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Effects of avian breeding colonies on a man-made freshwater marsh in East Central Florida

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EFFECTS OF AVIAN BREEDING COLONIES ON A MAN-MADE FRESHWATER MARSH IN EAST CENTRAL FLORIDA

BY

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THESIS

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ABSTRACT

The effects of nutrient loading from avian breeding colonies into aquatic/marine ecosystems have been well documented. Documented influences include increased productivity of aquatic/marine macrophytes, elevated sediment nutrient concentrations, and increased densities of zooplankton and planktivorus fishes. The primary pathway of nutrient export from the rookery is through excreta from adult birds and their offspring. This study examined the influences of a 400-nesting pair rookery of cattle egret (*Bubulcus ibis*) in 1990 and a 75-nesting pair rookery of cattle egret in 1991 on a man-made freshwater treatment marsh in east central Florida. Because the fundamental intent of the created marsh (study site) was the removal of nutrients, primarily nitrogen and phosphorus, from advanced treated wastewater prior to discharge into public surface waters, the main objective of this study was to document the effects of the avian breeding colonies on water quality within the system. Secondary objectives of the study were to document influences on phytoplankton density and aquatic faunal community structure, as well as to estimate spatial and temporal limits of rookery influences. The results indicated significant water quality differences between rookery and reference sites during 1990 and 1991. The results also indicated significant differences between phytoplankton productivity and aquatic macroinvertebrate community structure between rookery and reference sites during 1990 and 1991. The effects of nutrient loading from the rookeries were confined to within 150 m and background water quality conditions were regained within one month of rookery abandonment. In effect, the 1990 and 1991 rookery sites were characterized as limited, transient "islands" of increased eutrophication within the marsh.

Key Phrases: aquatic macroinvertebrate, avian breeding colony, community structure, nutrient loading, treatment wetland, and water quality.

Key Words: cattle egret, excreta, eutrophication, phytoplankton.

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INTRODUCTION

Study Purpose

It has been well documented that avian breeding colonies of several different taxa greatly affect or alter aquatic/estuarine ecosystems by the addition of nutrients excreted from birds comprising the rookeries (Leentvaar 1967; Manny et al. 1975; and Frederick and Powell 1994). The primary pathway of nutrient export from the rookery is typically through feces and disgorged food material from adult birds and their offspring. The excrement from rookeries of wading birds was shown to increase the productivity of mangrove swamps in south Florida (Onuf, et al. 1977) and seagrass densities in Florida Bay (Powell 1989). Stinner (1983) demonstrated that nutrient enrichment from large breeding colonies of white ibis (*Eudocimus albus*) elevated sediment nutrient concentrations and increased aquatic macrophyte productivity in the Okeefenokee Swamp of southeast Georgia.

The deposition of nutrients from avian rookeries also affects faunal distributions. Oliver and Shoenberg (1989) linked elevated nutrient levels from colonial seabird rookeries to increased densities of zooplankton and plankivorus fishes. It has also been documented that avian populations transport nutrients among ecosystems (Watson 1986; Ganning and Wolf 1969; Bildstein, et al. 1990) through foraging activities outside of rookery areas.

Given the suggestion that avian rookeries alter conditions within aquatic ecosystems, it is the intent of this thesis to identify cattle egret breeding colonies as point source inputs of nutrients into the Iron Bridge Wetlands Nutrient Removal System, to document the effects on particular biotic and abiotic elements of the system, to estimate spatial and temporal limits of rookery influences, and to use the observed results as evidence that avian rookeries create spatially limited and transient areas of increased eutrophication within the treatment marsh. Because the fundamental function of the man-made study wetland is the removal of nitrogen and phosphorus from advanced treated wastewater prior to discharge into public surface waters (Swindell and Jackson 1990), the primary objective of this study was to document effects on water quality within the system. Secondary study objectives were to document nutrient loading influences on phytoplankton density and aquatic fauna community structure.

The study was conducted in two phases: (1) a preliminary investigation in 1990 consisting of a nutrient loading estimations, rudimentary water quality analyses, sediment nutrient level analysis, and life history characteristics documentation of cattle egret and anhinga, and (2) an expanded investigation in 1991 consisting of increased water quality analyses, sediment nutrient level analysis, phytoplankton productivity investigation, aquatic macroinvertebrate community investigation, and life history characteristics documentation of cattle egret and anhinga (Table 1).

Study Area

In 1985, the City of Orlando, Florida, seeking to reduce wastewater discharges into the Econlockhatchee River, began construction on a 485 ha man-made treatment wetland in eastern Orange County, Florida (Figure 1). The primary function of the wetland system

TABLE 1

SUMMARY OF 1990 AND 1991 STUDY TOPICS AND PARAMETERS

STUDY TOPIC	PARAMETER	STATION [1]	1990	1991
Rookery Census	No. individuals & nests	RS	X	X
Nutrient Loading	Nitrogen Phosphorus (g/m2/day)	RS	X	
Water Quality	Ammonia Nitrogen (mg/L)	RS, ReS, & BS	X	X
	Total Kjeldahl Nitrogen (mg/L)	RS, ReS, & BS		X
	Total Phosphorus (mg/L)	RS, ReS, & BS	X	X
	Fecal Coliform (No. colonies/100 ml)	RS, ReS, & BS	X	X
	Dissolved Oxygen (mg/L)	RS, ReS, & BS	X	X
	Specific Conductivity (umhos/cm at 25C)	RS, ReS, & BS	X	X
	pH (s.u.)	RS, ReS, & BS	X	X
	Water Temperature (C)	RS, ReS, & BS	X	X
	Water Depth (cm)	RS, ReS, & BS	X	X
	Secchi Depth (cm)	RS, ReS, & BS	X	X
Phytoplankton	Chlorophyll-a (mg/m3)	RS, ReS, & BS		X
Sediment Nutrients	Nitrogen Phosphorus (mg/kg)	RS & ReS	X	X
Aquatic Macroinvertebrate	community structure	RS & ReS		X

1 RS= Rookery Site.
ReS= Reference Site.
BS= Marsh Background Site.

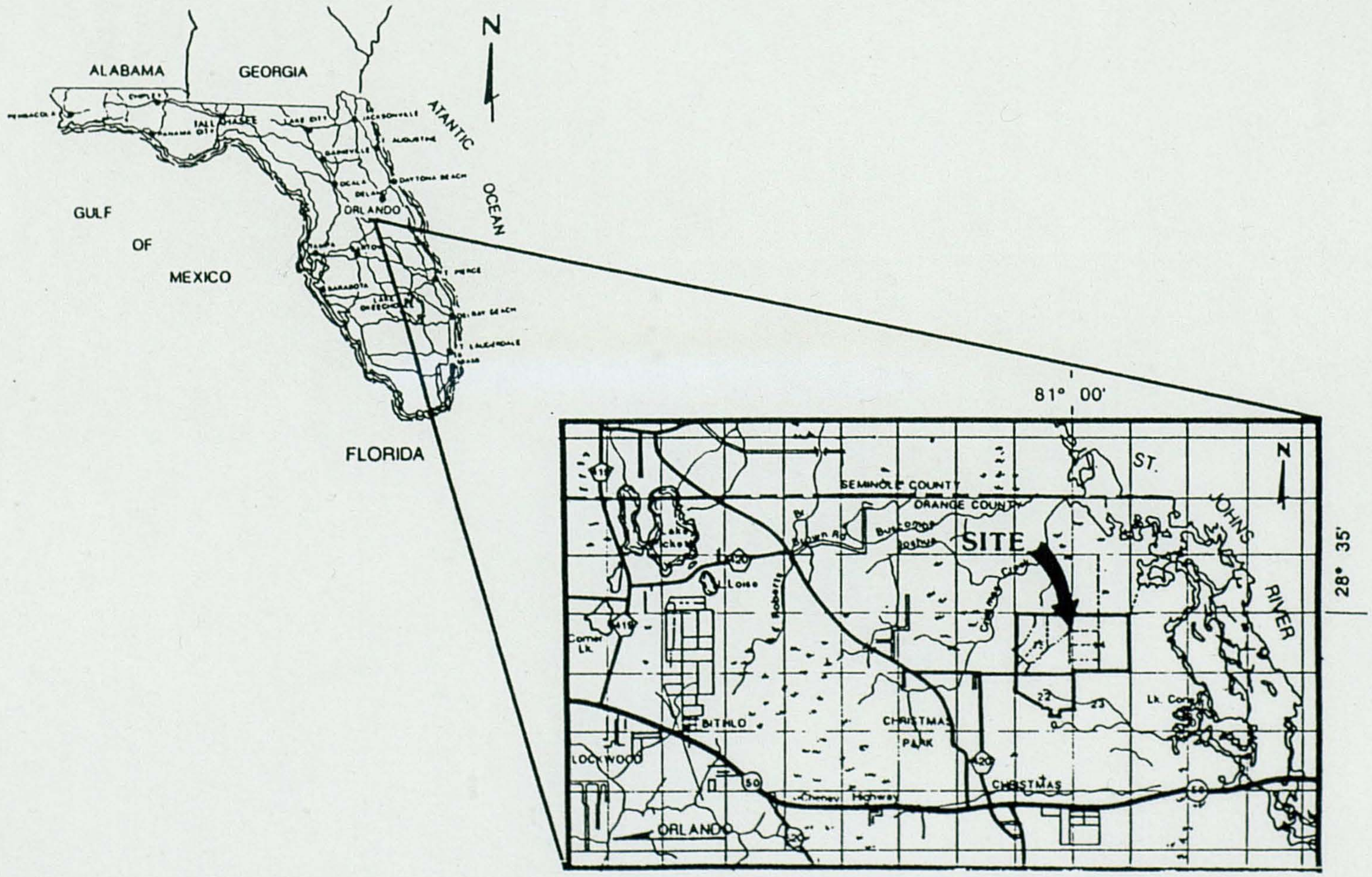

Figure 1. Site location of the Iron Bridge Wetlands Nutrient Removal System.

is to remove excess nutrients from advanced treated wastewater discharged from the City's Iron Bridge Regional Water Pollution Control Facility (IBRWPCF). The secondary goal of the created wetland is to provide suitable habitat for wetland-dependent species of wildlife (Burney, et al. 1989). Excess nutrients, primarily nitrogen and phosphorus, are removed from the wastewater by utilization in vegetative and microbial processes as the water flows through the system. Sedimentation of particulates also contributes greatly to the wetland polishing effects.

The treatment wetland system, the Orlando Easterly Wetlands Reclamation Project, was constructed on unimproved pasture, with construction completed and the site becoming operational in June 1987 (Figure 2). Currently, 0.58 m^3/s of IBRWPCF effluent is piped 29 km to the wetland located in eastern Orange County. Because the treated effluent originates at the IBRWPCF, the system is also referred to as the Iron Bridge Wetlands Nutrient Removal System (IBW). Once onsite, flow through the wetland is maintained from the west to the east through a naturally-occurring elevation gradient. The wetland system is subdivided by earthen berms into seventeen basins and a lake (borrow pit for the berm material). Weir structures at both inflow and outflow points in each of the basins (cells) allow for independent control, enabling the manipulation of detention time and water depth. Polished water is released offsite to the cordgrass (*Spartina bakeri*) dominated floodplain of the St. Johns River after a total detention time of approximately 30 days (Table 2). There was no contouring of the individual cells, consequently, water depth varies from saturated soils to 1.5 m in each cell.

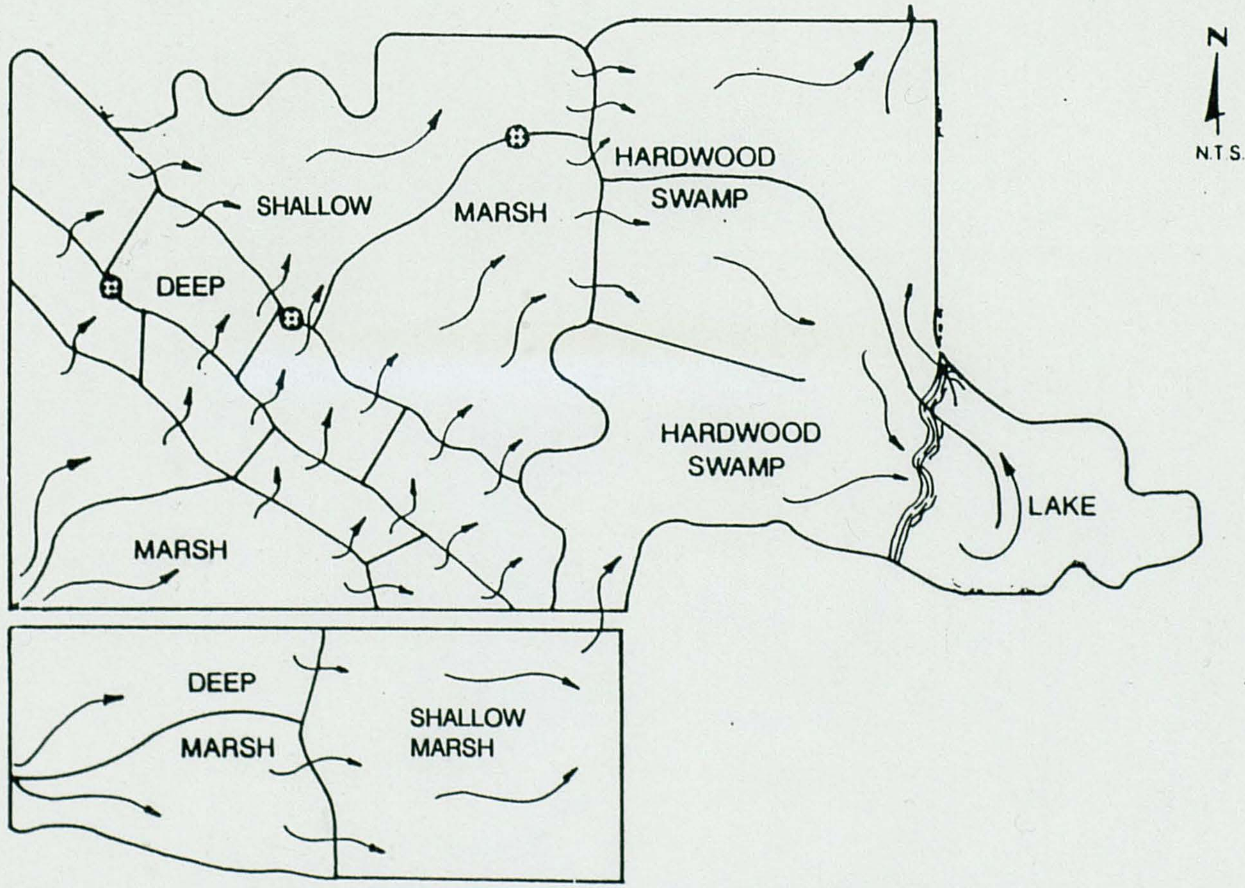

Figure 2. Plan view of the Iron Bridge Wetlands Nutrient Removal System.

