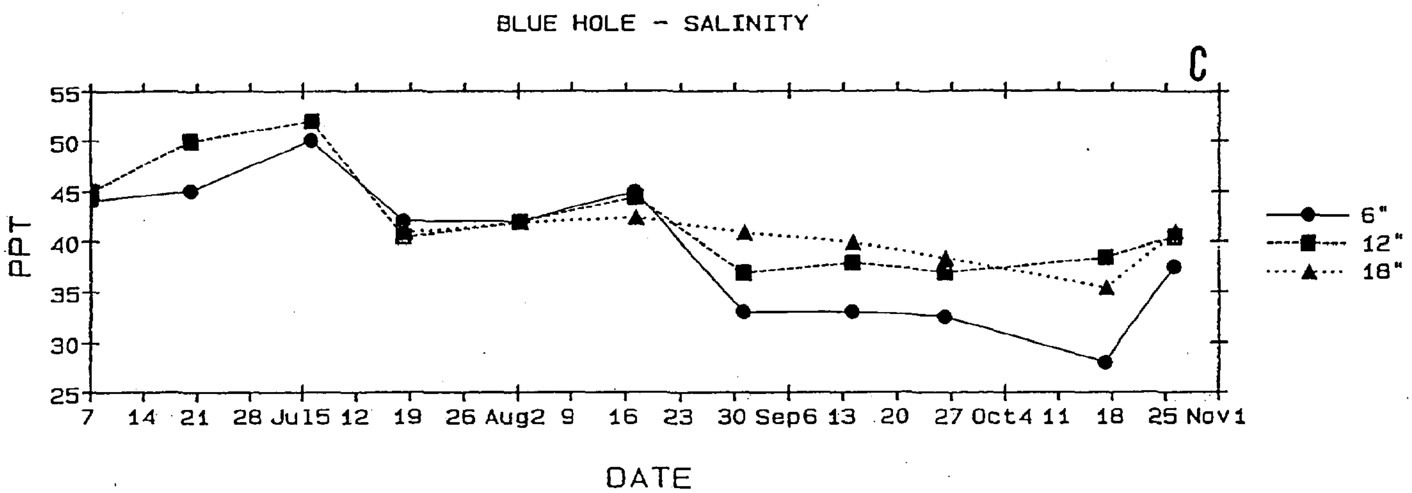

IRC #12 - DITCH
B
SULFIDE
1000
900
800
700
600
500
400
300
200
100
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"

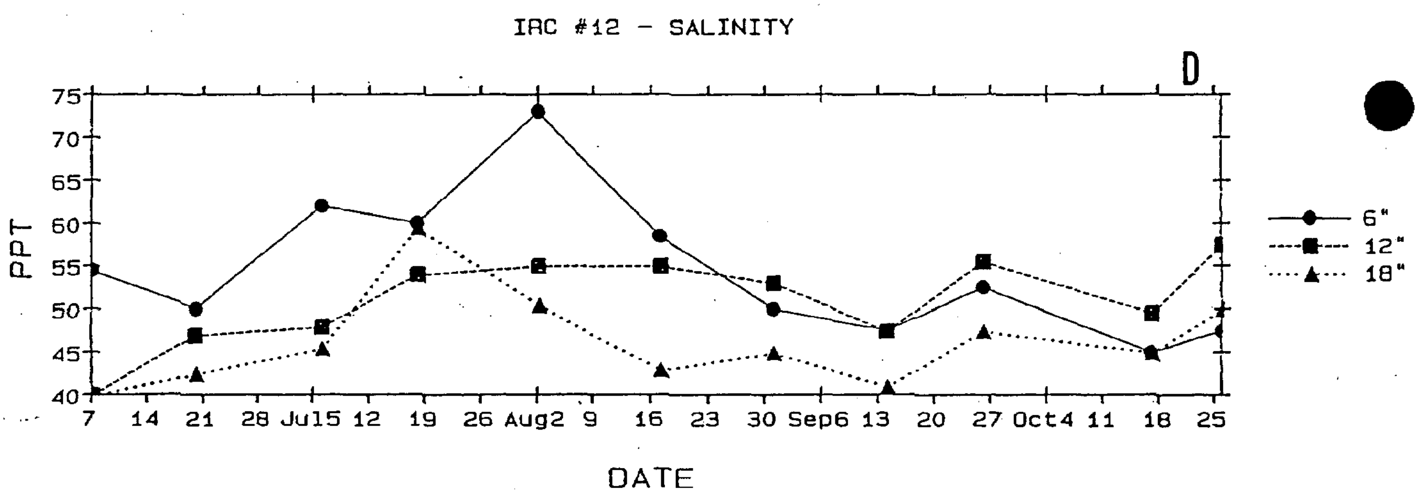


CREEK - CENTER
C
SULFIDE (PPM)
10
9
8
7
6
5
4
3
2
1
0
7
14
21
28 Ju15 12
19
26 Aug2 9
16
23
30 Sep6 13
20
27 Oct4 11
18
25 Nov1
DATE
6"
12"
18"


BLUE HOLE - DO
A
PPM
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"

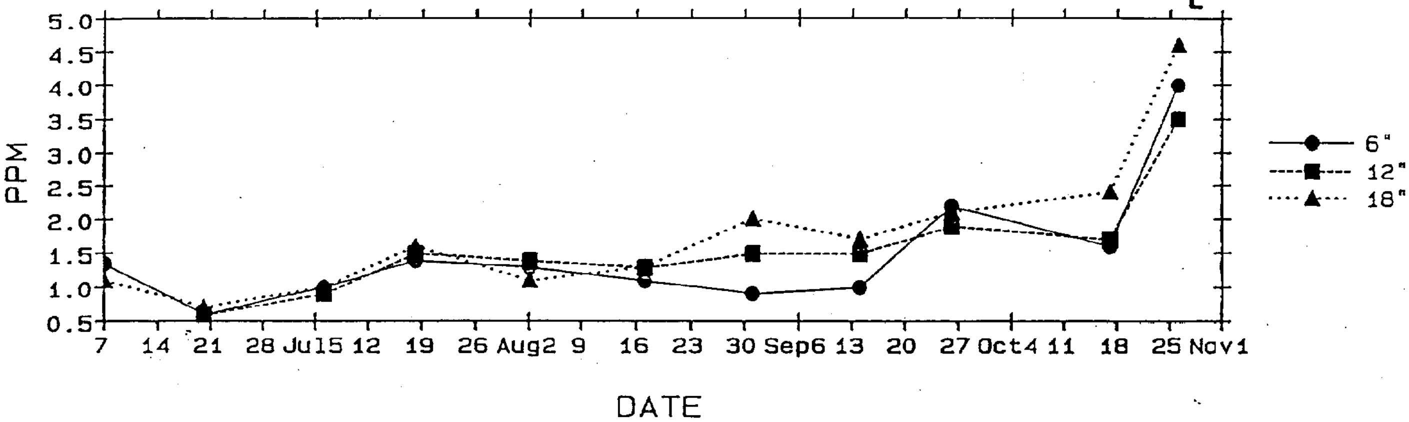

BLUE HOLE - pH
B
pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"


BLUE HOLE - SALINITY
C
55
50
45
40
35
30
25
PPT
7 14 21 28 Ju15 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"


IRC #12 - SALINITY
D
75
70
65
60
55
50
45
40
PPT
7 14 21 28 Ju15 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25
DATE
6"
12"
18"