TABLE 2

WATER QUALITY PERFORMANCE DATA FOR THE IRON BRIDGE WETLANDS NUTRIENT REMOVAL SYSTEM 1988 TO 1991

	Treatment Wetlands Discharge	
Year	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
1988	0.095	0.84
1989	0.076	0.92
1990	0.090	0.93
1991	0.087	0.80
FDEP Permit Criteria	0.200	2.31

Cells 1 through 12, referred to as deep marsh cells, are maintained at an average water depth of 60 cm with cattails (*Typha domingensis* and *latifolia*) and giant bulrush (*Scirpus californicus*) as the dominant species. Cells 13, 14 and 15, referred to as shallow marsh cells, have an average water depth of 30 cm with pickerelweed (*Pontederia cordata*), duck potato (*Sagittaria lancifolia*), and torpedograss (*Panicum repens*) as the dominant emergents. Open water areas and areas dominated by submergents such as bladderwort (*Utricularia* spp.), coontail (*Ceratophyllum* spp.) and southern naiad (*Najas* sp.), are also present. A hardwood swamp area (cells 16 and 17) was planted with 120,000 trees, consisting mainly of pond cypress (*Taxodium ascendens*), popash (*Fraxinus caroliniana*) and blackgum (*Nyssa sylvatica* var. *biflora*). Carolina willow (*Salix caroliniana*) heads and isolated "tree islands" of living and dead sabal palm (*Sabal palmetto*), live oak (*Quercus virginiana*) snags, and southern red cedar (*Juniperus silicicola*) snags are also scattered throughout the entire wetland system.

More specifically, the study area for both the 1990 and 1991 study seasons was confined to the northeast corner of shallow marsh Cell 14 and the southeast corner of shallow marsh Cell 13 (Figure 3).

The 1990 rookery of 400 nesting pairs of cattle egret occupied an entire 2420 m^2 willow head (Craighead 1971) in northeast Cell 14. The willow head, comprised solely of Carolina willow (forming the rookery structure), was permanently inundated with an annual average water depth of 66 cm. Although the dominant species comprising the rookery were cattle egret, anhinga (*Anhinga anhinga*), tricolored heron (*Egretta tricolor*) and little blue heron (*E. caerulea*) were also present.

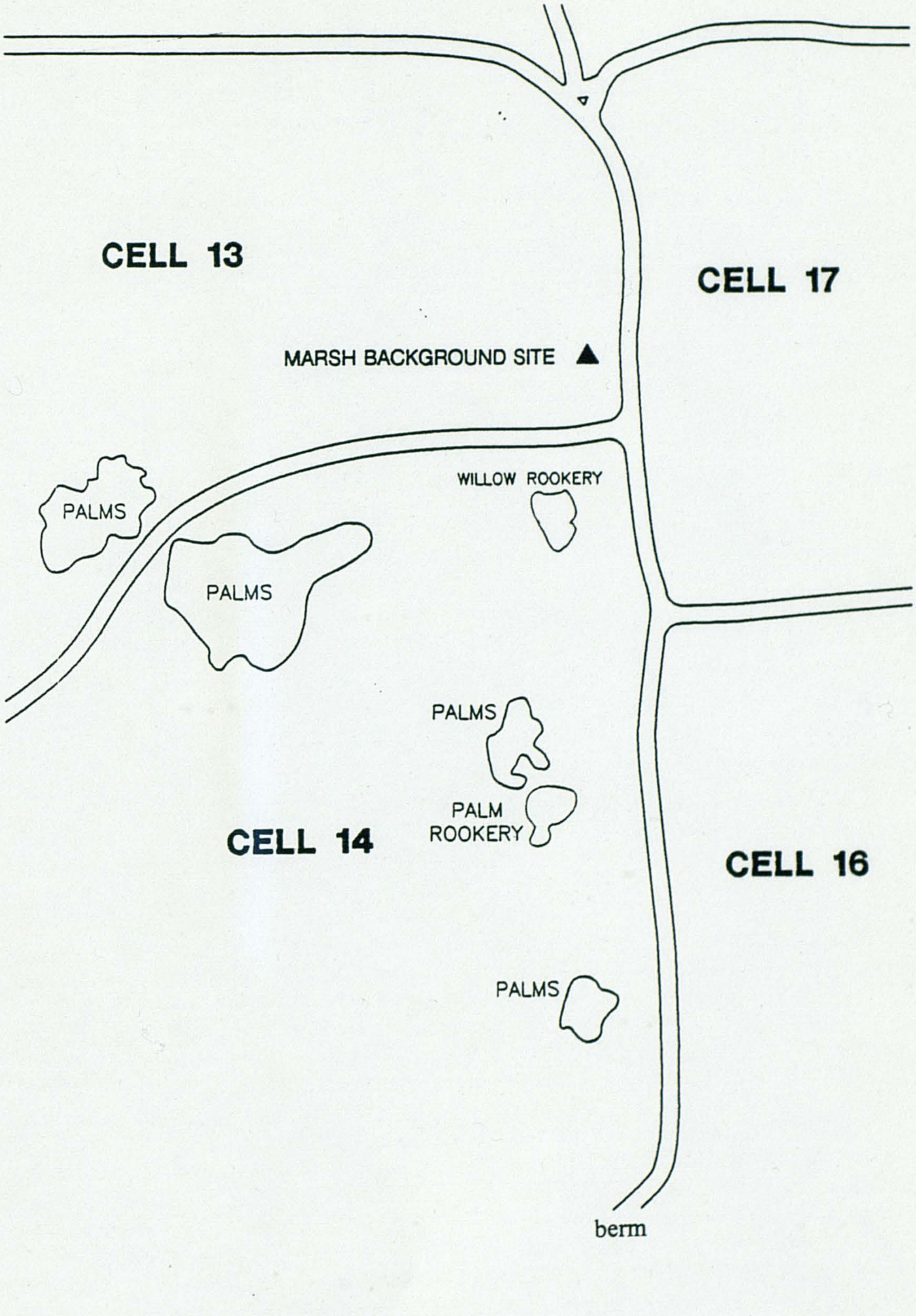

Figure 3. Plan view of the study area.

To compare monitored rookery area conditions and marsh background conditions within the same treatment basin (Cell 14), a 1990 reference site was established approximately 150 m to the west of the rookery. The reference site had an annual average water depth of 46 cm and was vegetatively dominated by willow and pickerelweed. To compare rookery conditions with background marsh conditions outside of Cell 14, a marsh background condition site was established in southeast Cell 13. The marsh background site had an annual average water depth of 45 cm and was dominated by pickerelweed and torpedograss. Because Carolina willow was the only tree species forming the structure of the colony, the 1990 Rookery was referenced as the Willow Rookery. However, it should be noted that willow mortality was such that less than five percent coverage of living trees remained at the end of avian occupation.

Because the willows that had formed the structure of the 1990 Rookery did not survive the stress of avian breeding activity (thus, providing structure for less than 10 nests in 1991), the 1991 study site was shifted. The 1991 Rookery of 70 nesting pairs of cattle egret was located in a sabal palm "island" adjacent to the abandoned Willow Rookery in the northeast corner of Cell 14. Southern red cedar and live oak snags also formed an integral part of the rookery structure. The palm "island" was permanently inundated with an annual average water depth of 41 cm. Anhinga was the only other avian species present in the 1991 rookery. Because sabal palm was the dominant tree species forming the colony site, the 1991 Rookery was referenced as the Palm Rookery.

As with the 1990 investigation, a 1991 marsh reference site was established to compare the rookery results with reference conditions in Cell 14. The 1991 reference site was a permanently inundated palm "island" located approximately 150 m southwest of the rookery. The annual average water depth was 38 cm. The marsh background condition site located in the southeast corner of Cell 13 was also monitored during the 1991 study season to compare rookery results with background conditions outside of Cell 14.

METHODS AND MATERIALS

Willow Rookery- 1990

Rookery Census

A weekly census of the Willow Rookery, conducted from 19 April through 31 October 1990, enumerated each individual by species and age class. To facilitate an accurate count from a distance, two age classes were designated: (1) adult/juvenile: composed of adults and juveniles which had deserted the nest for adjacent branches, and (2) nestlings: younger birds that still exhibited strict nest fidelity. Counts were conducted with binoculars and a spotting scope from a berm 75 m west of the rookery to minimize disturbances caused by direct rookery visitations. Immediately following each weekly remote census, nests, eggs, and nestlings (too small to be counted from a distance) were counted from canoe during water sample collection activities. Nests were classified as either: (1) containing eggs, (2) containing nestlings, or (3) deserted, without eggs or nestlings.

Water Quality

Water samples were collected weekly from 19 April through 11 October 1990 at one station located in the interior of the nesting area, the Rookery Site (RS), and at one reference station, the Reference Site (ReS), located 150 m southwest (250°) of the colony

(Figure 4). A reference site was established to provide data on marsh conditions (not associated with the rookery) within Cell 14 for comparisons with data collected at the rookery. The two sites were of similar vegetative composition and water depth. The surface grab water samples from each station were collected in virgin plastic bottles (nutrient samples) and pre-sterilized whirlpak bags (fecal coliform samples). Samples were then transported at 4 C to a state certified laboratory (Florida Health and Rehabilitation Services #E53087), and analyzed for total phosphorus concentration, ammonia nitrogen concentration, and fecal coliform bacteria density (Table 3). All lab procedures followed standard APHA and EPA criteria (APHA, AWWA, WPCF 1989 and EPA 1983). Field measurements were also recorded at both sites. Surface water temperature, dissolved oxygen concentration, specific conductivity, pH, and flow were measured using a YSI Dissolved Oxygen Meter, Model 57; YSI SCT Meter, Model 33; Orion pH meter, Model SA250; and Marsh/McBirney Flow Meter, Model 201D.

In addition to the rookery and reference sites, a third location, the Background Marsh Site (BS), was sampled monthly. Sampling procedures for the background site followed those previously described for RS and ReS. This site, located in Cell 13 (northeast of the rookery site) was initially sampled as part of a separate water quality investigation, but the data were incorporated into this study to obtain marsh background data that were independent of conditions in Cell 14 (the wetland basin containing the rookery). Although separated from the other two sites by an earthen berm, this station (BS) had similar vegetation and water depths.

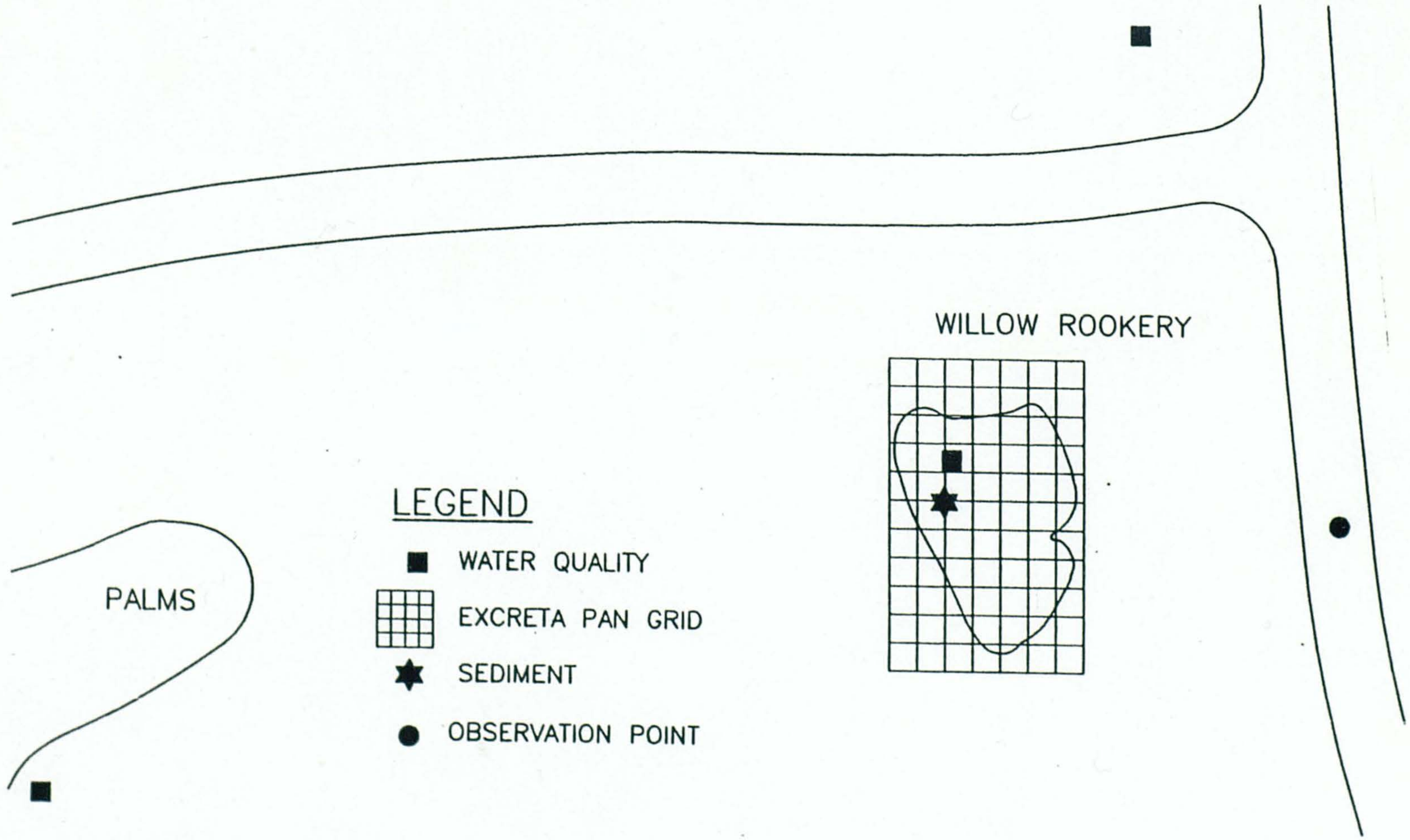

Figure 4. Location map depicting sample stations for the Willow Rookery (1990) study.

TABLE 3

SUMMARY OF 1990 WATER QUALITY PARAMETERS

PARAMETER	STATION [1]	ANALYSIS LOCATION	INTERVAL
Ammonia Nitrogen (mg/L)	RS, ReS & BS	lab	weekly
Total Phosphorus (mg/L)	RS, ReS & BS	lab	weekly
Fecal Coliform (No. colonies/100 ml)	RS, ReS & BS	lab	weekly weekly
Dissolved Oxygen (mg/L)	RS & ReS BS	field field	weekly monthly
Specific Conductivity (umhos/cm at 25C)	RS & ReS BS	field field	weekly monthly
Water Temperature (C)	RS & ReS BS	field field	weekly monthly
pH (s.u.)	RS & ReS BS	field field	weekly monthly
Water Depth (cm)	RS & ReS BS	field field	weekly monthly
Secchi Depth (cm)	RS & ReS BS	field field	weekly monthly

1 RS= Rookery Site.
ReS= Reference site.
BS= Background Site.

The relationship between rookery population and selected water quality parameters were statistically tested using ANOVA (McClave and Dietrich, II 1988).

Sediments

Five 1.9 cm diameter core samples from the Rookery Site (RS) were collected at a depth of 12.7 cm on 15 May 1990, 23 October 1990, and 10 July 1991 (Figure 4). The five subsamples were combined into one composite sample for each sampling event. Each composite sample was placed in a pre-sterilized whirlpak bag and transported to the lab (FHRS #E53087) at 4 C. Three replicate 50 g grab samples from each site composite were oven dried at 100 C for 48 hours and then analyzed for total nitrogen and total phosphorus content following standard EPA guidelines (EPA 1983).

Excreta Nutrient Content and Loading Rates

Twenty-five consecutively numbered 0.25 m^2 aluminum pans were suspended randomly under the rookery on 5 July 1990 to estimate the weight of excreta entering the system per day during the estimated period of maximum colony population. Prior to pan placement, a grid was placed on a map of the rookery and placement sites selected using a random numbers table. After a 24-hour period, the pans were collected, transported to the lab and oven dried at 100 C for 48 hours. The dry weight of total excreta per pan was then determined using:

wt of excreta = wt. of pan and excreta - pre-determined pan wt.

The average loading rate (g/0.25 m^2/day) of excreta entering the wetlands on 5 July, 1990 was then calculated using the weight (g) of excreta for each individual pan deposited over the 24-hour period. The average loading rate for a m^2 was calculated by multiplying the 0.25 m^2 rate by four. An estimated loading rate (g/m^2/day) for the entire 2420 m^2 rookery on 5 July 1990 was calculated by multiplying the area of the rookery times the estimated m^2 loading rate.

Next, three subsamples of excreta (25 g) were selected randomly from the entire group of pans and analyzed for total nitrogen (TN) and total phosphorus (TP) content. Average nutrient loading rates (g/m^2/day) into the wetland system were then estimated for 5 July 1990 (estimated to be the period of maximum rookery occupation) using the results of the nutrient content analyses and following the same procedures for estimating total excreta rates. The percentages of TN and TP contained in the excreta were then calculated using:

% nutrient content of excreta= (wt. of nutrient/wt. of total excreta)(100).

The total weights (kg) of TN and TP entering the system on 5 July 1990 from the entire rookery were then estimated using:

estimated rookery nutrient loading= (nutrient weight/m^2)(rookery area)(day).

Observed Ecological Aspects

Observed life history characteristics associated with rookery activity were documented concurrent with other study efforts (i.e., water sample collection, sediment collection, pan placement, and population censusing). Notes included observations on behavior, habitat selection, predation, and mortality (other than predation) of avian species.

Palm Rookery- 1991

Rookery Census

A weekly census of the Palm Rookery, conducted from 2 May through 19 September 1991, enumerated each individual by species and age class following methods previously described for the 1990 study season.

Water Quality

Water samples were collected weekly from 2 May through 19 September 1991 at one station located in the interior of the nesting area, the Rookery Site (RS), and at one reference station, the Reference Site (ReS), located 150 m south (190°) of the colony (Figure 5). A reference site was established to provide Cell 14 background condition data for comparisons with data collected at the rookery. The two sites were of similar vegetative composition and water depth. In addition to the rookery and reference sites, a third location, the Background Marsh Site (BS), was sampled monthly. This site, located in Cell 13 northeast of the rookery site, was initially sampled as part of a separate water quality investigation but the data were incorporated into this study to obtain marsh

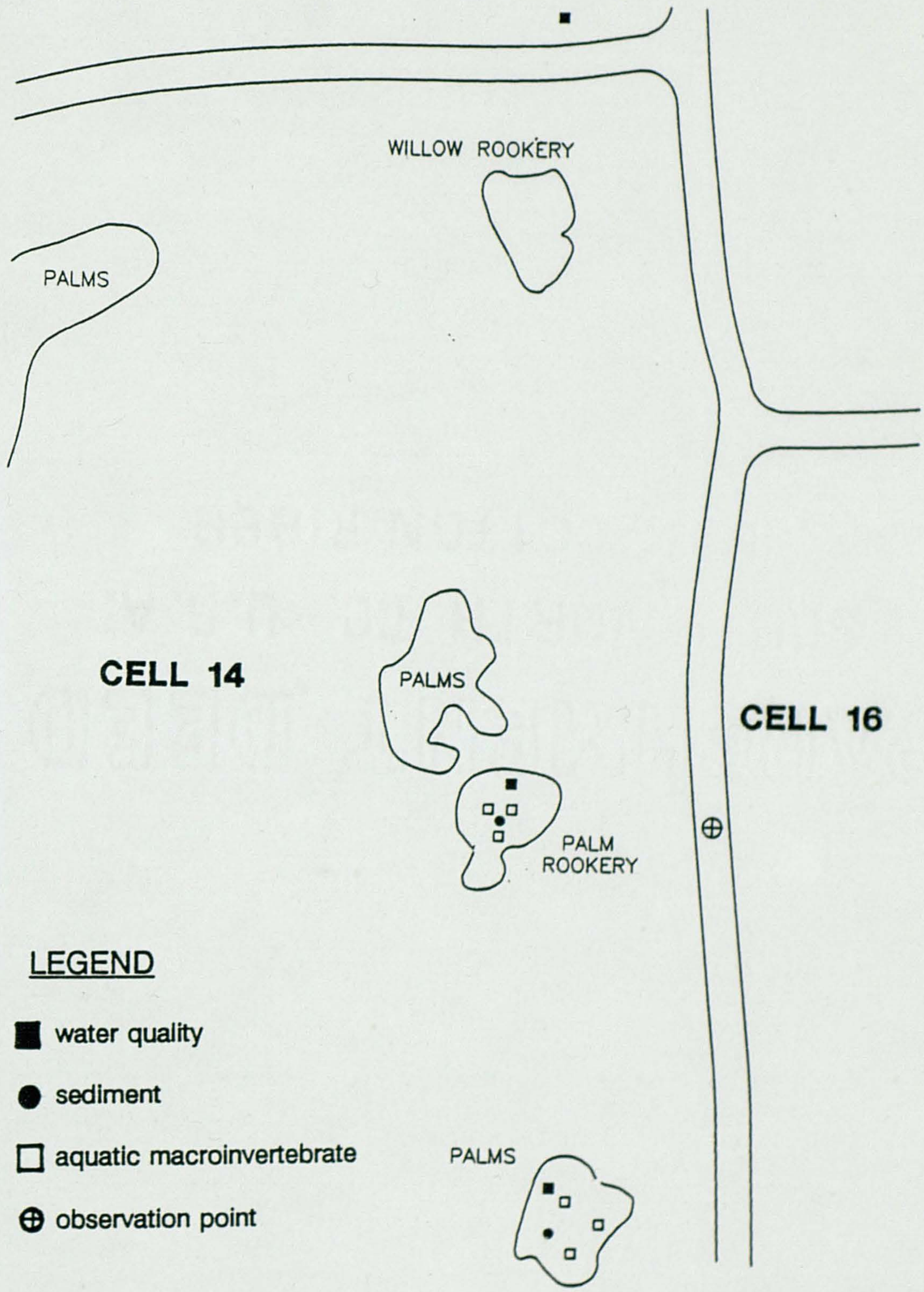

Figure 5. Sample station locations for the Palm Rookery, 1991.

background data that was independent of conditions in Cell 14 (the wetland cell containing the rookery).

The parameter list and sampling frequencies for the 1991 study are presented in Table 4. Water sample collection techniques, field measurement methodologies, and sample transport procedures followed those previously described for the 1990 study. Laboratory analytical procedures were also the same, with the exception of additional analyses (a parameter comparison between 1990 and 1991 was provided in Table 1). However, the additional parameters were also analyzed following standard APHA and EPA criteria (APHA, AWWA, WPCF 1989 and EPA 1983).

As with the 1990 data, the relationship between rookery population and selected water quality parameters were statistically tested using ANOVA.

Sediments

Five 1.9 cm core samples were collected on 30 April, 10 July, and 19 October 1991 from the Rookery Station. The five subsamples from each sampling event were combined into one composite sample for each site. Each composite sample was placed in a pre-sterilized whirlpak bag and transported to the lab (FHRS #E53087) at 4 C. Three replicate 50 g grab samples from each site composite were oven dried at 100 C for 48 hours and then analyzed for total nitrogen and total phosphorus content following standard EPA guidelines.

TABLE 4

SUMMARY OF 1991 WATER QUALITY PARAMETERS

PARAMETER	STATION [1]	ANALYSIS LOCATION	INTERVAL
Ammonia Nitrogen (mg/L)	RS, ReS & BS	lab	weekly
Total Kjeldahl Nitrogen (mg/L)	RS, ReS & BS	lab	weekly
TP (mg/L)	RS, ReS & BS	lab	weekly
Fecal Coliform Bacteria (No. colonies/100 ml)	RS, ReS & BS	lab	weekly
Dissolved Oxygen (mg/L)	RS & ReS BS	field field	weekly monthly
Specific Conductivity (umhos/cm at 25 C)	RS & ReS BS	field field	weekly monthly
Water Temperature (C)	RS & ReS BS	field field	weekly monthly
pH (s.u.)	RS & ReS BS	field field	weekly monthly
Water Depth (cm)	RS & ReS BS	field field	weekly monthly
Secchi Depth (cm)	RS & ReS BS	field n/a	weekly none
Chlorphyll-a (mg/m3)	RS, ReS & BS	lab	weekly bi-weekly

1 RS= Rookery Site.
ReS= Reference Site.
BS- Background Site.

Excreta Nutrient Content and Loading Rates

The amount of excreta discharged from the birds within the rookery could not be accurately measured because the great majority of nests were located in sabal palm branches or "boots". Unlike the 1990 Willow Rookery (where excreta passed easily from the willow branches into the collection pans), the dead palm branches intercepted and stored large quantities of excreta. Therefore, excreta (and nutrient) loading rates were not calculated for the 1991 Palm Rookery due to sampling limitations imposed by the physical structure of the colony.

Phytoplankton Productivity

Chlorophyll$_a$ samples were collected weekly from 2 May to 19 September 1991 (concurrent with the nutrient and coliform bacteria samples) at rookery and background sites to compare phytoplankton productivity between rookery and background conditions. Samples were transported at 4 C to a state certified laboratory (Florida Health and Rehabilitation Services #E53087) and analyzed following standard APHA and EPA criteria (APHA, AWWA, WPCF 1989 and EPA 1983).

Aquatic Macroinvertebrate Communities

Aquatic macroinvertebrates were sampled in the Palm Rookery and Reference Site on 13 June and 5 September 1991 using Hester-Dendy artificial substrate samplers (Hester and Dendy 1962). One artificial substrate sampler was placed at three stations in each site and remained in place for twenty eight days (Figure 5). Samplers were suspended approximately halfway down the water column. Samplers were collected using a D-frame dipnet and placed in zip-lock plastic bags (with water) for transport to the laboratory. Upon reaching the lab, each sampler was disassembled and the organisms were removed with forceps. All organisms from each individual sampler were placed into one jar containing ethanol and sent to a qualified sub-consultant for identification.

Observed Ecological Aspects

Observed avian life history characteristics associated with rookery activity were documented concurrent with other study efforts (i.e., water sample collection, faunal data collection, sediment sampling, and population censusing). Notes included observations on behavior, habitat selection, predation, and mortality (other than predation) of avian species.

RESULTS

Willow Rookery- 1990

Rookery Census

The anhinga population declined from a maximum of 48 individuals in April (wk 2) to 17 individuals in October (wk 22) with some fluctuations corresponding to increased activity of late season nesting (Figure 6). The number of active anhinga nests peaked in mid-April (prior to wk 0) with greater than 16 nests and steadily declined throughout the study period, with slight peaks appearing in mid-May (wk 5) and early August (wk 14).

The peak population density of cattle egrets, including adults, juveniles, and nestlings, was approximately 1300 during early July (wk 10). The population then steadily decreased as nestlings abandoned nests, juveniles left the rookery, and adults deserted the nesting area (Figure 7). Cattle egret nesting was initiated in mid-April (wk 0), peaked in mid-June (wk 7) with approximately 390 nests, and ended in late August (wk 18).

Excreta Nutrient Content and Loading Rates

An estimated 64.8 g/m^2/day of excreta was discharged from rookery inhabitants on 5 July 1990, during the week (wk 10) of maximum rookery population (Table 5). Based on analytical results indicating that excreta from the Willow Rookery contained

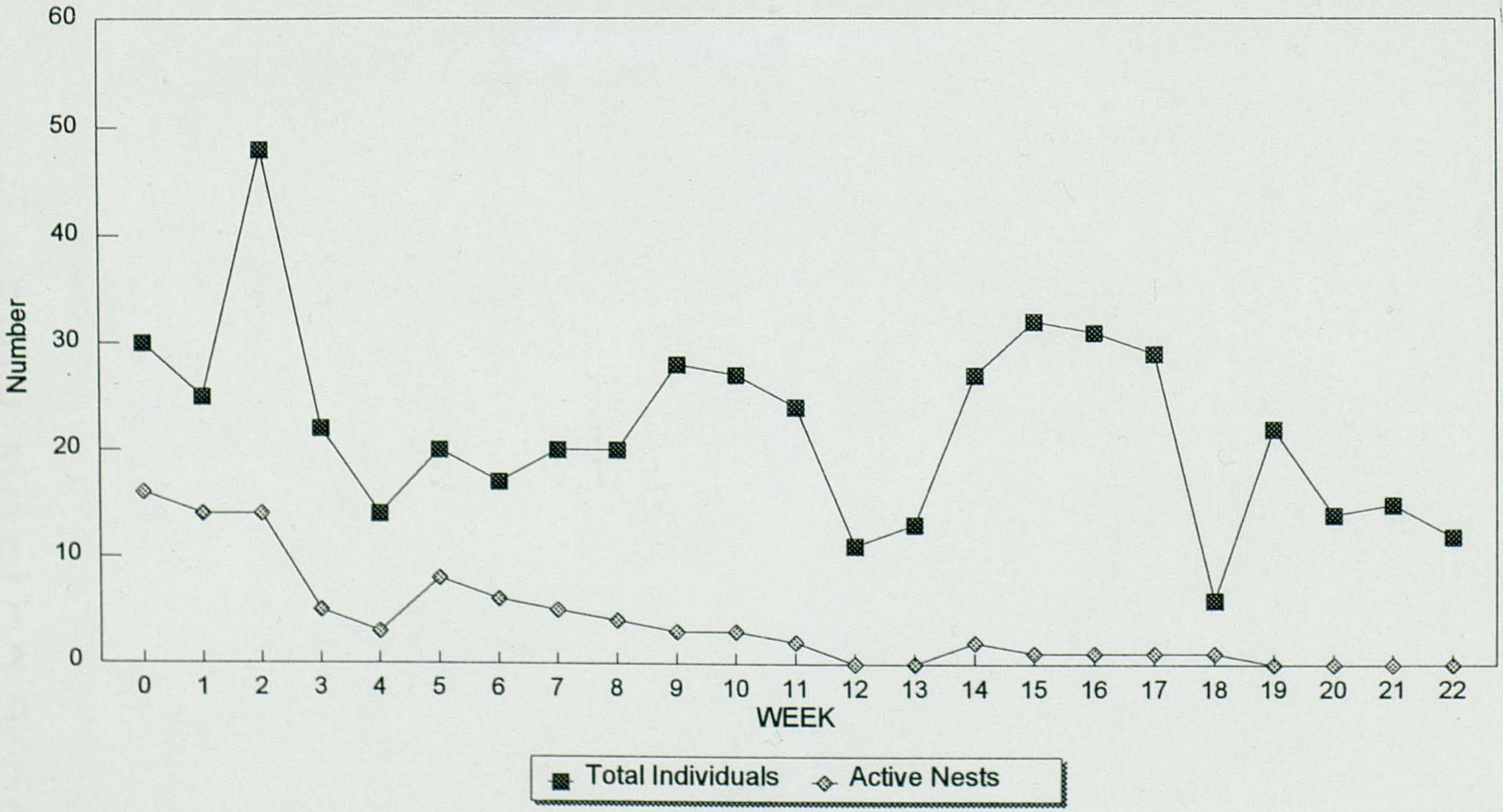

Figure 6. Anhinga population of the IBW Willow Rookery from 19 April to 11 October 1990.