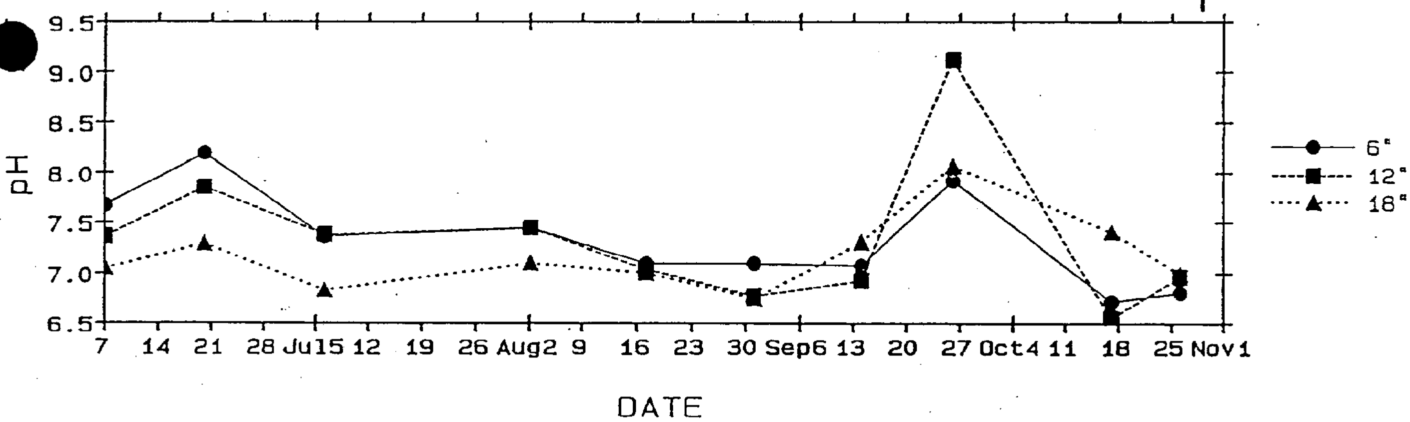
IRC #12 - DO

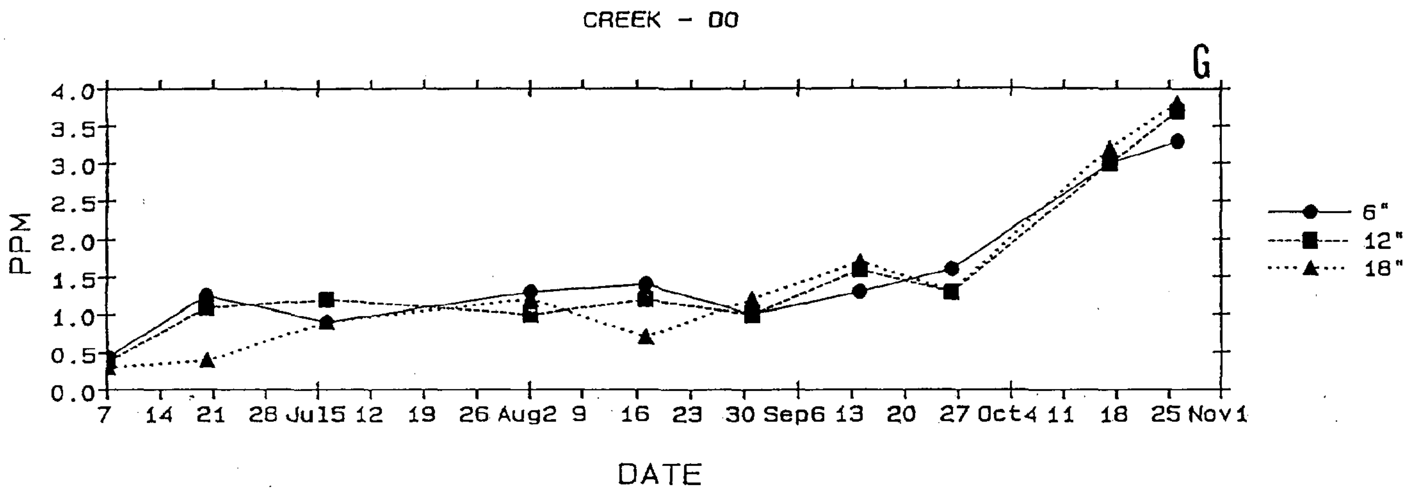
E

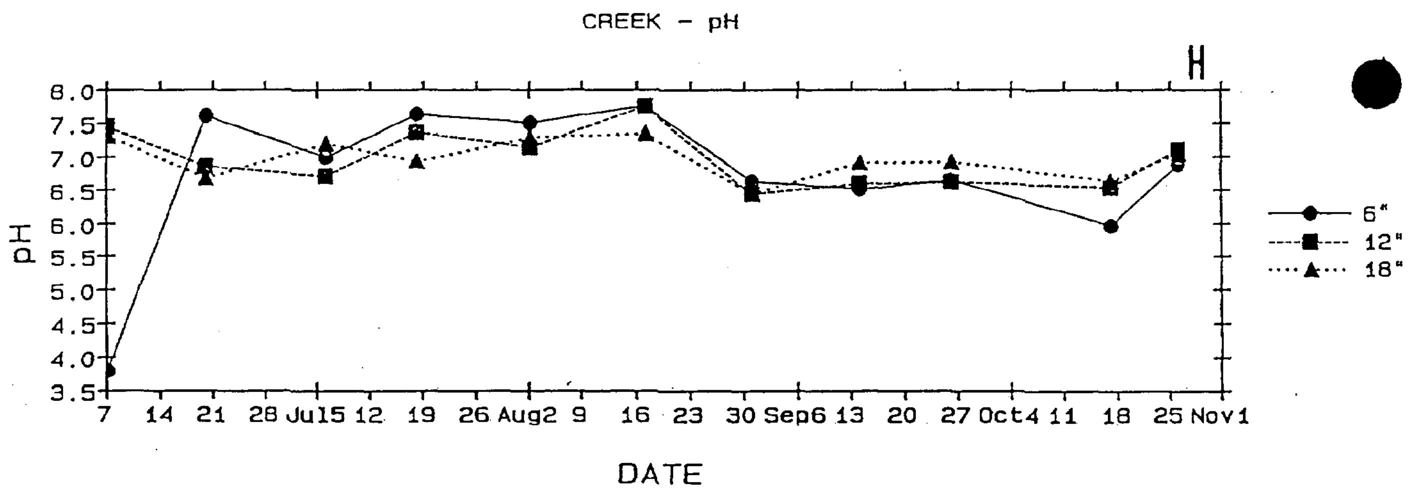


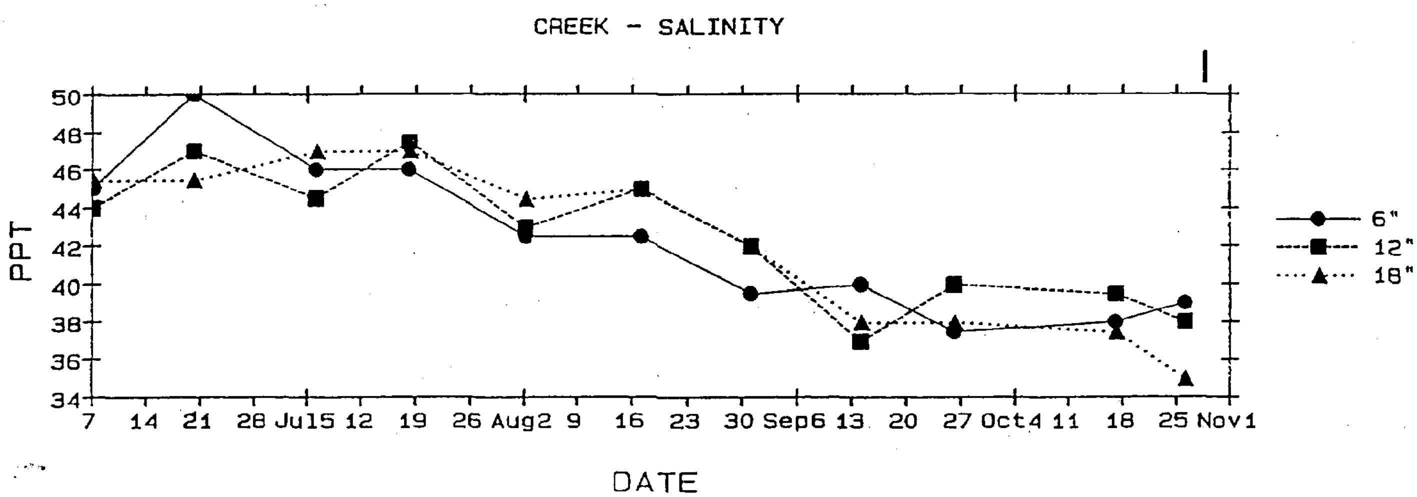
IRC #12 - pH

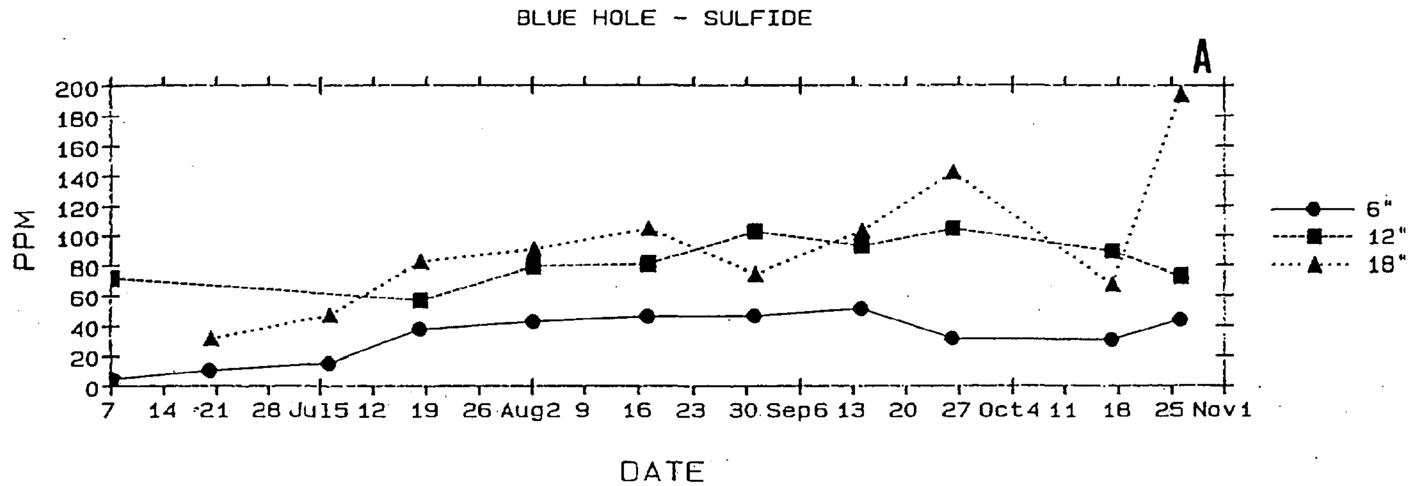
F

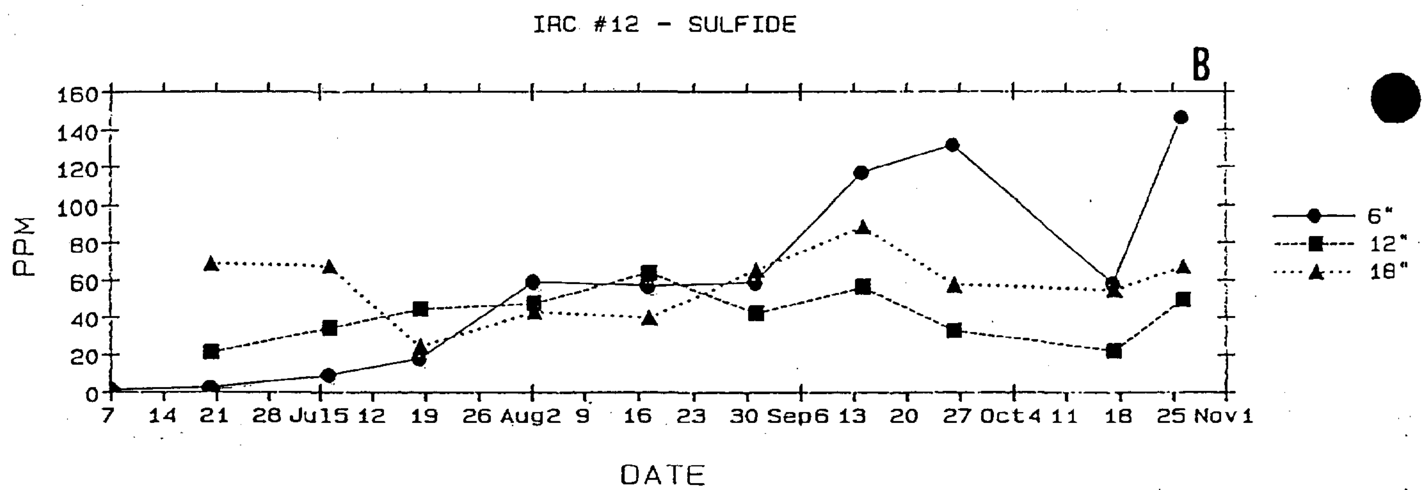


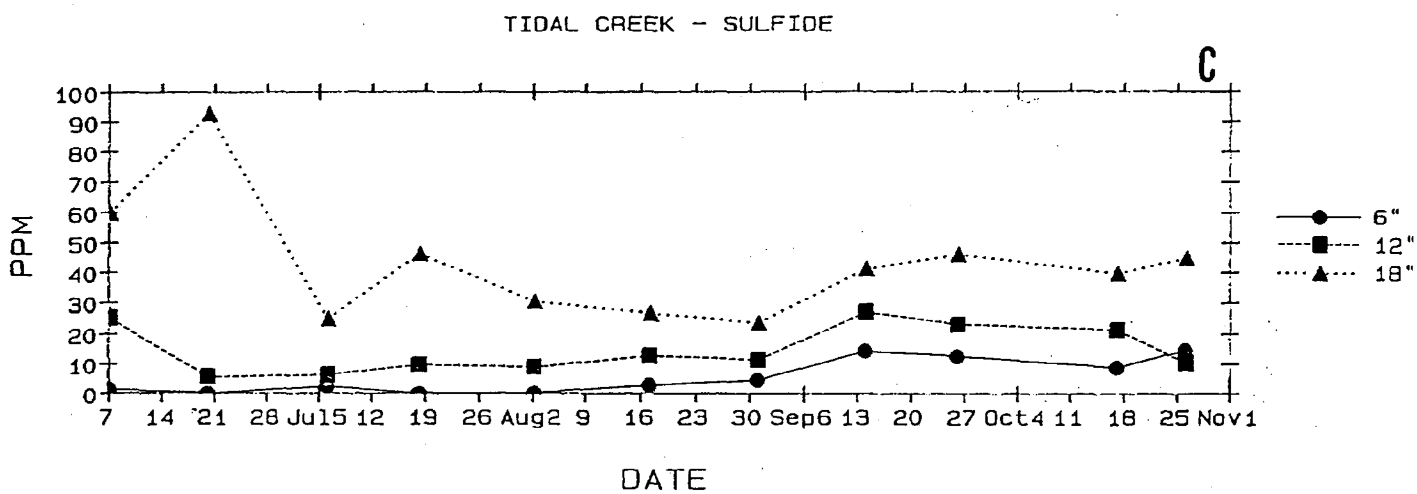

CREEK - DO
G
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PPM
7 14 21 28 Ju15 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"