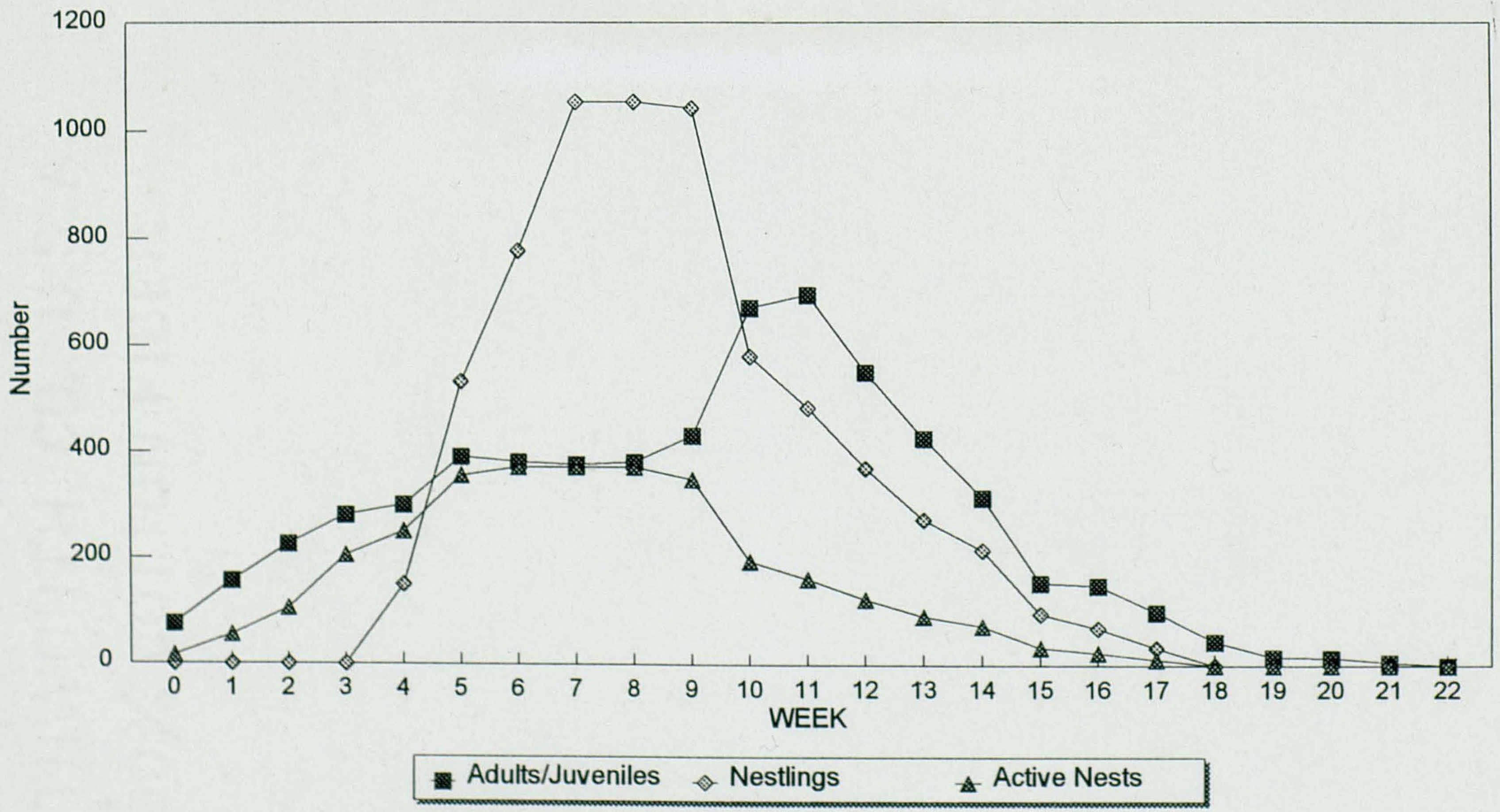

Figure 7. Cattle Egret population of the IBW Willow Rookery from 19 April to 11 October 1990.

TABLE 5

EXCRETA NUTRIENT CONTENT AND ESTIMATED LOADING RATES FOR THE WILLOW ROOKERY, 5 JULY 1990

Area	Total Excreta (g/day)	Nitrogen[1] (g/day)	Phosphorus[2] (g/day)
0.25 m2[3]	16.2	1.3	0.1
1.0 m2[4]	64.8	5.2	0.4
Total Rookery (2420 m2)	156,816	12,584	968

1 Calclated at 8.0% of the total excreta weight.
2 Calculated at 0.9% of the total excreta weight.
3 Measured in the field.
4 Estimated from field measurements.

8.0% nitrogen and 0.9% phosphorus, it was estimated that 5.2 $g/m^2/$ day TN and 0.4 $g/m^2/day$ TP were discharged from the rookery on this date. It was then estimated, based on these loading rates, that 16.5 kg of TN and 1.9 kg of TP were excreted from the entire 2420 m^2 rookery on 5 July 1990 (during wk 10).

Water Quality

A summary of average water quality values from April to October 1990 for the Rookery Site (RS), Reference Site (ReS), and Background Site (BS) is presented as Table 6 and a summary of correlation coefficients (r^2) between rookery population and water quality parameters is presented as Table 7. Results of the weekly water quality analyses for RS, ReS, and BS through the study period are presented following the order listed in Table 6 (Figures 8 to 14).

The average ammonia nitrogen (NH_3N) concentrations (mg/L) for RS, ReS, and BS were 0.49, 0.10, and 0.08, respectively. Ammonia nitrogen concentrations were significantly ($p < 0.05$) different between RS and ReS and RS and BS (Table 8). Furthermore, the results indicated that ReS concentrations differed slightly from those at BS, but this difference was not statistically tested. Ammonia nitrogen levels fluctuated through time, but RS consistently exhibited greater concentrations and RS levels were still greater than ReS and RS values at the end of the study period on 11 October 1991 (Figure 8). Maximum concentrations (mg/L) at RS, ReS, and BS were 1.1, 0.22 and 0.2, respectively. Rookery population through time and NH_3N concentration at RS were not significantly ($p > 0.05$) correlated, $r^2 = 0.06$.

TABLE 6

COMPARISON OF AVERAGE WATER QUALITY VALUES FOR THE WILLOW ROOKERY FROM APRIL TO OCTOBER 1990

Parameter	Unit	Rookery Site	Reference Site	Background Site
Ammonia Nitrogen	(mg/L)	0.49	0.10	0.08
Total Phosphorus	(mg/L)	0.30	0.09	0.05
Fecal Coliform Bacteria	(No. colonies/ 100 ml)	989	61	43
Dissolved Oxygen	(mg/L)	4.6	2.4	2.3
Specific Conductivity	(umhos/cm at 25 C)	600	590	540
pH	(s.u.)	7.23	6.94	7.12
Water Temperature	(C)	28.6	27.3	25.7
Water Depth	(cm)	69	43	40

TABLE 7

CORRELATION COEFFICIENTS BETWEEN ROOKERY POPULATION AND WATER QUALITY PARAMETERS FOR THE WILLOW ROOKERY - 1990

PARAMETER	r2
Ammonia Nitrogen	0.06*
Total Phosphorus	0.06*
Total Phosphorus[1]	0.61
Fecal coliform	0.64
Dissolved Oxygen	0.21*
Specific Conductivity	0.34*
Water Temperature	0.29*
pH	0.34*
Secchi Depth[2]	0.42

1 Adjusted TP values; shifted population counts back 3 weeks.

2 Secchi depth= difference between water depth and secchi measure

* value less than significance level of 0.41; $p < 0.05$

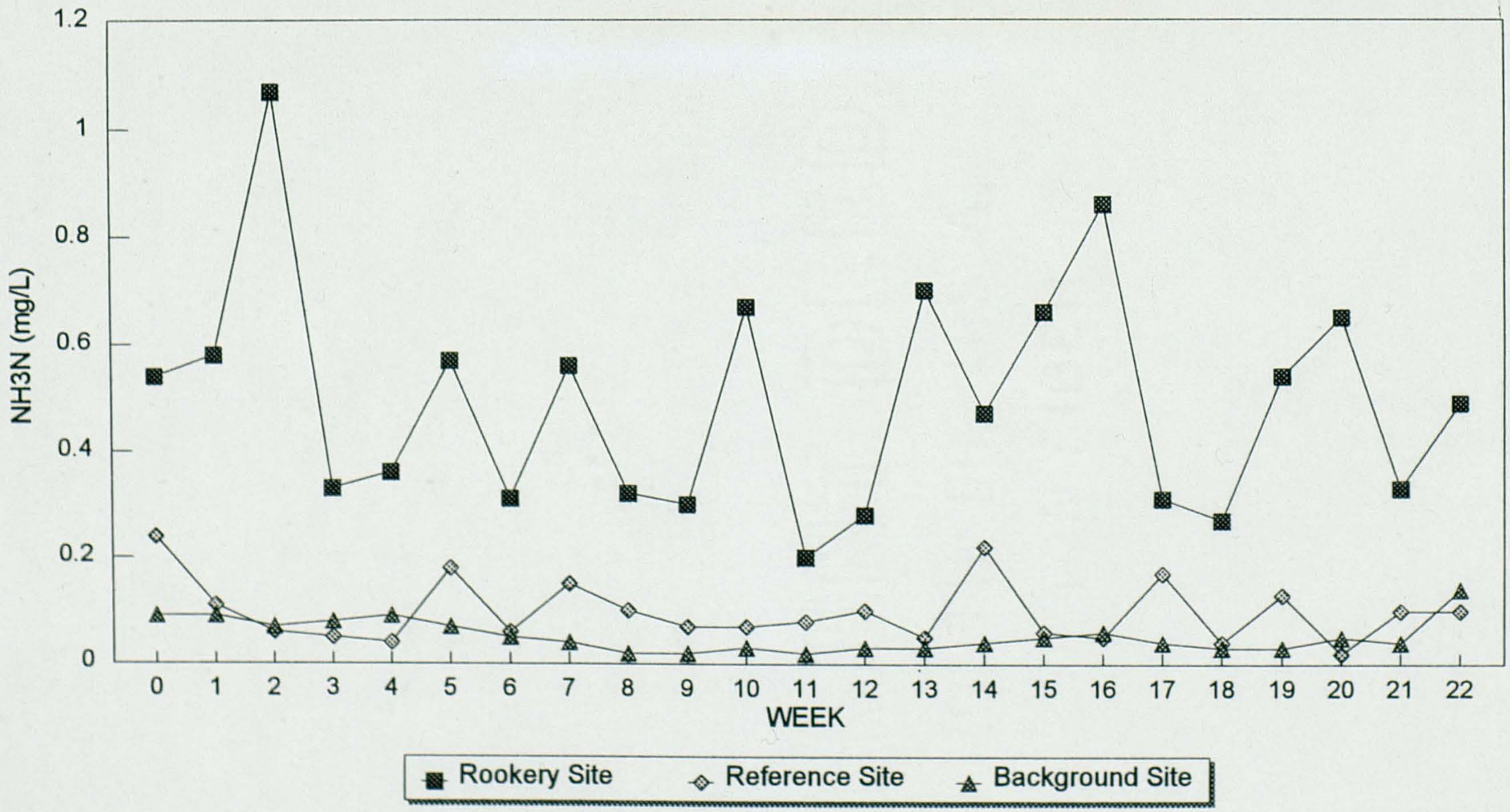

Figure 8. Comparison of NH_3N over time at IBW Willow Rookery from 19 April to 11 October 1990.