CREEK - pH
H
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
pH
7 14 21 28 Ju15 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"


CREEK - SALINITY
50
48
46
44
42
40
38
36
34
PPT
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
DATE
6"
12"
18"

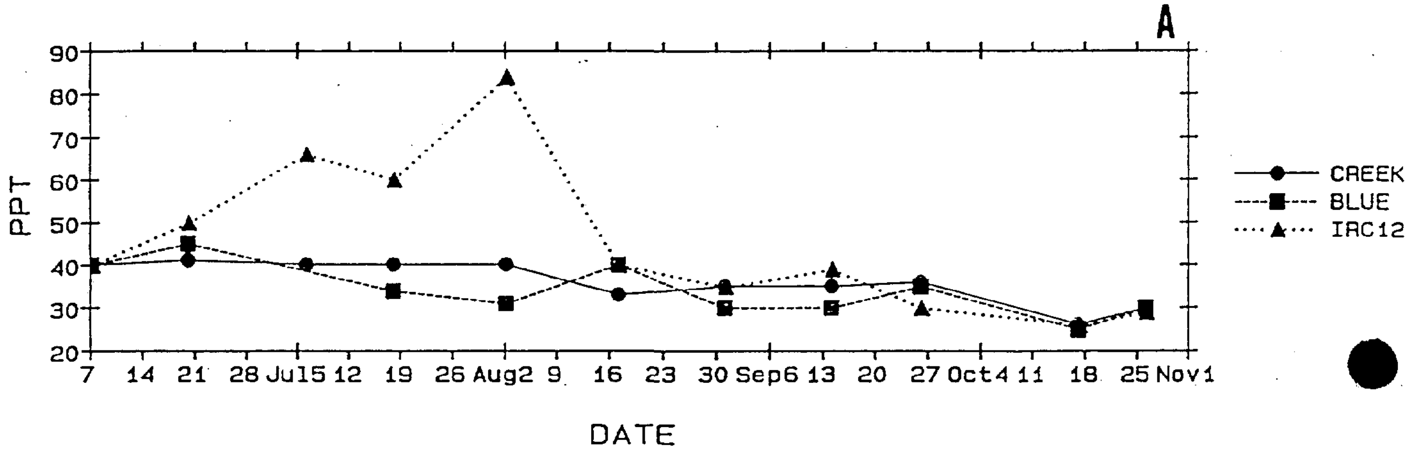

BLUE HOLE - SULFIDE
A
PPM
DATE
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
6"
12"
18"


IRC #12 - SULFIDE
B
PPM
DATE
7 14 21 28 Jul5 12 19 26 Aug2 9 16 23 30 Sep6 13 20 27 Oct4 11 18 25 Nov1
6"
12"
18"

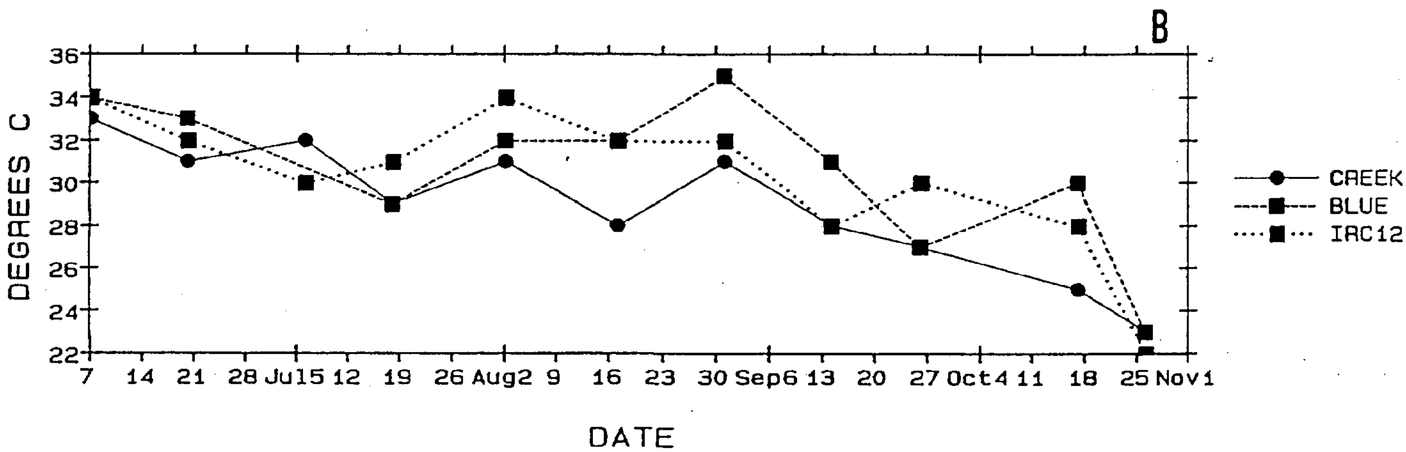


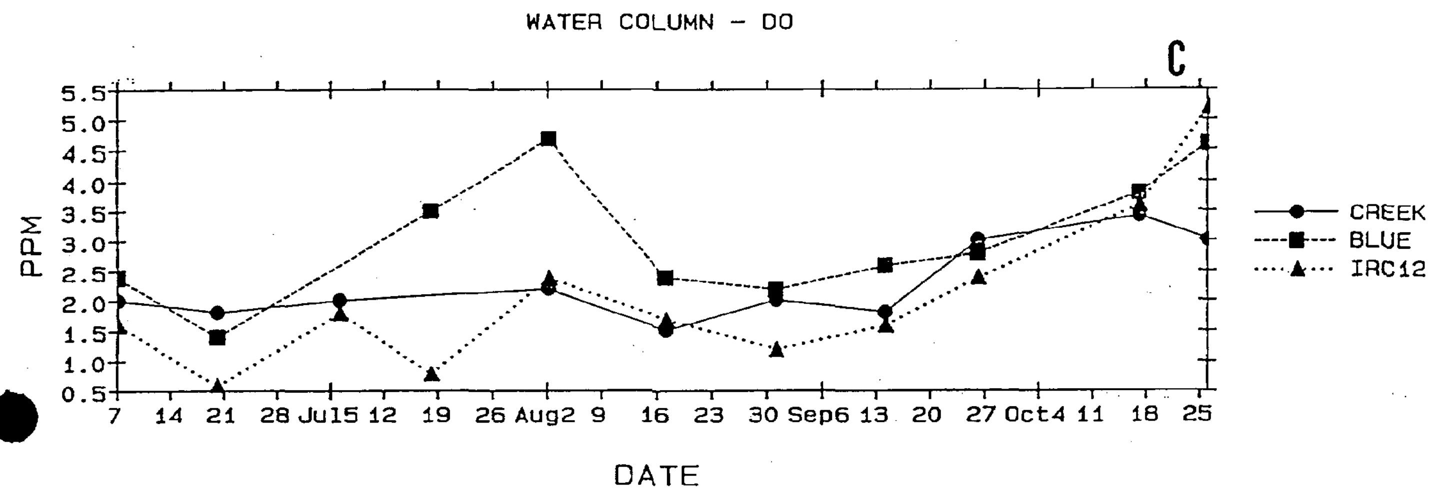
TIDAL CREEK - SULFIDE
C
PPM
100
90
80
70
60
50
40
30
20
10
0
7
14
21
28 Jul5 12
19
26 Aug2 9
16
23
30 Sep6 13
20
27 Oct4 11
18
25 Nov1
DATE
6"
12"
18"

WATER COLUMN - SALINITY



WATER COLUMN - TEMPERATURE




WATER COLUMN - DO
C
5.5
5.0
4.5
4.0
3.5
3.0
2.5
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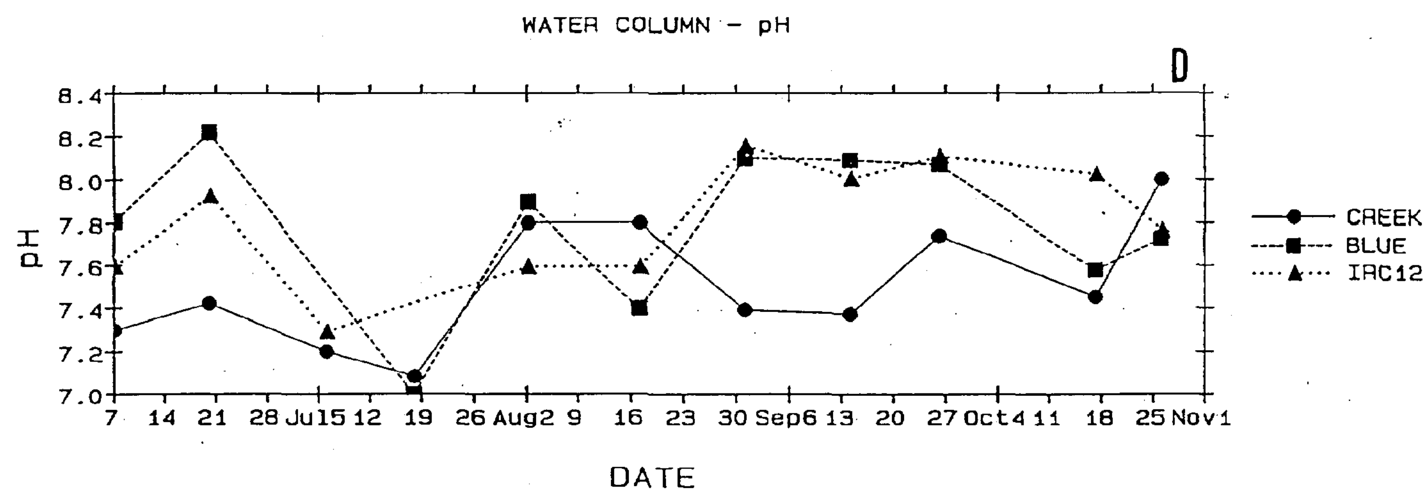
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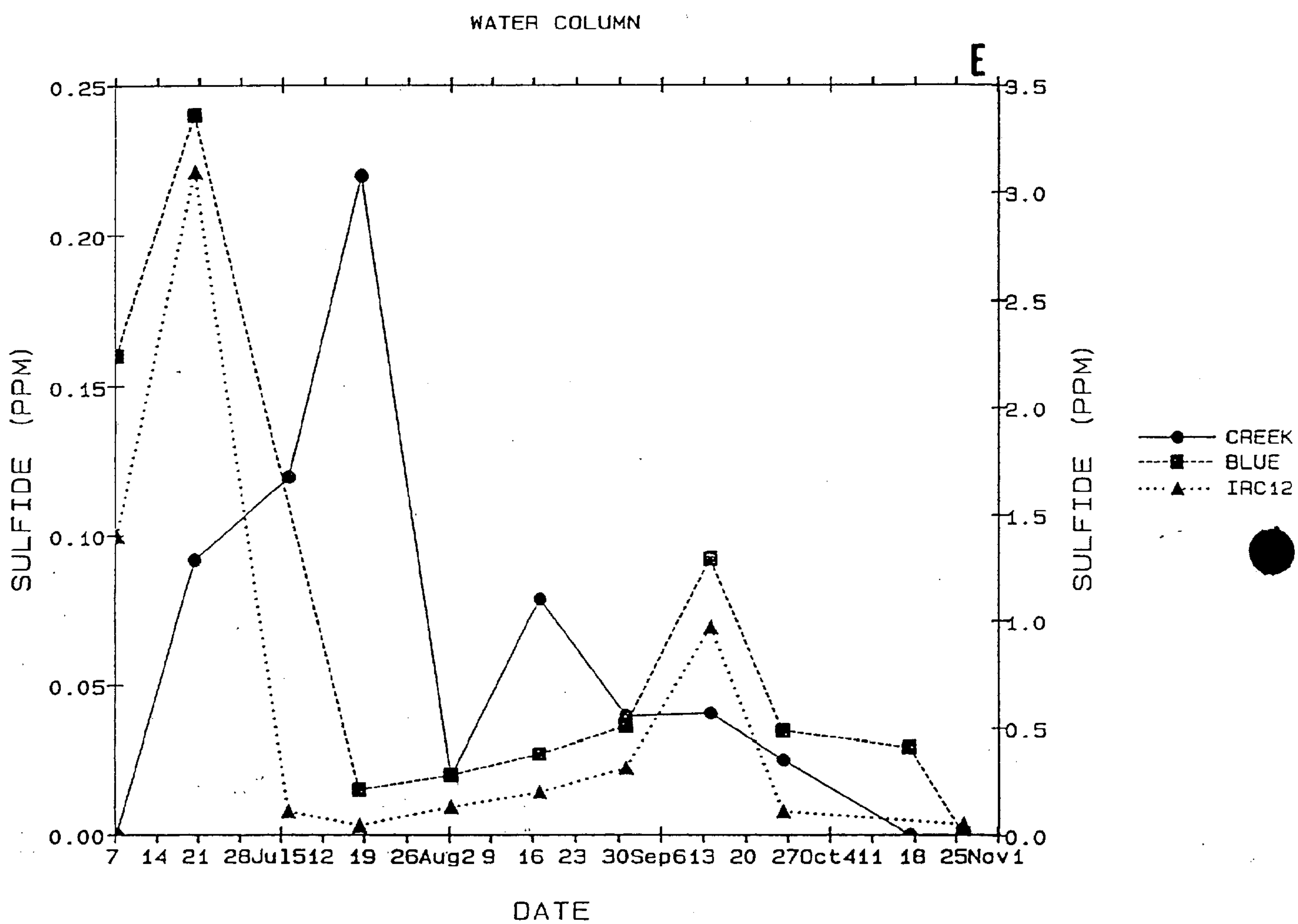
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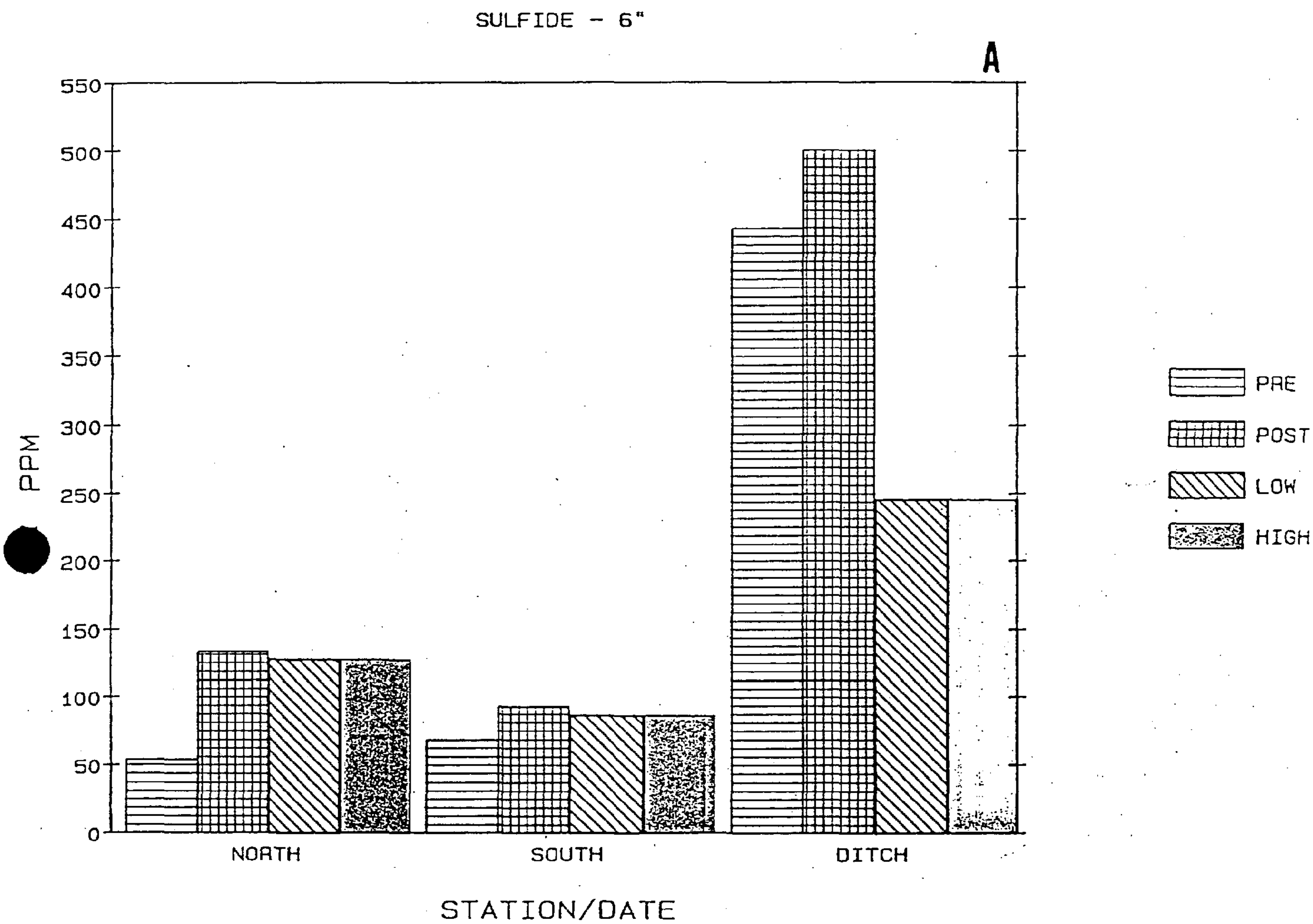
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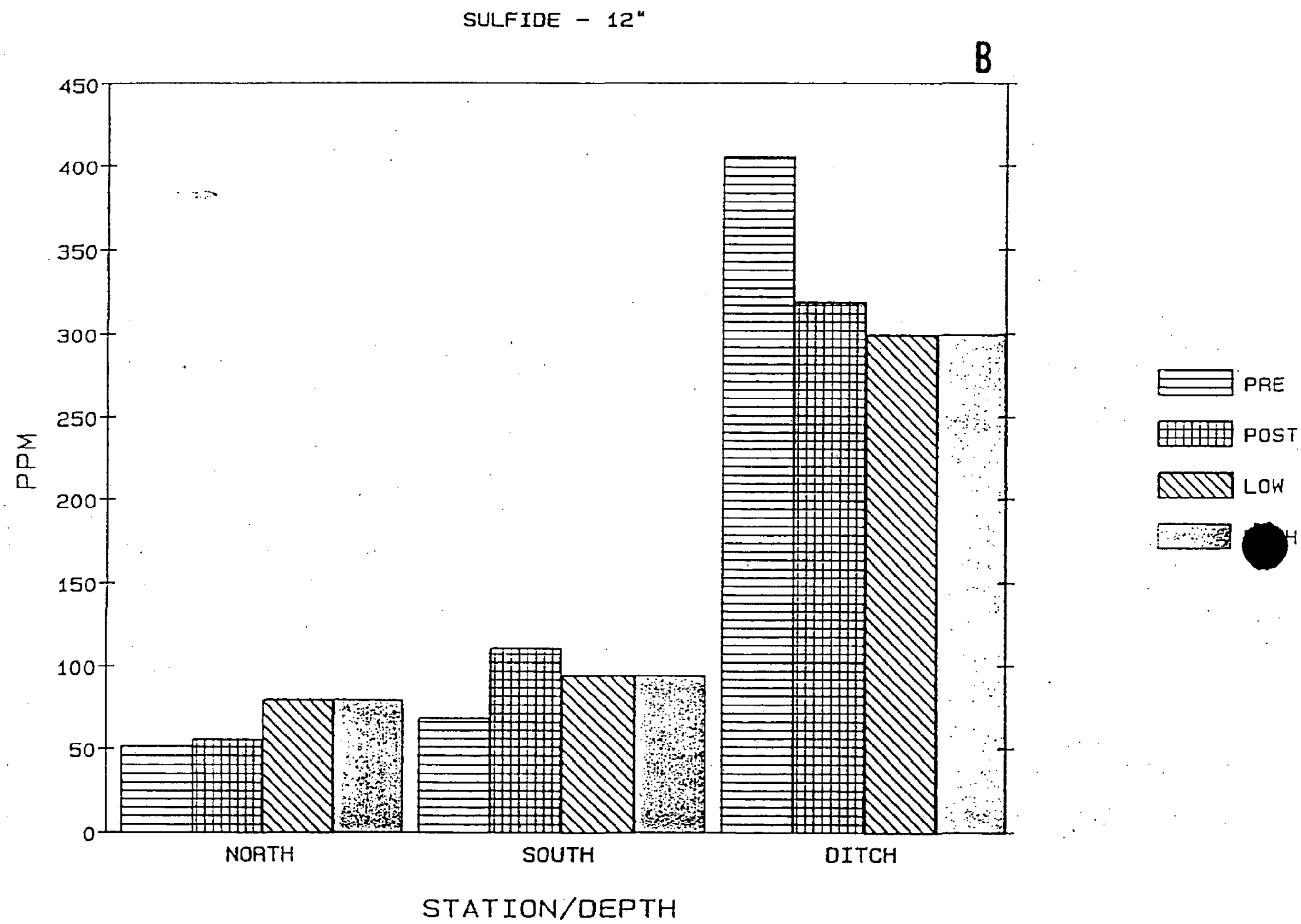
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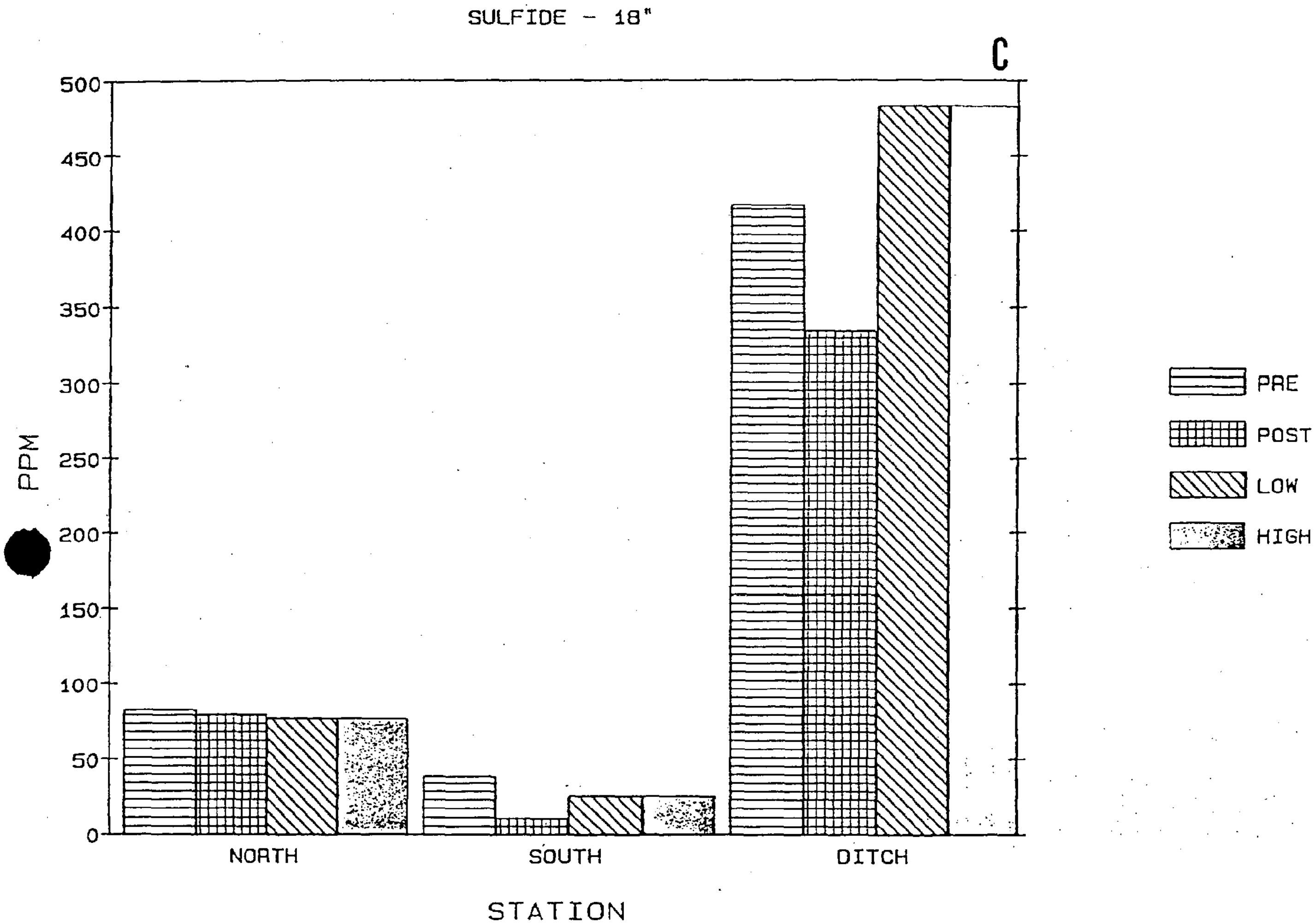
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TABLE 1. Spearman correlation coefficients among the physical variables (top) and significance level (bottom).