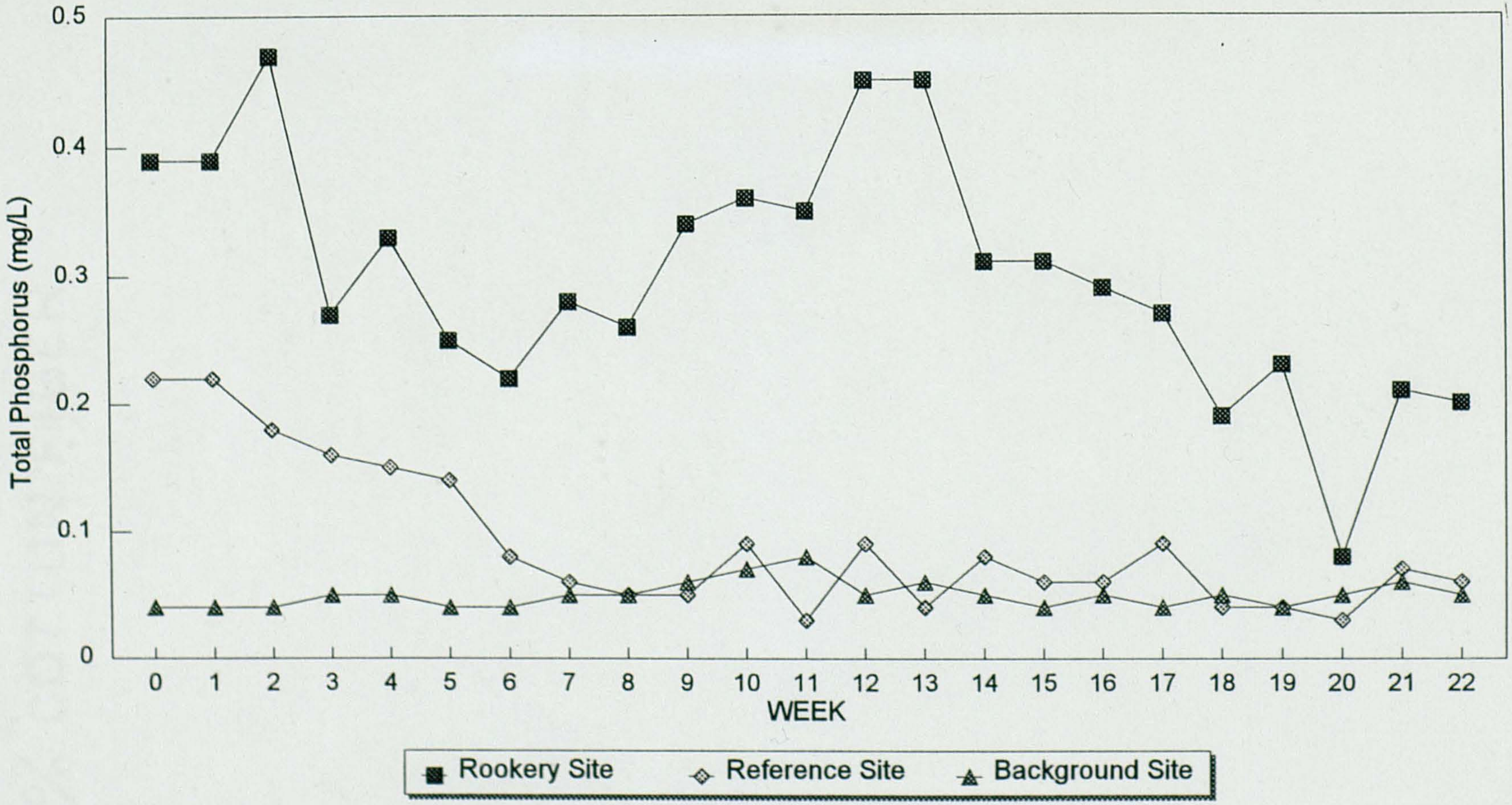

Figure 9. Comparison of TP over time at IBW Willow Rookery from 19 April to 11 October 1990.

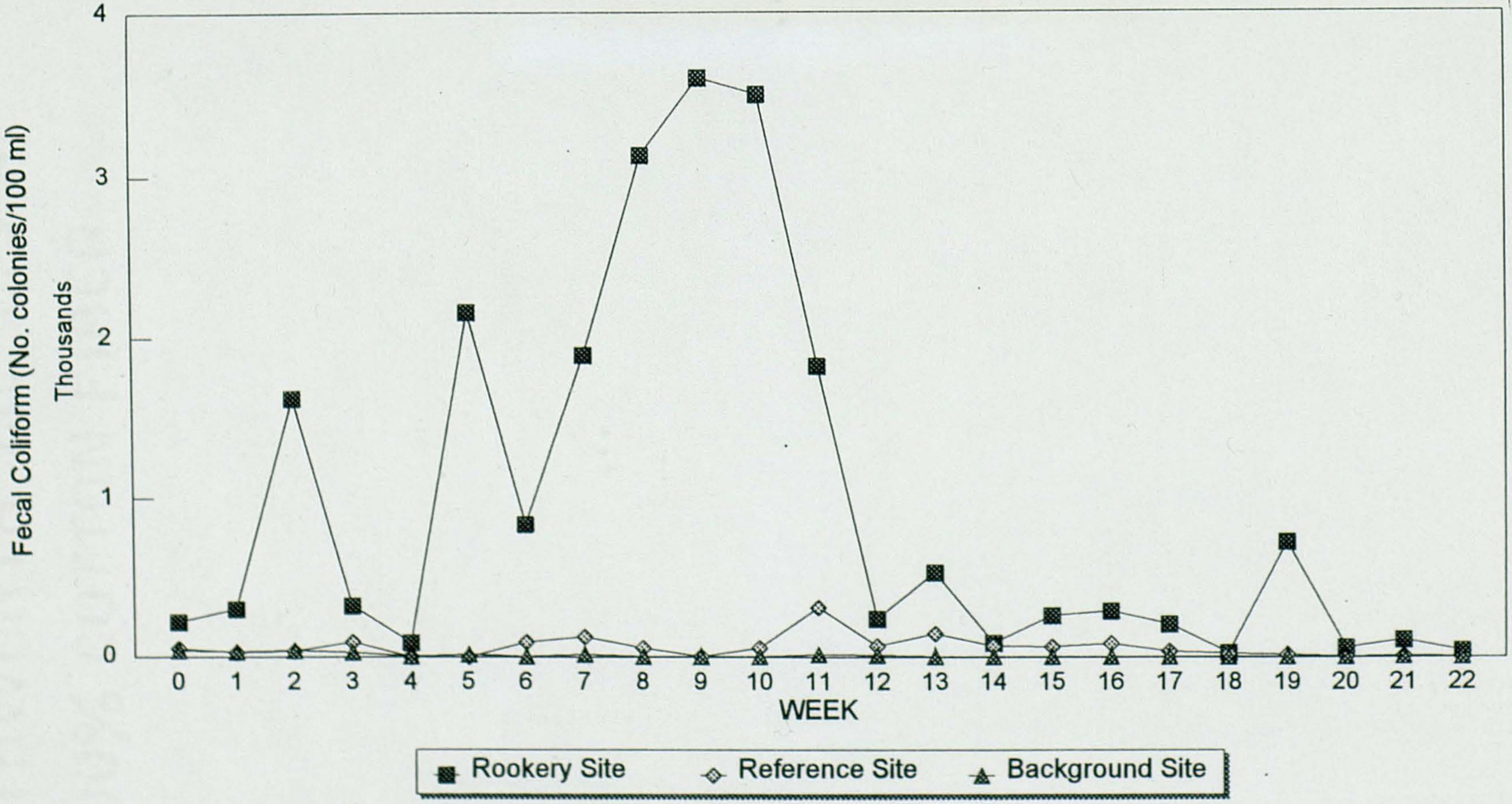

Figure 10. Comparison of fecal coliform bacteria at IBW Willow Rookery from 19 April to 11 October 1990.

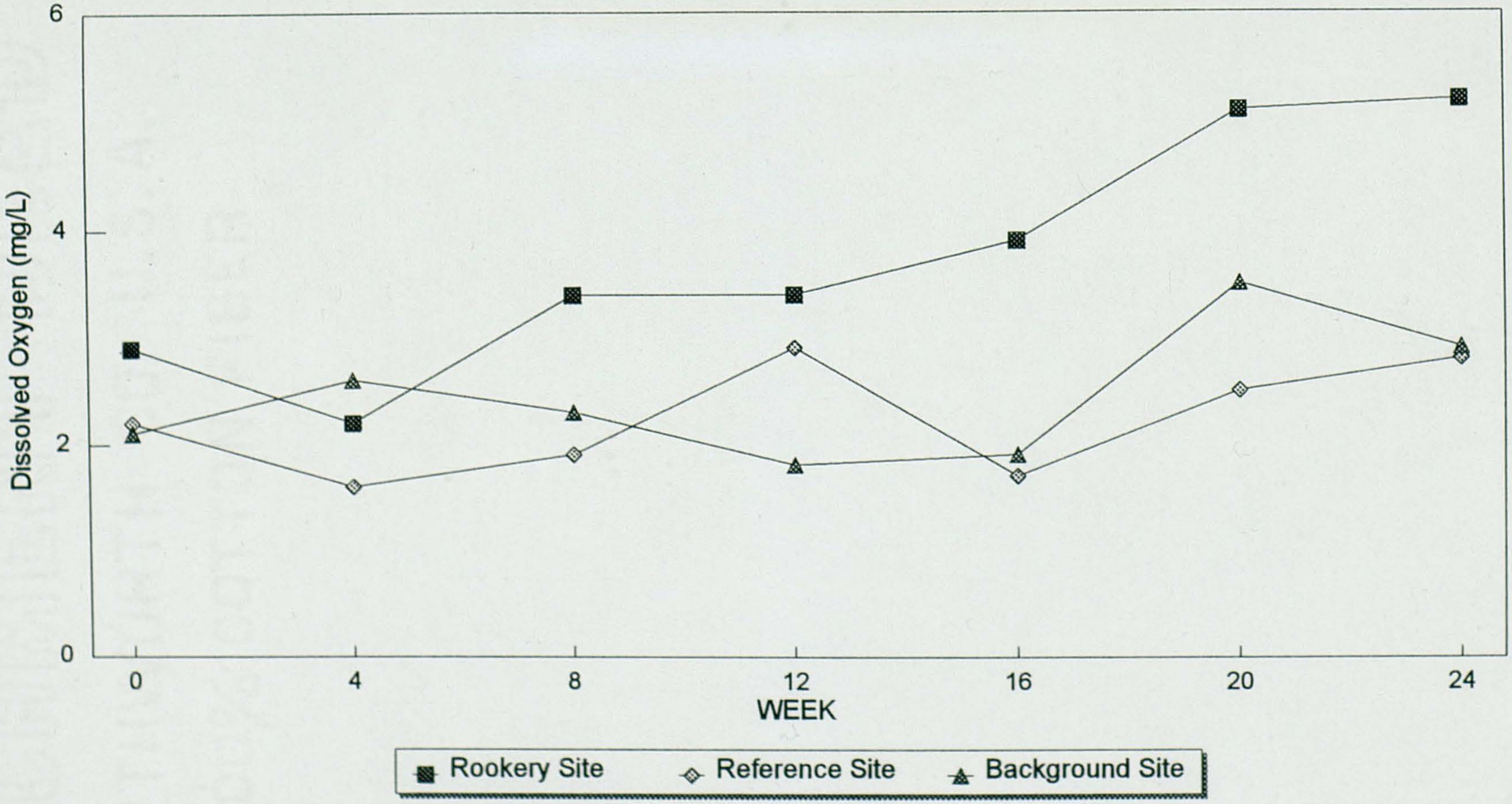

Figure 11. Comparison of dissolved oxygen levels at IBW Willow Rookery from 19 April to 25 October 1990.

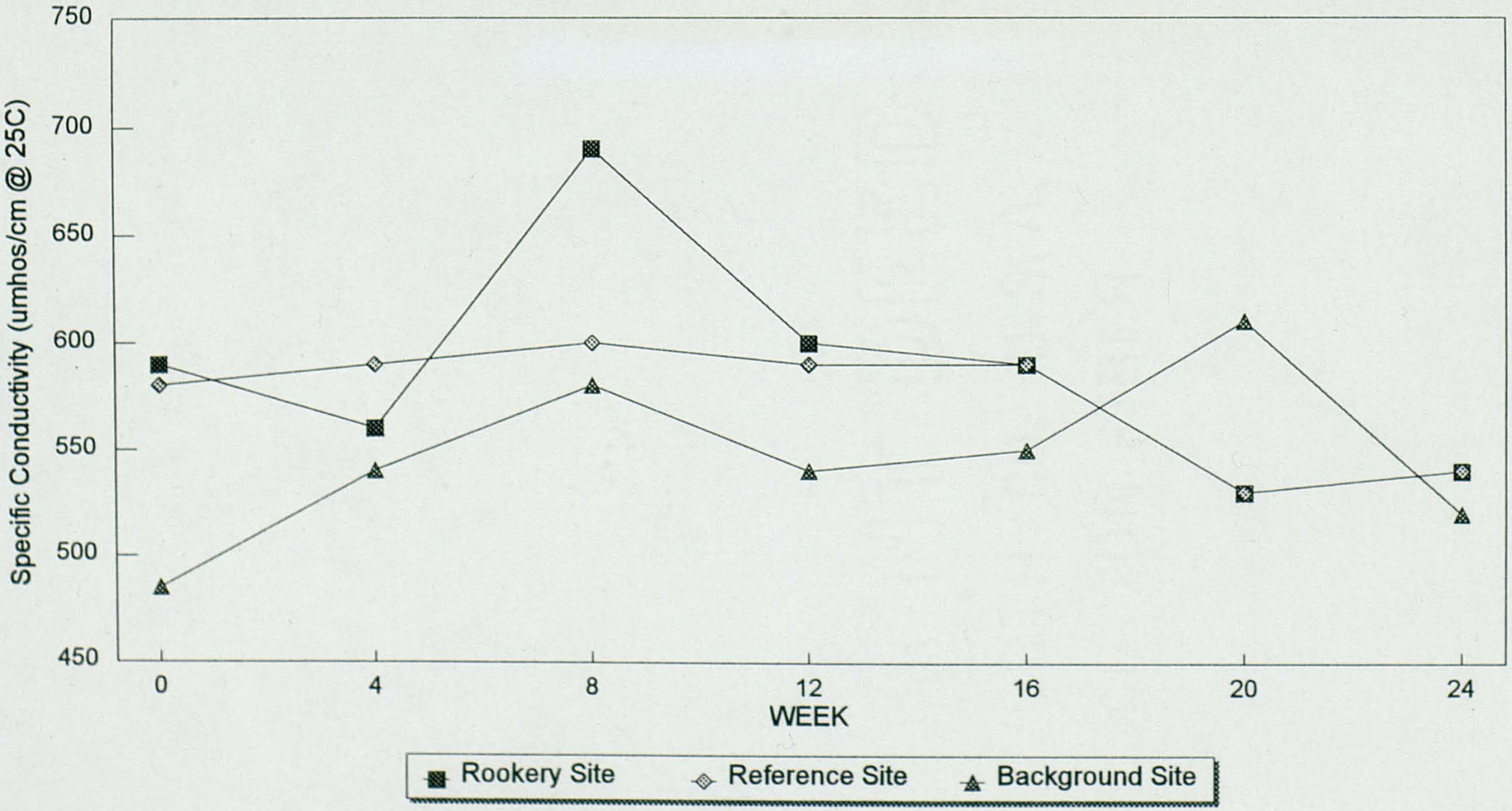

Figure 12. Comparison of specific conductivity at IBW Willow Rookery from 19 April to 25 October 1990.