	DEPTH	DO	SAL	pH	TEMP	SULF
			BLUE HOLE			
DEPTH	-	0.005 0.963	0.360 0.001	-0.214 0.056	-0.131 0.244	0.235 0.029
DO		-	-0.038 0.730	0.040 0.726	-0.299 0.007	-0.030 0.788
SAL			-	-0.039 0.728	0.209 0.062	-0.027 0.809
pH				-	0.141 0.209	-0.005 0.965
SULF						-
			IRC #12			
DEPTH	-	0.148 0.179	-0.259 0.018	-0.141 0.231	-0.187 0.089	0.083 0.427
DO		-	0.187 0.090	-0.161 0.173	-0.559 0.001	-0.006 0.955
SAL			-	-0.028 0.807	-0.121 0.272	-0.685 0.001
pH				-	0.169 0.151	0.035 0.768
SULF						-
			TIDAL CREEK			
DEPTH	-	-0.125 0.242	0.101 0.320	-0.054 0.600	-0.065 0.522	0.480 0.001
DO		-	-0.449 0.001	-0.161 0.132	-0.582 0.001	-0.042 0.697
SAL			-	0.321 0.002	0.253 0.012	-0.263 0.009
pH				-	0.041 0.685	-0.307 0.002
SULF						-

TABLE 2. Results of nested ANOVA (sites within depths) for differences in physical variables at the study sites. Waller Duncan tests were run separately for each depth. BH = Blue Hole, IR = IRC #12, TC = tidal creek, NSD = $p > 0.05$.

VARIABLE	df	F	p	WALLER-DUNCAN	
				Depth	Ranking
Temperature	8	3.95	0.0001	6"	BH = IR > TC
				12"	BH > TC
				18"	BH = IR > TC
Salinity	8	10.86	0.0001	6"	IR > TC > BH
				12"	IR > TC = BH
				18"	NSD
pH	8	2.49	0.0131	6"	IR > TC
				12	IR > TC
				18"	IR > TC = BH
Sulfide	8	9.68	0.0001	6"	IR = BH > TC
				12"	IR > BH = TC
				18"	IR > BH > TC

TABLE 3. Results of one way ANOVAs for differences in water column physical variables between stations. Entries under WALLER-DUNCAN indicate the rankings obtained after application of the test to comparisons that resulted in significant main effects. BH = Blue Hole, IR = IRC #12, TC = tidal creek

VARIABLE	SOURCE	df	F	p	WALLER-DUNCAN
Temperature	SITE	2	0.77	0.4734	-
Salinity	SITE	2	3.01	0.0651	-
pH	SITE	2	3.09	0.0613	-
D.O.	SITE	2	2.35	0.1141	-
Sulfide	SITE	2	3.71	0.0371	IR > BH = TC

TABLE 4. Results of two-way analyses of variance for differences in physical variables between stations and depths at Blue Hole. Entries under WALLER-DUNCAN indicate the rankings obtained after application of the test to comparisons that resulted in significant main effects. S = South station, N = North, D = Ditch.

VARIABLE	SOURCE	df	F	p	WALLER-DUNCAN
Temperature	STATION	2	2.77	0.0694	-
	DEPTH	2	0.66	0.5206	-
	S x D	4	0.22	0.9241	
Salinity	STATION	2	19.44	0.0001	D = S > N
	DEPTH	2	9.10	0.0003	18 = 12 > 6
	S x D	4	3.07	0.0216	
PH	STATION	2	3.44	0.0373	D > S
	DEPTH	2	3.64	0.0311	6 > 18
	S x D	4	3.38	0.0137	
D.O.	STATION	2	0.41	0.6643	-
	DEPTH	2	0.03	0.9730	-
	S x D	4	0.79	0.5383	
Sulfide	STATION	2	21.82	0.0001	D > N > S
	DEPTH	2	4.03	0.0216	18 > 12
	S x D	4	21.72	0.0001	

TABLE 5. Results of two-way analyses of variance for differences in physical variables between stations and depths at IRC #12. Entries under WALLER-DUNCAN indicate the rankings obtained after application of the test to comparisons that resulted in significant main effects. S = South station, N = North, D = Ditch.

VARIABLE	SOURCE	df	F	p	WALLER-DUNCAN
Temperature	STATION	2	1.02	0.3660	-
	DEPTH	2	0.55	0.5821	-
	S x D	2	0.67	0.6148	-
Salinity	STATION	2	27.37	0.0001	N > D
	DEPTH	2	6.84	0.0019	6 > 18
	S x D	4	1.60	0.1827	
pH	STATION	2	2.60	0.0817	-
	DEPTH	2	0.48	0.6234	-
	S x D	4	0.19	0.9443	
D.O.	STATION	2	0.64	0.5302	-
	DEPTH	2	0.61	0.5448	-
	S x D	4	0.34	0.8474	
Sulfide	STATION	2	67.60	0.0001	D > N = S
	DEPTH	2	0.11	0.8934	-
	S x D	4	0.46	0.7646	

TABLE 6. Results of two-way analyses of variance for differences in physical variables between stations and depths at the tidal creek. Entries under WALLER-DUNCAN indicate the rankings obtained after application of the test to comparisons that resulted in significant main effects. E = East station, W = West, C = crek center.

VARIABLE	SOURCE	df	F	p	WALLER-DUNCAN
Temperature	STATION	2	3.17	0.0467	C > E
	DEPTH	2	0.38	0.6851	-
	S x D	4	0.22	0.9279	
Salinity	STATION	2	3.43	0.0368	W = C > E
	DEPTH	2	0.14	0.8666	-
	S x D	4	0.47	0.7585	
pH	STATION	2	0.70	0.4978	-
	DEPTH	2	0.33	0.7192	-
	S x D	4	0.89	0.4748	
D.O.	STATION	2	0.29	0.7460	-
	DEPTH	2	0.12	0.8831	-
	S x D	4	0.10	0.9822	
Sulfide	STATION	2	25.89	0.0001	E = W > C
	DEPTH	2	33.63	0.0001	18 > 12 > 6
	S x D	4	9.50	0.0001	

TABLE 7. Results of one-way ANOVA by depth for variables that had significant site-depth interactions (df = 2).

VARIABLE	DEPTH	F	p	WALLER-DUNCAN
		BLUE HOLE		
Salinity	6	4.32	0.0240	SOUTH > NORTH
	12	6.85	0.0046	SOUTH = DITCH > NORTH
	18	23.96	0.0001	DITCH > SOUTH > NORTH
pH	6	1.86	0.1764	-
	12	9.27	0.0011	DITCH > NORTH = SOUTH
	18	0.52	0.6036	-
Sulfide	6	37.37	0.0001	DITCH > NORTH = SOUTH
	12	10.68	0.0005	NORTH > SOUTH = DITCH
	18	1.58	0.2249	-
		TIDAL CREEK		
Sulfide	6	3.69	0.0370	WEST > CENTER
	12	10.31	0.0004	WEST = EAST > CENTER
	18	16.33	0.0001	WEST = EAST > CENTER

COASTAL ZONE MANAGEMENT,

FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

FINAL REPORT CZM- 194 1988/89

EFFECTS OF WATER QUALITY, HYDROLOGY AND SYNTOPIC SULFIDE CONDITIONS ON FISHES INDIGENOUS TO IMPOUNDED, SEMI-IMPOUNDED AND NATURAL SALT MARSH/ MANGROVE SWAMP HABITATS

by

R. Grant Gilmore

with

Ronald E. Brockmeyer, Jr. and Douglas M. Scheidt

FISH BIOLOGY DEPARTMENT

HARBOR BRANCH OCEANOGRAPHIC INSTITUTION, INC.

INTRODUCTION AND OBJECTIVES

Over the past six years considerable information has been gathered on the spatial and temporal distribution of fish and macrocrustacean populations inhabiting the subtropical estuarine wetlands of east central Florida. Much of this information has allowed wetland management interests to consider the potential impact of various impoundment closure scenarios on the fisheries considered to be so vital to the coastal economy of Florida. We now have a rather complete description of fish distribution patterns within impounded wetlands under a variety of management conditions. During these studies several mass mortalities of fish occurred many of which could not be explained by the environmental conditions which were typically monitored during the event.

Therefore, one of the most prominent management problems continuing to face marsh and mangrove swamp management groups, wetland ecologists and fisheries interests in Florida is the periodic mortality of fishes in impounded mangrove habitats. The present Harbor Branch Oceanographic Institution contribution to this problem under the FDER funded program, CZM - 194, is to determine the physiological tolerance levels of three abundant marginal wetland species to a variety of salinity, temperature and dissolved oxygen conditions. The species under study are the common snook, Centropomus undecimalis, sailfin molly, Poecilia latipinna and the sheepshead minnow, Cyprinodon variegatus. This research has produced the needed background information on the preferred environmental conditions of these species based on laboratory determinations of their basic eco-physiological requirements. However, it is also evident that various other physical environmental parameters may also play a definitive role in physiologically stressing indigenous wetland fish and periodically producing mass mortalities of various species in managed impoundments. Two of the most notable parameters which are likely candidates for precipitating mass mortalities are toxic plankton blooms and hydrogen sulfide originating from bacterial decomposers within submerged impoundment soils and detrital deposits.

Hydrogen sulfide is known to be toxic to a variety of organisms including fish (Smith, et.al. 1976; Abel, et.al. 1987). It is particularly abundant in anoxic detrital layers which are a conspicuous element of tropical and subtropical mangrove habitats. Considering the magnitude of recent fish mortalities, it would be particularly expedient to monitor environmental sulfide levels along with salinity, temperature, dissolved oxygen, pH and water level conditions and record fish distributions simultaneously. We proposed to capture fishes at the specific locations where these various water quality parameters and environmental sulfide levels are determined (conducted by Dr. Jorge Rey).

Our objectives are as follows:

1. To determine if there is a direct association between the distribution of indigenous mangrove swamp/salt marsh fish and syntopic sulfide concentrations in addition to the other water quality and hydrological parameters monitored.

2. To determine if there is a sulfide level which may be considered lethal to indigenous mangrove swamp/salt marsh fish populations, by recording mortalities which may occur simultaneously with high sulfide levels in the local microhabitat.

3. To analyze sulfide data along with water level, dissolved oxygen, pH, salinity and temperature data to determine if these parameters are synergistic or associated with sulfide effects on fish.

METHODOLOGY

Fishes were collected using quantitative gear types (following Gilmore, et. al, 1987) simultaneously with water samples taken for sulfide analyses. A 30 m 19 x 19 mm mesh gill net was pulled along a 25 m transect to a bridge at each site to capture larger fishes. Following this collection a 15 x 1.8 m, 3.2 mm mesh ace weave pull net was drawn along the same transect to capture smaller fishes which could have passed through the gill net mesh. Both nets were pulled up to a 3.2 mesh (ace weave) barrier net suspended from the bridge. Fishes captured were counted and measured (size range in standard length) in the field while alive and returned to their respective habitats. Managed (Indian River County Impoundment No. 12) and breached (St. Lucie County Impoundment No. 23, Blue Hole Point) impoundments were compared with natural tidal creeks (TC site adjacent to Jack Island State Preserve, St. Lucie County) and embayments in order to determine if these various habitats differ in sulfide-fish occurrence. This latter spatial comparison is quite important in that sulfide conditions and it's deleterious impact on fish populations may not be limited to impounded mangrove habitats under RIM management. Twice monthly fish collections were conducted in Indian River County Impoundment No. 12 under RIM management conditions and St. Lucie County Impoundment 23 which is breached and permanently tidal. In addition, a saline tidal tributary to the Indian River lagoon located on the barrier island was examined.

No statistical treatment of these data was possible due to the very limited catch of fishes at the study sites.

RESULTS

A total of 29 fish species, 2,208 individuals were collected at all three study sites using both pull nets and transect gill nets. The gill net captures were low with 15 species, 28 individuals having been taken (Table). However, the largest individuals of snook, Centropomus undecimalis (4, 175 - 260 mm SL), striped mullet, Mugil cephalus (4, 200 -360 mm SL), white mullet, Mugil curema, (2, 140 mm SL), tarpon, Megalops atlanticus (2, 190-260 mm SL) and sheepshead, Archosargus undecimalis (3, 80 - 95 mm SL) were captured with the gill net. In fact the only collections of tarpon, sheepshead, gafftopsail catfish, Bagre marinus, toadfish, Opsanus tau, and checkered puffers, Sphoeroides testudineus, were captured in the gill net transect.

The pull net captured 26 species, 2,180 individuals with the largest collections consisting of schooling planktivores: Anchoa mitchilli, Brevoortia smithi; marsh residents: Cyprinodon variegatus, Gambusia holbrooki and Poecilia latipinna; and juvenile mojarras: Eucinostomus spp. and Diapterus auratus.

Spatial Distribution - The number of species captured at each station were similar, 13 at the tidal creek site (TC), 19 at Blue Hole Point (BHP) and 12 at Impoundment 12 (IMP). However, the species composition and numbers of individuals collected differed greatly. Resident fish species, C. variegatus, P. latipinna, G. holbrooki, Fundulus confluentus and F. grandis, were only collected at the IMP site and these accounted for 63% (1,397 fish) of the total number of individuals captured at all sites. Of the transient species, tarpon, ladyfish, Elops saurus and most of the white mullet were captured only at the IMP site. Most mojarras (182, 91%) were captured at the tidal creek (TC) site. In fact no resident species, 11 transient species were collected at the TC site. More individuals of non-planktivorous transient species were collected at this site than either BHP or IMP sites. Only 4 transient species were collected at the IMP site while 12 were collected at the breached impoundment BHP site. Although the TC and BHP sites were qualitatively comparable excluding anchovies, fewer individuals of transient species were collected at the BHP site than at TC.

Temporal Distribution - Temporal changes in fish captures were difficult to discern principally due to the low numbers of individuals captured over the study period. The IMP site was under RIM management during the study period and therefore was closed to tidal influence from June to September 22nd. Only two collections were possible after the impoundment was reopened to tidal influence, therefore, most of the temporal and spatial differences between sites may be related to the differences in habitat access, particularly for transient species. Exceptions to this were the consistent capture of ladyfish, a transient species, during June and July and the capture of seven pinfish, Lagodon rhomboides, during July at the IMP site. Otherwise all other fish captured at IMP were resident species, principally from June to August. After the IMP site was returned to tidal access on Sept. 22nd, a high water period, only four mosquitofish were captured. Transient species capture at the TC and BHP sites were sporadic throughout the study period with an increase in mojarra captures during the October study period.

When temporal patterns of species occurrence and number of individuals is compared with sulfide levels for each site some differences are noted (Table 1). Sulfide levels were considerably lower at the TC site than at the BHP or IMP sites. In fact when sulfide concentrations increased at the TC site, so did the number of species and individuals, particularly mojarras (Fig. 1). However, when sulfide levels increased at BHP during late July and August into September the number of fish species and individuals declined (Fig. 2). Sulfide levels were highest at the IMP site where few transient species were captured (Fig. 3). Resident species were responsible for the temporal numerical patterns observed which showed a steady decline in species captured during the survey as sulfides increased, particularly after the impoundment was reopened on September 22nd. Two peaks in numbers of individuals captured on 3 August and 1 September are due to sheepshead minnows, mosquitofish and sailfin mollies, all euryeocious resident species captured when sulfide levels were both relatively low (3 August) and high (1 September).

Twenty one specimens of the redfin needlefish, Strongylura notata, and five of timucu, S. timucu, were captured at the tidal sites, BHP and TC and none at the IMP site. Data from tidal impoundments opened through culverts have produced very few needlefish even after literally thousands of collections. These comparisons appear to imply that needlefishes do not pass through culverts. Similar observations were made of specimens of the Atlantic stingray, Dasyatis sabina, which was observed, not captured, on several occasions and locations at the TC and BHP sites but never in a culverted impoundment in spite of its reconnection to the adjacent estuary.

DISCUSSION AND SUMMARY

The occurrence of the abundant resident species, mosquitofish, sheepshead minnows, sailfin mollies, marsh killifish and Gulf killifish only at the RIM managed IMP site is not easily explained. They should have been present at the other tidal study sites. It is possible that predation by a variety of transient species present at the TC and BHP sites could have reduced resident species populations or precluded their occurrence at the net stations.

The relative absence of transient species, except for tarpon and ladyfish, at the IMP site could be explained by a variety of environmental conditions including the greater concentration of sulfides at this station. Transient species typically do not occur in closed impoundments as demonstrated by Gilmore et al. (1982) and Harrington and Harrington (1982). The recruitment of these species to the impounded wetland is not possible during the closure period unless the dike is topped by unusually high storm tides. The transients captured in the closed impoundment (IMP) are limited to those which remain in the impoundment after it is close during the spring and survive the low water quality conditions which typically develop during the summer closure period. Hypersaline waters, low dissolved oxygen and highly discolored waters were observed at the IMP study site in August and some fish mortality was observed (Cyprinodon variegatus). This event could have also caused mortality in any transient species present. The decline in resident species with the opening of the IMP site to tidal influence in September during the annual high sea level period could be attributed to increased dispersal, particularly to high marsh flats, a phenomenon documented in previous studies (Gilmore et al. 1984). In addition, water column levels of sulfide increased in the perimeter ditch which could have caused emigration from the impoundment or to other locations in the impoundment.

Transient species captured at the tidal sites, BHP and TC, were present at these sites due to a variety of physiological and environmental parameters. Estuarine access is unimpeded allowing migration of transients during tidal intervals at both BHP and TC. This tidal access also moderates environmental conditions such as temperature, salinity and dissolved oxygen making these sites more hospitable to transient fishes. Sulfide concentrations were lower at the BHP and TC sites than at IMP. The most numerous transients captured at the tidal sites were anchovies, menhaden and a variety of mojarras. Eco-physiological studies have not been conducted on these species to allow determination of their sensitivity to low sulfide levels under the temperature and salinity conditions encountered in this survey. Therefore, we cannot separate sensitivity to sulfide conditions from tidal access in explaining their occurrence at BHP and TC.

The lower sulfide levels and higher transient fish populations at the tidal locations whether previously impounded or not indicates that these sites are preferred sites for a variety of estuarine species. The absence of the most abundant wetland resident species from these same tidal sites cannot be explained by the data acquired during this short study. The disappearance of transient species at IMP may be due to their fatality during excessive environmental conditions observed in August. It is also possible that the topography of the sites differ significantly enough to preclude certain species in spite of tidal access. However, capture of tarpon and ladyfish at the IMP site early in the closure period indicates that these species were surviving in the impoundment prior to August.