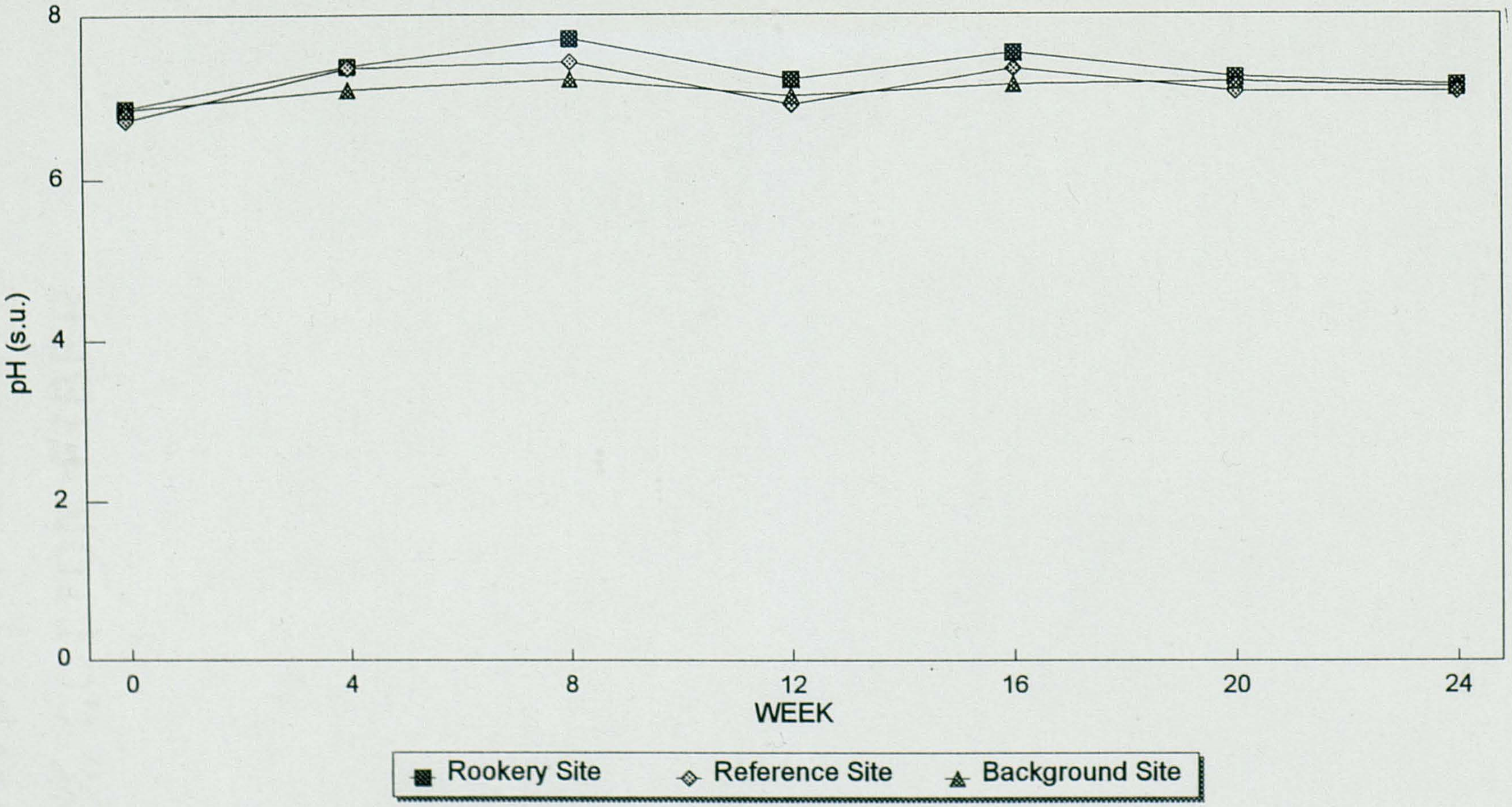

Figure 13. Comparison of pH at IBW Willow Rookery from 19 April to 25 October 1990.

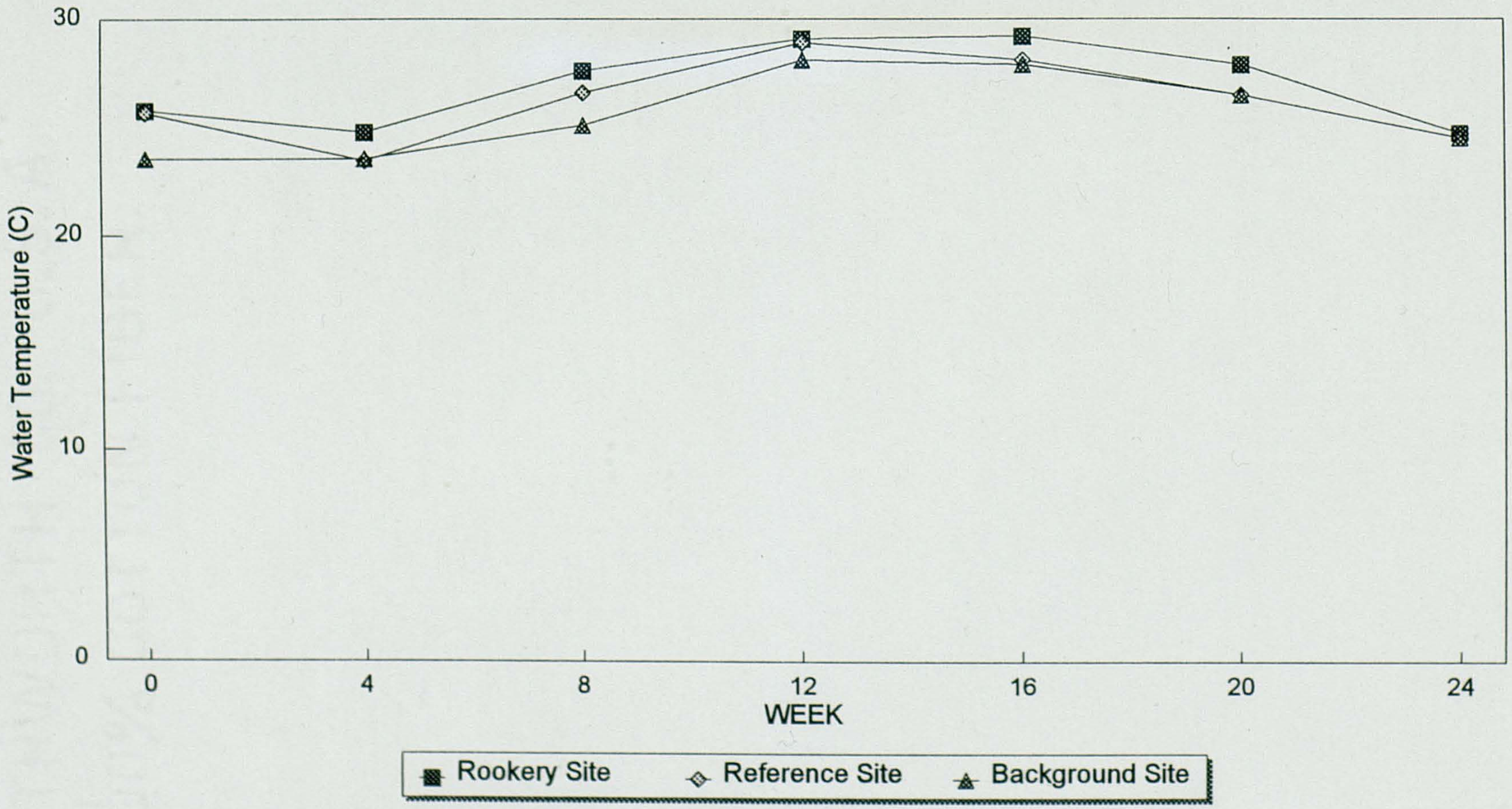

Figure 14. Comparison of water temperature at IBW Willow Rookery from 19 April to 25 October 1990.

Average total phosphorus concentrations (mg/L) of 0.3, 0.09, and 0.05 were recorded at RS, ReS, and BS, respectively. The concentrations were significantly ($p < 0.05$) different between RS and ReS and RS and BS. The results indicated that ReS concentrations differed from those at BS, but this difference was not statistically tested. Total Phosphorus concentrations at RS appeared to lag behind reported population trends of the rookery and consistently were greater than ReS and BS measurements (Figure 9). Peak TP concentrations at RS were recorded in early May (wk 2) and mid July (wks 12 and 13). TP concentrations at ReS were also greater than BS values, with the trend through time somewhat resembling that of RS. However, both RS and ReS concentrations had approached BS values by the end of the study period. Maximum concentrations (mg/L) at RS, ReS, and BS were 0.46, 0.22, and 0.10, respectively. Total rookery population through time and the adjusted total phosphorus concentration at RS were significantly ($p < 0.05$) correlated, $r^2 = 0.61$.

Average densities of fecal coliform bacteria (no. colonies/100 ml) were 989, 61, and 43 for RS, ReS, and BS, respectively. Coliform densities were significantly ($p < 0.05$) different between RS and ReS and between RS and BS. However there was not a significant ($p > 0.05$) difference between ReS and BS. The maximum bacteria density at RS (3500 colonies/100 ml) was recorded in early June (wk 9), while coliform counts at ReS and BS peaked during early July at 270 and 30, respectively. Fecal coliform bacteria density at RS was much greater than ReS and BS during much of the study period (April to October), and appeared to follow rookery population trends (Figure 10). However, both RS and ReS bacteria densities had returned to background conditions (BS values) by mid September (wk 20). Total rookery population was significantly ($p < 0.05$) correlated to fecal coliform bacteria density at RS, $r^2 = 0.64$.

Average dissolved oxygen (DO) concentrations (mg/L) of 4.5, 2.4, and 3.4 were reported at RS, ReS, and BS, respectively. There was a significant ($p < 0.05$) difference between RS and ReS and between RS and BS. The results indicated that DO levels at ReS did not differ from those at BS, but this observation was not statistically tested. DO concentrations were consistently greater at RS (exception 10 May, wk 4), and followed an escalating trend through the study period (Figure 11). DO levels at RS remained greater than values for ReS and BS at the end of the study period. Maximum DO concentrations at RS, ReS, and BS were 5.2, 2.9, and 3.5, respectively. Total rookery population was not significantly ($p > 0.05$) correlated to dissolved oxygen concentration at RS, $r^2 =$ was 0.21.

The average specific conductivity (micromhos/cm at 25 C) was 600, 590 and 550 at RS, ReS, and BS, respectively, but there was not a significant ($p > 0.05$) difference between RS and ReS nor RS and BS (Table 8). The results also indicated that there was there was not a significant difference between ReS and BS, but this comparison was not statistically tested. The specific conductivity at ReS closely tracked that of RS, with the exception of early July, wk 8 (Figure 12). Both RS and ReS exhibited greater conductivity than BS (with the exception of mid September, wk 20), but were comparable to BS values at the end of the study period. Maximum values at RS, ReS, and BS were 690, 600, and 610, respectively. Total rookery population and specific conductivity at RS was not significantly ($p > 0.05$) correlated, $r^2 = 0.34$).

TABLE 8

STATISTICAL VALUES USED IN COMPARING WATER QUALITY MEANS FOR 1990 ANOVA COMPARISONS

Parameter	RS to ReS [1]	RS to BS
Ammonia Nitrogen	0.05; 44; 1; 73.7; 4.08 [2]	0.05; 44; 1; 115.7; 4.08
Total Phosphorus	0.05; 44; 1; 81.9; 4.08	0.05; 44; 1; 160.1; 4.08
Fecal Coliform Bacteria	0.05; 44; 1; 13.6; 4.08	0.05; 44; 1; 15.1; 4.08
Dissolved Oxygen	0.05; 44; 1; 28.9; 4.08	0.05; 12; 1; 7.3; 4.75
Specific Conductivity	0.05; 44; 1; 0.03; 4.08	0.05; 12; 1; 2.42; 4.75
pH	0.05; 44; 1; 9.62; 4.08	0.05; 12; 1; 67.7; 4.75
Water Temperature	0.05; 44; 1; 4.19; 4.08	0.05; 12; 1; 12.9; 4.75
Secchi Depth	0.05; 44; 1; 32.0; 4.08	No Comparison

1 Null Hypothesis: RS mean = ReS or BS mean.

2 Alpha; denominator df; numerator df; test statistic; rejection region.

Average pH values (s.u.) were 7.23, 6.94 and 7.07, at RS, ReS, and BS, respectively. The pH was significantly ($p < 0.05$) different between RS and ReS and between RS and BS. The results also indicated that ReS concentrations differed from those at BS, but this difference was not statistically tested. The pH measurements at all three sites followed similar trends, but values at RS were consistently greater (Figure 13). The pH at RS appeared to be approaching ReS values by the end of the study period. In addition, both RS and ReS values appeared to be approaching that of BS. Maximum values at RS, ReS, and BS were recorded during early June (wk 8) and measured 7.71, 7.42, and 7.21, respectively. Total rookery population and pH was not significantly ($p > 0.05$) correlated at RS during the 1990 study season, $r^2 = 0.04$.

Average surface water temperature (C) was 28.6, 27.3, and 22.4 at RS, ReS, and BS, respectively. There was a slight statistical difference ($p < 0.05$) between water temperature at RS and ReS and a significant ($p < 0.05$) difference between RS and BS. The results also indicated that ReS concentrations differed from those at BS, but this difference was not statistically tested. Surface water temperature followed similar trends at all three sites, but was consistently greater at RS (Figure 14). Values at all three sites appeared to be similar by the end of the study period. Maximum values of 29.2, 28.9, and 28.2 were recorded in week 12 at RS, ReS, and BS, respectively. Total rookery population and surface water temperature was not significantly ($p > 0.05$) correlated at RS, $r^2 = 0.29$.

Unlike the other parameters, water depth (cm) and Secchi depth (cm) were measured only at RS and ReS. The water depth at both RS and ReS fluctuated slightly through the study period, but that of RS was consistently greater (Table 9). Secchi depth measurements (cm) at RS decreased (in relation to water depth) through time and appeared to inversely track observed population trends of the colony. However, there was no observed difference between Secchi and water depths at RS by mid September (wk 20). Secchi depth measurements at ReS did not decrease in relation to water depth during the study period. There was a significant ($p < 0.05$) difference in depth differences between RS and ReS and total rookery population and the difference between water and Secchi depths was significantly correlated at RS, $r^2 = 0.42$.

Sediments

Sediments under the rookery exhibited an increase in total nitrogen from 3740 mg/kg at the onset of rookery activity (15 May 1990) to 4100 mg/kg approximately one month after rookery abandonment (23 October 1990). Total phosphorus also increased from 159 mg/kg on 5 May 1990, to post-rookery measurements of 210 mg/kg (23 October, 1990). Approximately one year later (10 July 1991) total nitrogen and total phosphorus concentrations in rookery sediments were 4550 mg/kg and 238 mg/kg, respectively (Table 10).