The occurrence of needlefishes and stingrays at the tidal sites and not at IMP or in previous tidal culverted impoundments indicates that these species do not swim through culverts. However, they could also be sensitive water quality conditions. This may be particularly true for the benthic dwelling stingray. RIM and wetland impoundment apparently precludes the occurence of these two species groups in the idiiieous wetland fauna.

All of these conclusions demonstrate major differences between RIM managed impoundment perimeter ditch fish faunas and tidal creek or breached impoundment perimeter ditch faunas. The factors causing these differences are difficult to isolate as tidal access influences bottom-sediment characteristics and water column chemistry which in turn influence fish distributions and faunal composition in spite of similarities in habitat vegetative communities or topography. RIM managed impoundments without water quality problems during closure periods, if such systems exist, are necessary to study in order to isolate the "estuarine access" influence versus the "water quality" influence.

SUMMARY

1. More individuals were collected in the RIM managed impoundment (IMP site) than at the tidal sites (TC and BHP) due to the abundance of resident species, which were not captured at the tidal sites.

2. More transient species were captured at the tidal sites (TC and BHP) possibly due to (a) better access to these sites from the estuary, (b) more favorable habitat conditions, i.e. lower tolerance to low dissolved oxygen condition, high sulfides, high salinities and high water temperatures encountered in the tidally closed impoundments.

3. When sulfide levels rose during the fall in the tidal creek (TC) so did fish species and number of individuals although there was a negative relationship between number of individuals and sulfide concentrations at 12 in depths. The lack of a distinct negative relationship between fish and sulfide levels may be due to the very low concentrations of sulfide detected at this site relative to the other two study sites (BHP & IMP).

4. When sulfide levels increased in the later summer and fall at the breached impoundment site (BHP) fish numbers and species declined. Sulfide levels at this site were an order of magnitude above the tidal creek site.

5. When water column sulfide levels increased at the RIM managed impoundment (IMP) after reopening the fish populations reduced significantly. However, this may not only be due to sulfide concentrations but due to renewed estuarine access allowing emigration or to high water states allowing migration from the perimeter ditch to the upper marsh flats. The latter migration is most likely due to past documentation of resident fish dispersal in RIM managed impoundments.

6. It is difficult to rely heavily on these data due to the low number of stations examined and the low number of fish captured. However, there is some indication of an inverse relationship between sulfide and numbers of fish species and individuals captured. There is little question that the occurrence of more transient species at the tidally influenced stations is due to better access in addition to any differences in water quality parameters.

7. The capture of needlefishes and observation of stingrays at the tidal sites and their absence from the RIM managed impoundment (IMP) and in previous studies of impoundments with culvert access indicates a possible reluctance of these species to pass through culverts or sediment and water quality conditions created by RIM and culverts which precludes their use of RIM wetlands.

8. All results of this study indicate differences in fish faunas between RIM managed impoundments and tidal breached impoundments or tidal creeks. These studies, however, do not conclusively define the reasons for these differences due to the complex interaction of a wide variety of environmental parameters which must be examined on an experimental basis associated with a long term study of a variety of habitats.

LITERATURE CITED

Abel, D.C., C.C. Koenig and W.P. Davis. 1987. Emersion in the mangrove forest fish Rivulus marmoratus: a unique response to hydrogen sulfide. Envir. Biol. Fish. 18(1): pp. 67-72.

Gilmore, R.G. 1984. Fish and macrocrustacean population dynamics in a tidally influenced impounded subtropical salt marsh. 35 pp. 21 tbls., 35figs., in Final Report: Fla. Dept. Env. Reg. Contract No. CZM-47 and CZM-73.

Gilmore, R.G., D.W. Cooke and C.J. Donohoe. 1982. A comparison of the fish populations and habitat in open and closed salt marsh impoundments in east-central Florida. Northeast Gulf Science, 5: 25-37.

Gilmore, R.G., R. Eames, D.J. Peters, B.J. Mclaughlin. 1987. Fish, macrocrustacean and hydrological studies of an impounded subtropical high marsh. pp. 1-17. in Final Report Fla. Dept. Env. Reg., Grant No. CZM-167.

Gilmore, R.G., B.J. McLaughlin and D. Tremain. 1987. Fish and macrocrustacean utilization of an impounded and managed red mangrove swamp with a discussion of the resource value of managed mangrove swamp habitat. Final Report to the Homer Hoyt Institute. 132 pp., 12 tbls., 31 figs.

Harrington, R.W., Jr. and E.S. Harrington. 1982. Effects on fishes and their forage organisms of impounding a Florida salt marsh to prevent breeding by salt marsh mosquitos. Bulletin of Marine Science, 32: 523-531.

Smith, Jr.,L.L., D.M. Oseid, I.R. Adelman, S.J. Broderius. 1976. Effect of hydrogen sulfide on fish and inverteberates. Part I. Acute and chronic toxicity studies. Final Report on Grant No. R800992 to U.S. Envir. Prot. Agency, EPA-600/3-76-062a.

Table 1. Number of individuals for species collected at each site on each collection date. TC (Tidal Creek), BHP (Blue Hole Point) and IMP (Impoundment #12, IRCMCD). Date of collection is designated above the station.

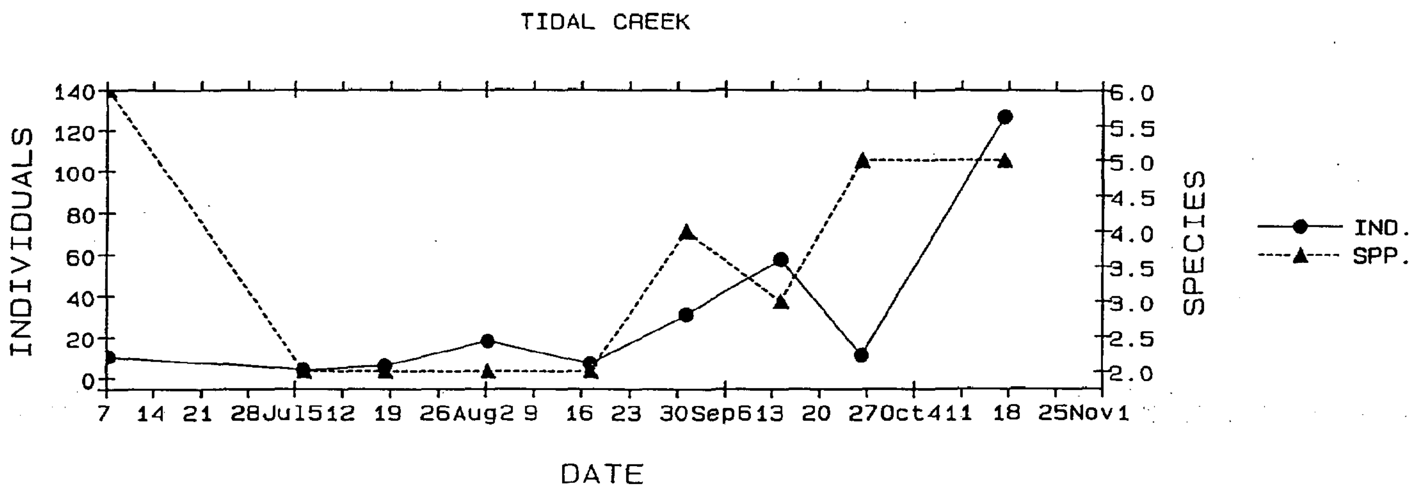
	JUNE			JULY			JULY		
	6 TC	7 BHP	8 IMP	5 TC	6 BHP	7 IMP	17 TC	18 BHP	19 IMP
Elops saurus			4			4			1
Brevoortia smithi									
Harengula jaguana		1							
Anchoa mitchilli		400			35				
Bagre marinus					1				
Strongylura notata	2			1	5		3		
Strongylura timucu									
Cyprinodon variegatus			16						
Fundulus confluentus			1						
Fundulus grandis			2						
Gambusia holbrooki			32			1			1
Poecilia latipinna			52						
Menidia beryllina					4				
Syngnathus scovelli									
Centropomus undecimalis	1	1							
Oligoplites saurus									
Eucinostomus harengulus	1								
Eucinostomus gula									
Eucinostomus spp	2			3			3	1	
Gerres cinereus	3								
Eugerres plumeri		2							
Diapterus auratus									
Archosargus probatocephalus									
Lagodon rhomboides	1								
Mugil curema						7			
Mugil cephalus								1	
Mugil spp			4						
Sphoeroides testudineus									
Chilomycterus schoepfi									
Total	10	404	111	4	45	12	6	2	2

Table 1 (Cont).

	AUG			AUG			AUG-SEPT		
	1 TC	2 BHP	3 IMP	16 TC	17 BHP	18 IMP	30 TC	31 BHP	1 IMP
Elops saurus									
Brevoortia smithi									
Harengula jaguana									
Anchoa mitchilli									
Bagre marinus									
Strongylura notata	2				4			1	
Strongylura timucu							1		
Cyprinodon variegatus			1050			12			47
Fundulus confluentus									
Fundulus grandis									
Gambusia holbrooki						20			24
Poecilia latipinna			100			13			18
Menidia beryllina									
Syngnathus scovelli									
Centropomus undecimalis		1			1				
Oligoplites saurus					1			2	
Eucinostomus harengulus	16						16		
Eucinostomus gula								1	
Eucinostomus spp		6		1					
Gerres cinereus									
Eugerres plumeri		1							
Diapterus auratus				6			13		
Archosargus probatocephalus							1		
Lagodon rhomboides									
Mugil curema									
Mugil cephalus								2	
Mugil spp									
Sphoeroides testudineus									
Chilomycterus schoepfi									
Total	18	8	1150	7	6	45	31	6	89

Table 1 (Cont).