Palm Rookery- 1991

Rookery Census

The adult anhinga population remained fairly steady (ranging from four to six individuals) throughout the breeding season with some fluctuations corresponding to

TABLE 9

COMPARISONS OF WATER DEPTH AND SECCHI DEPTH DIFFERENCES FOR THE WILLOW ROOKERY FROM APRIL TO OCTOBER 1990

	Rookery Site			Reference Site		
WEEK	Water Depth (cm)	Secchi Depth (cm)	Difference (cm)	Water Depth (cm)	Secchi Depth (cm)	Difference (cm)
1	67	67		38	38	0
2	65	56	9	38	38	0
3	68	54	14	45	45	0
4	63	63	0	43	43	0
5	68	56	12	42	42	0
6	71	63	8	42	42	0
7	71	57	14	42	42	0
8	69	58	11	43	43	0
9	70	49	21	43	43	0
10	69	47	22	44	44	0
11	68	51	17	44	44	0
12	70	44	26	44	44	0
13	69	59	10	45	45	0
14	71	55	16	46	46	0
15	69	56	13	46	46	0
16	67	55	12	45	45	0
17	69	47	22	45	45	0
18	70	69	1	46	46	0
19	69	68	1	42	42	0
20	68	68	0	43	43	0
21	69	69	0	43	43	0
22	69	69	0	42	42	0
23	68	68	0	42	42	0
Average			10			0

TABLE 10

SEDIMENT NUTRIENT CONCENTRATIONS AT THE ROOKERY SITE OF THE WILLOW ROOKERY, 1990

DATE	Total Phosphorus (mg/Kg)	Total Nitrogen (mg/Kg)
5 May 1990	159	3640
23 October 1990	210	4100
10 July 1991	238	4550

increased activity of late season nesting (Figure 15). Maximum anhinga population was approximately 20 individuals (adults, juveniles, and nestlings) during late June (wk 8). The number of active anhinga nests peaked in early June with five nests (wk 6) and steadily declined throughout the remainder of the study period, with a slight peak appearing in early July (wk 10).

The peak population of cattle egret, including adults, juveniles, and nestlings, was approximately 340 individuals during early June (wk 6). The population then steadily decreased as nestlings abandoned nests, juveniles left the rookery, and adults deserted the nesting area (Figure 16). Cattle egret nesting was initiated in late April (prior to census initiation), peaked in early June (wk 6) with approximately 70 nests, and ended in late August (wk 16).

Excreta Nutrient Content and Loading Rates

Excreta samples were not collected during the 1991 Palm Rookery Study. Therefore, results of nutrient content analyses and loading rate estimations are not available.

Water Quality

A summary of average water quality values from May to September 1991 for the Rookery Site (RS), Reference Site (ReS), and Background Site (BS) is presented as Table 11 and a summary of correlation coefficients (r^2) between rookery population and water quality parameters at RS is presented as Table 12. Further results presentation, including the results of weekly water quality analyses for RS, ReS, and BS through the study period

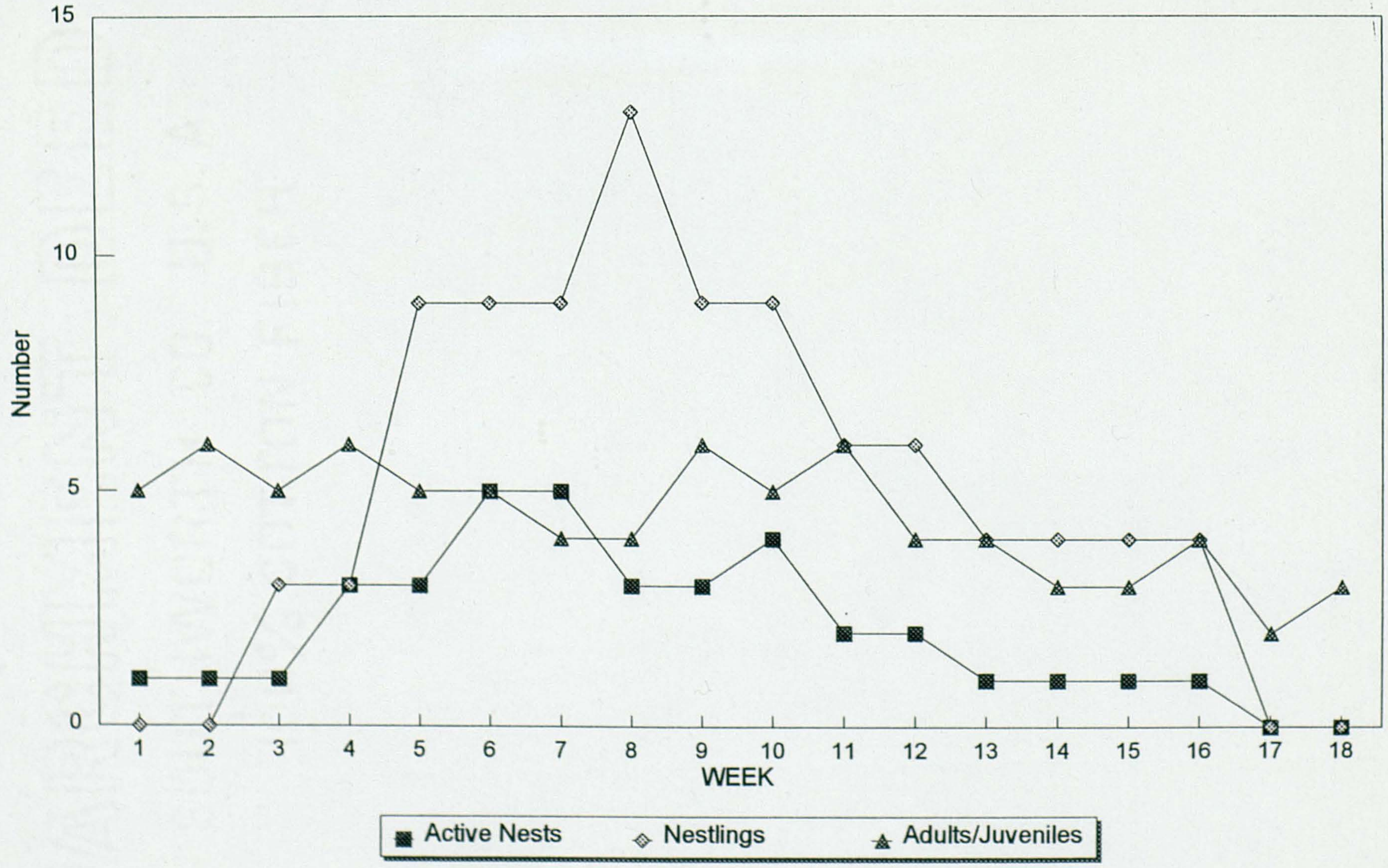

Figure 15. Anhinga population of IBW Palm Rookery from 2 May to 19 September 1991.

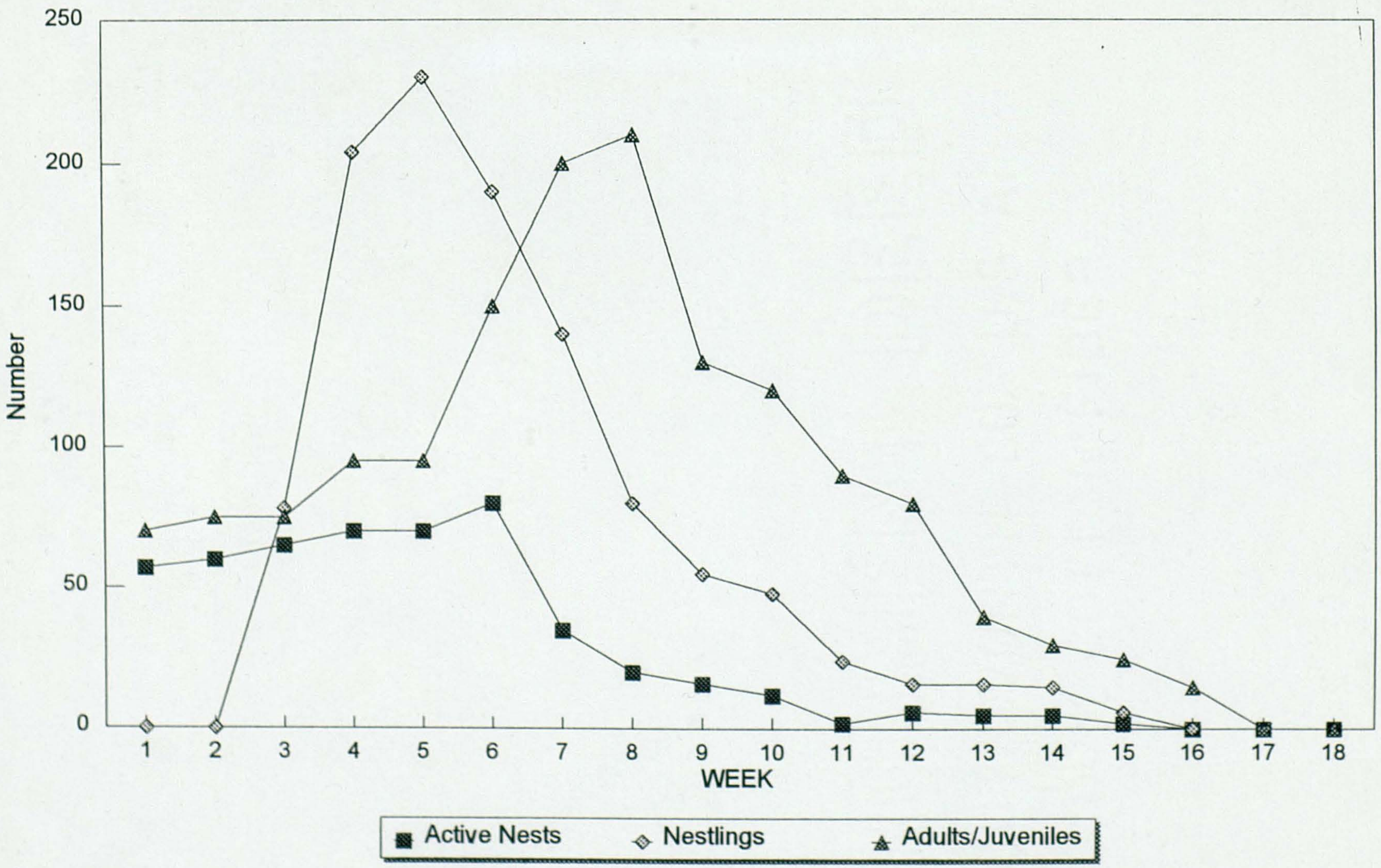

Figure 16. Cattle Egret population of IBW Palm Rookery from 2 May to 19 September 1991.

TABLE 11

COMPARISON OF AVERAGE WATER QUALITY VALUES FOR THE PALM ROOKERY FROM MAY TO SEPTEMBER 1991

Parameter	Unit	Rookery Site	Reference Site	Background Site
Ammonia Nitrogen	(mg/L)	0.14	<0.10	<0.10
Total Kjeldahl Nitrogen	(mg/L)	1.25	1.05	0.74
NOxN	(mg/L)	0.12	<0.1	<0.1
Total Phosphorus	(mg/L)	0.14	0.09	0.05
Fecal Coliform Bacteria	(No. colonies/ 100 ml)	2266	173	75
Dissolved Oxygen	(mg/L)	4.3	2.9	0.07
Specific Conductivity	(umhos/cm at 25 C)	460	460	440
pH	(s.u.)	7.39	7.01	6.81
Water Temperature	(C)	23.1	22.6	20.6
Water Depth	(cm)	41	38	31
Secchi Depth	(cm)	39	38	45
Chlorophyll-a	(mg/m3)	17.45	14.03	1.44

TABLE 12

CORRELATION COEFFICIENTS BETWEEN ROOKERY POPULATION AND WATER QUALITY PARAMETERS FOR THE PALM ROOKERY - 1991

PARAMETER	r2
Ammonia Nitrogen	0.16*
Total Kjeldahl Nitrogen	0.02*
Total Phosphorus	0.21*
Total Phosphorus [1]	0.01*
Fecal coliform	0.37*
Dissolved Oxygen	0.02*
Specific Conductivity	0.01*
Water Temperature	0.45
pH	0.37*
Secchi Depth [2]	0.14*
Chlorophhyll-a	0.01*

1 Adjusted TP values; shifted population counts back 3 weeks.
2 Secchi depth= difference between water depth and secchi measure
* value less than significance level of 0.41; $p < 0.05$

are presented following the order listed in Table 11 (Figures 17 to 24).

Average ammonia nitrogen (NH_3N) concentrations (mg/L) for RS, ReS, and BS were 0.14, <0.10, and <0.10, respectively. Ammonia nitrogen concentrations were significantly ($p < 0.05$) different between RS and ReS and between RS and BS (Table 13). Ammonia nitrogen levels fluctuated through time only at RS, ranging from 0.24 to 0.10 mg/L (Figure 17). Conversely, NH_3N levels at ReS and BS remained steady (<0.10 mg/L) for the entire study period. However, RS levels appeared to reach background conditions (<0.10 mg/L) by late August (wk 16). Maximum concentrations (mg/L) at RS, ReS, and BS were 0.28, 0.10 and 0.10, respectively. Total rookery population and NH_3N concentration were not significantly ($p > 0.05$) correlated at RS, $r^2 = 0.16$.

Average total kjeldahl nitrogen (TKN) concentrations (mg/L) for Rs, ReS, and BS were 1.25, 1.05, and 0.74, respectively, and the concentrations were significantly ($p < 0.05$) different between RS and ReS and between RS and BS. The results also indicated that ReS concentrations differed from those at BS, but this difference was not statistically tested. TKN levels at RS fluctuated through time (ranging from 1.7 to 0.82, but were consistently greater than corresponding values at ReS and BS prior to 12 September, wk 18 (Figure 18). The TKN concentration at RS appeared to reach background conditions (less than or equal to values for ReS and BS) by the end of the study period (wk 18). Maximum concentrations (mg/L) at RS, ReS, and BS were 1.68, 1.45, and 0.93, respectively. Total rookery population and TKN concentration at RS were not significantly ($p > 0.05$) correlated, $r^2 = 0.02$.