	SEPT			SEPT			OCT		
	13 TC	14 BHP	15 IMP	25 TC	26 BHP	27 IMP	16 TC	17 BHP	18 IMP
Elops saurus									
Brevoortia smithi				65					
Harengula jaguana									
Anchoa mitchilli									
Bagre marinus									
Strongylura notata				1					
Strongylura timucu	3	1							
Cyprinodon variegatus									
Fundulus confluentus									
Fundulus grandis									
Gambusia holbrooki						4			
Poecilia latipinna									
Menidia beryllina									
Syngnathus scovelli		1							
Centropomus undecimalis									
Oligoplites saurus				2			4	3	
Eucinostomus harengulus				1			1		
Eucinostomus gula					6				
Eucinostomus spp	18		18				41		
Gerres cinereus									
Eugerres plumeri					2		1		
Diapterus auratus	37			7	1		13	1	
Archosargus probatocephalus									
Lagodon rhomboides								1	
Mugil curema		1							
Mugil cephalus									
Mugil spp									
Sphoeroides testudineus		1							
Chilomycterus schoepfi		1							
Total	58	4	18	11	10	4	127	5	0



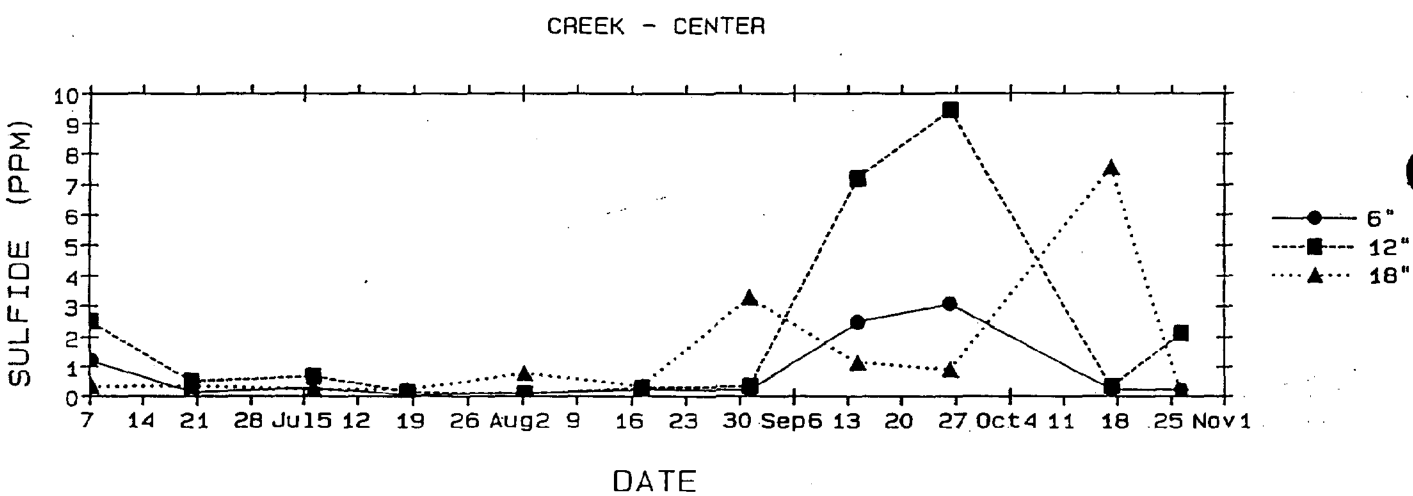
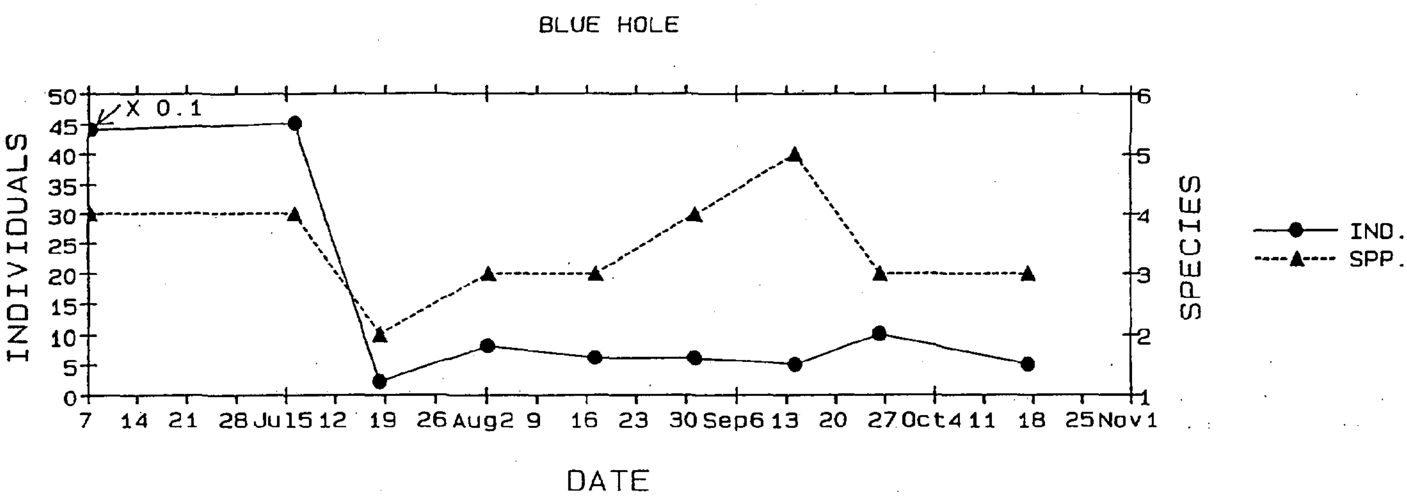


Figure 1. Fish and sulfide data plotted by date for the natural tidal creek site (TC).



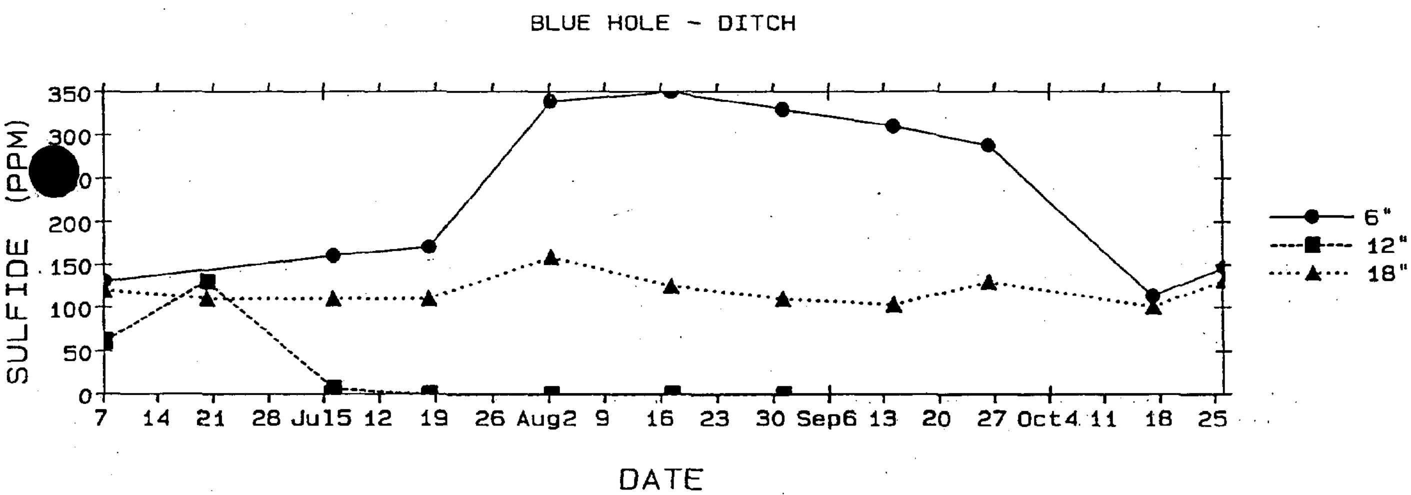
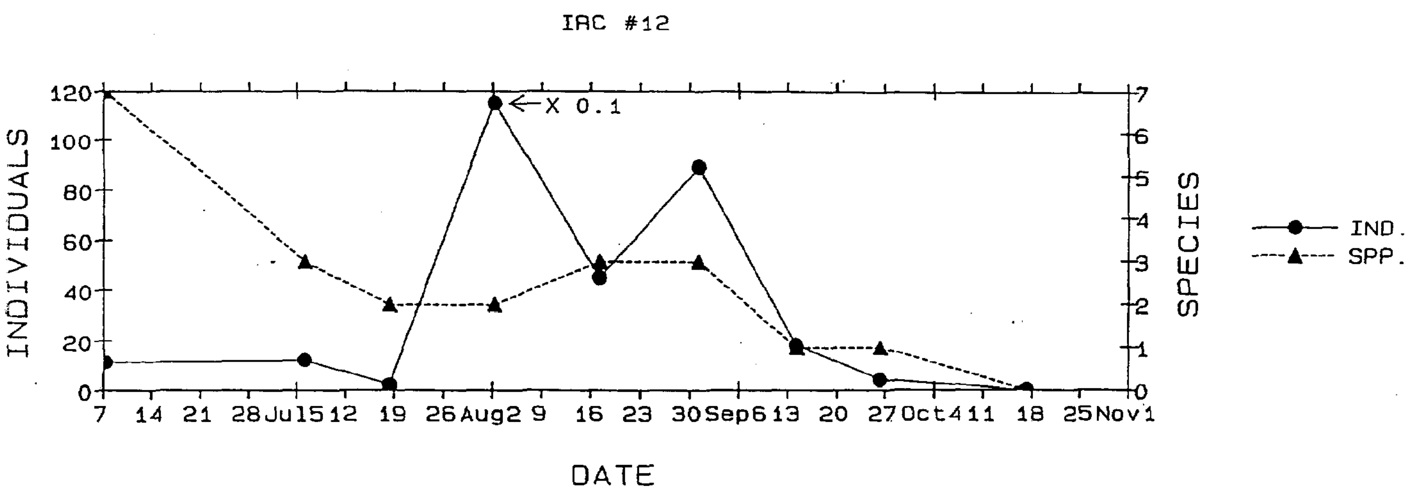


Figure 2. Fish and sulfide data plotted by date for the Blue Hole Point site (BHP).



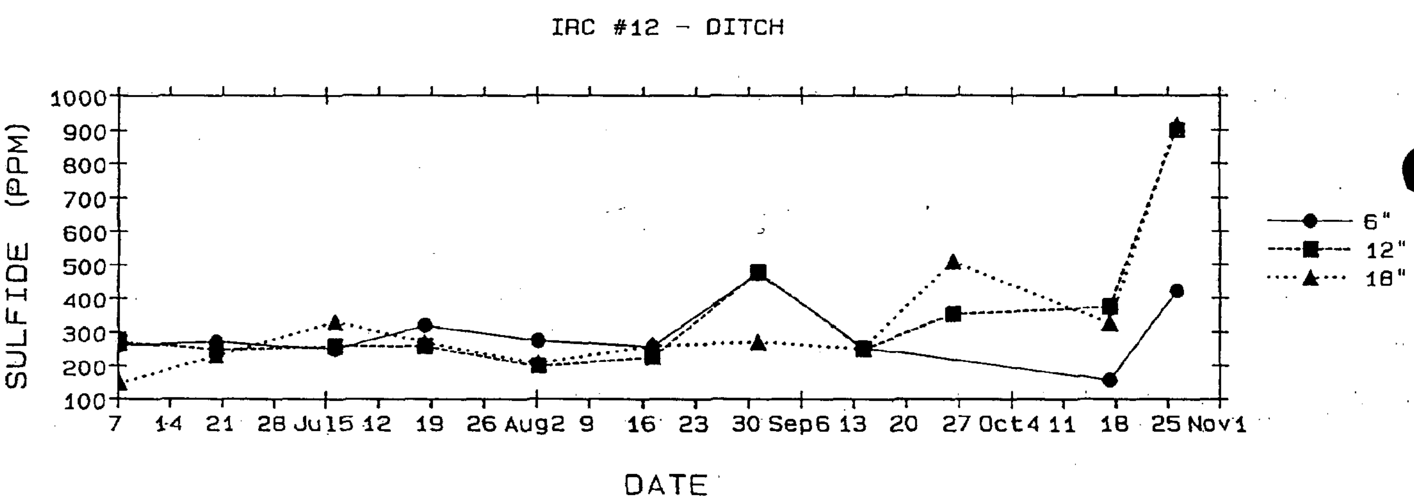


Figure 3. Fish and sulfide data plotted by date for the Indian River County Impoundment #12 site (IMP).