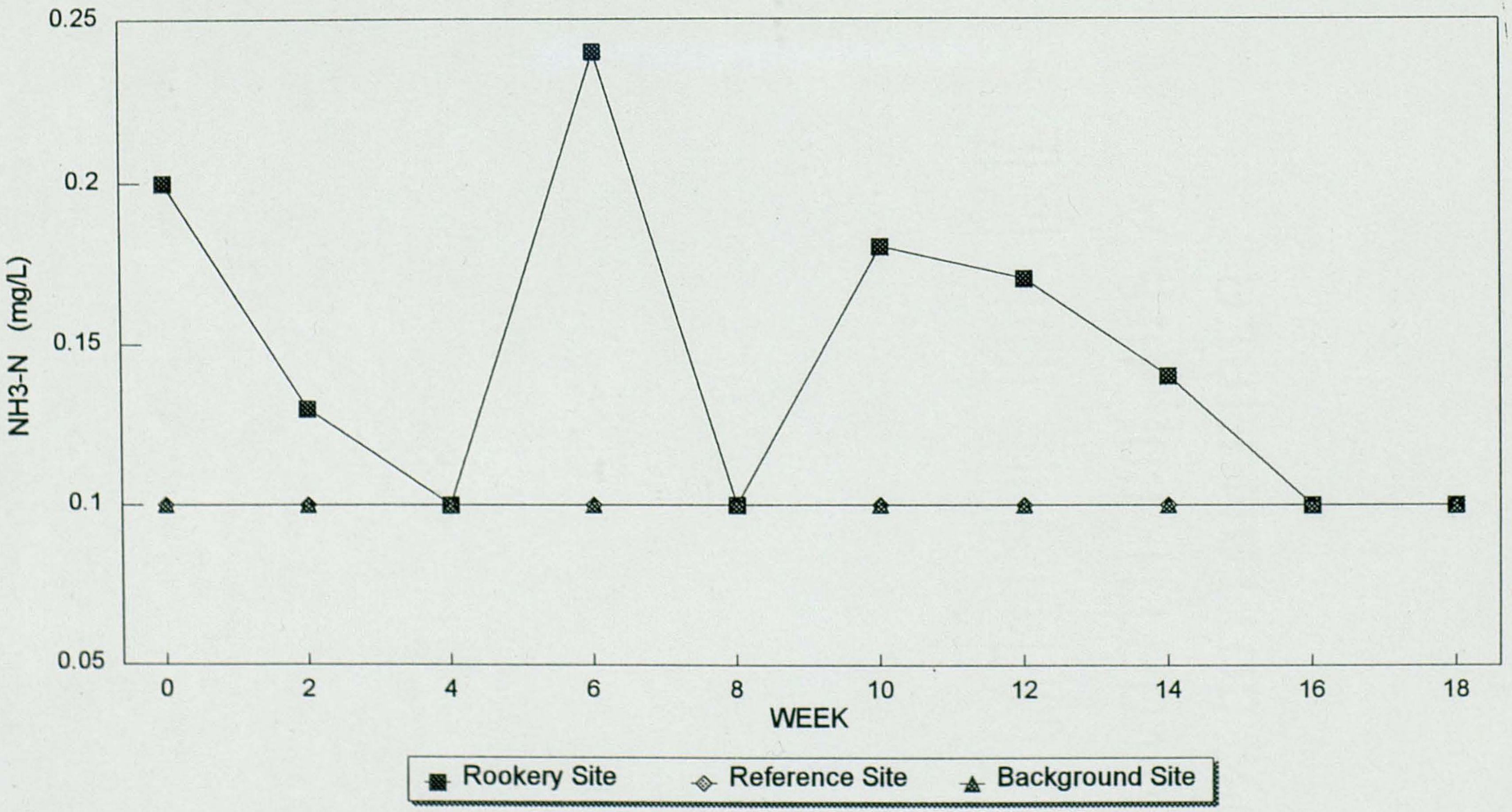

Figure 17. Comparison of NH_3N at IBW Palm Rookery from 2 May to 19 September 1991.

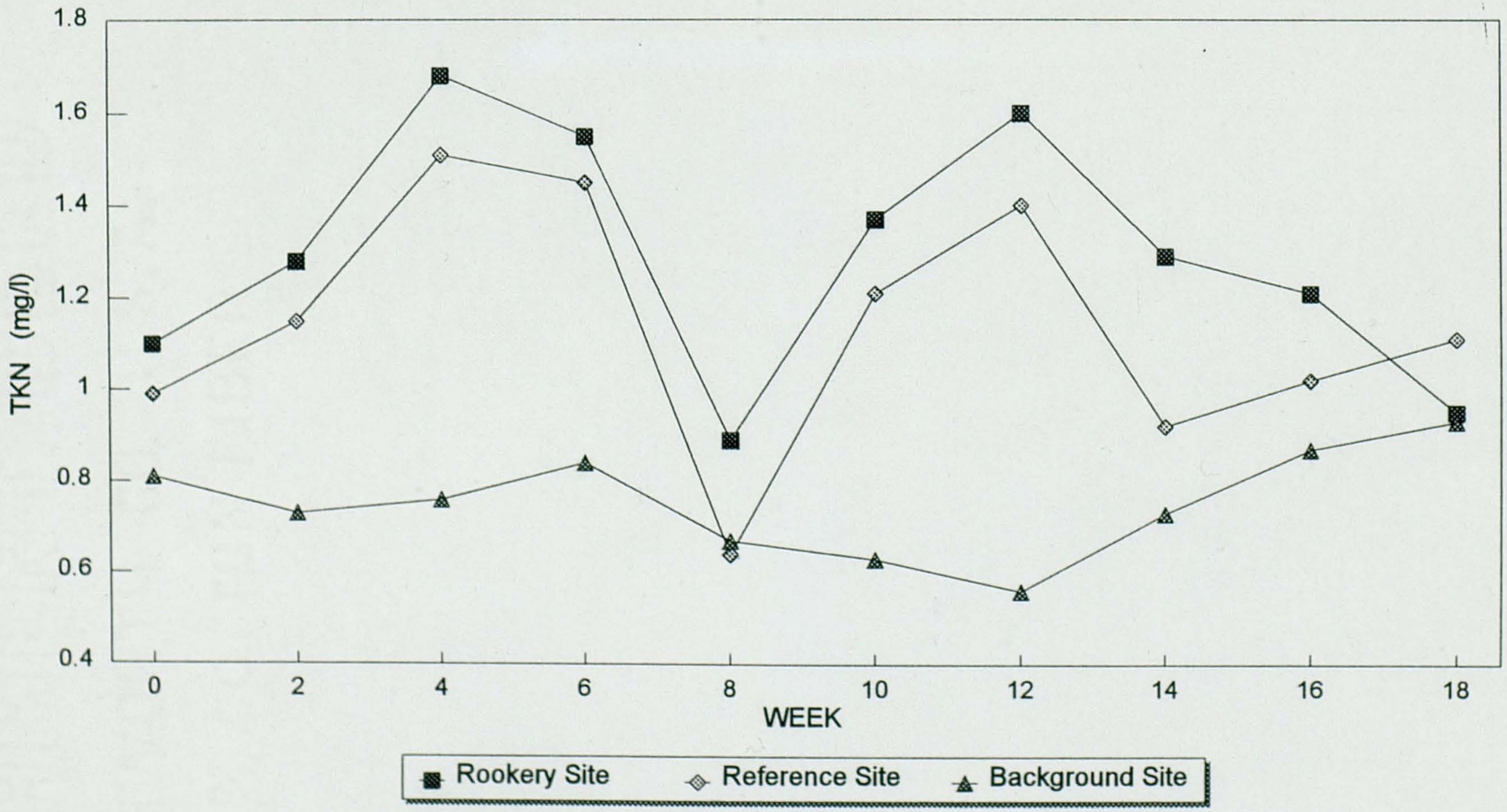

Figure 18. Comparison of TKN at IBW Palm Rookery from 2 May to 19 September 1991.

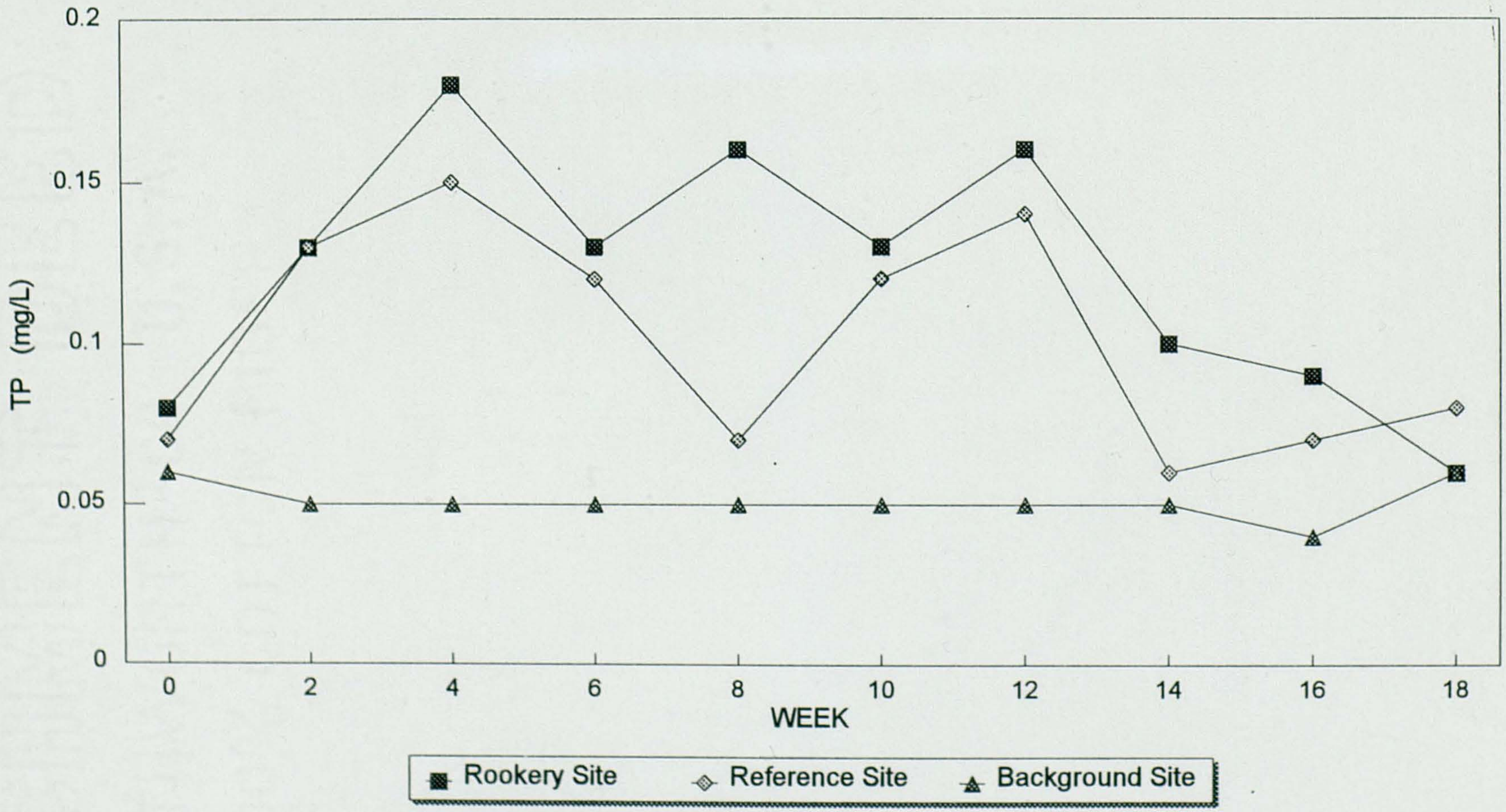

Figure 19. Comparison of TP at IBW Palm Rookery from 2 May to 19 September 1991.

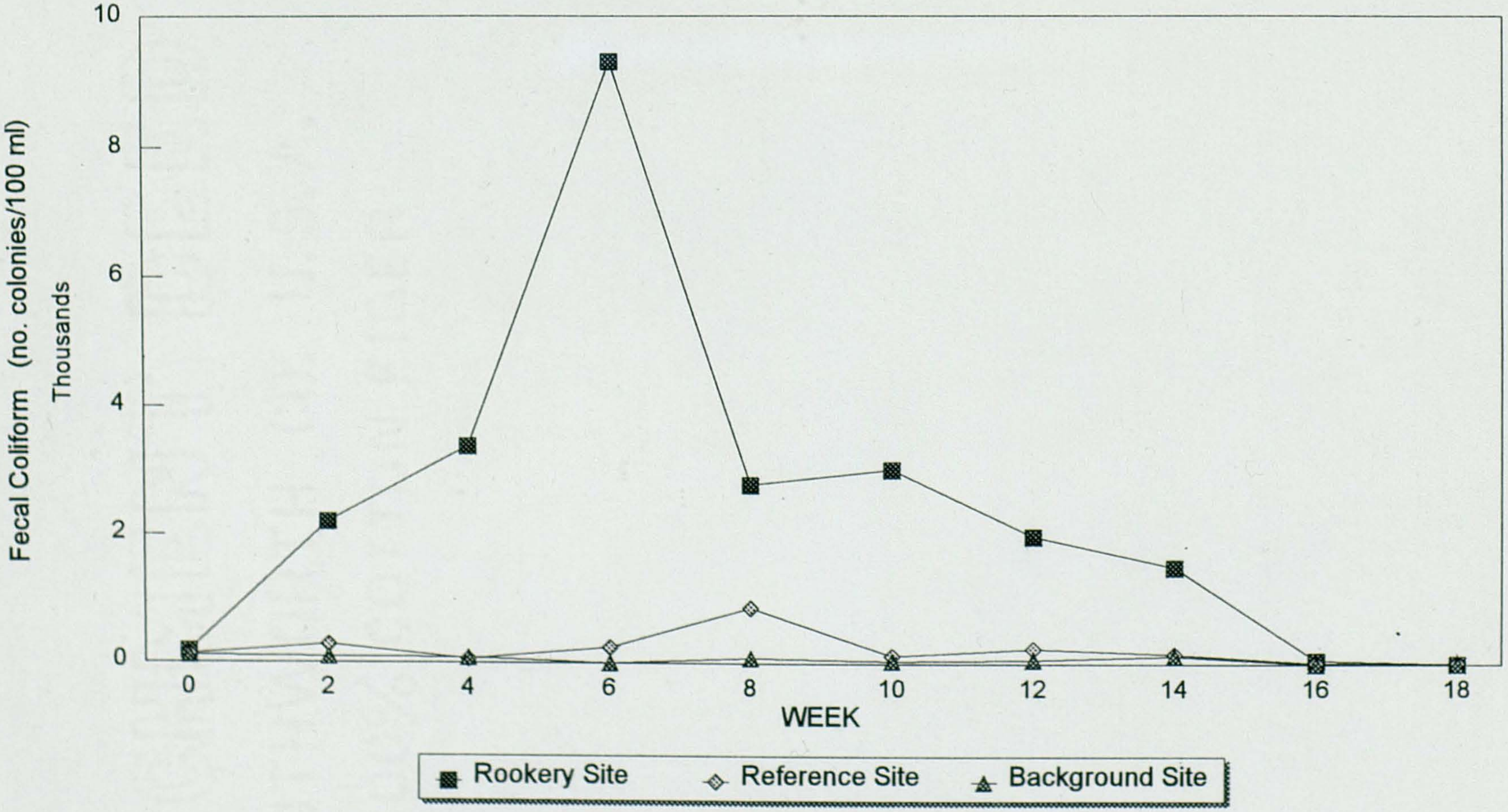

Figure 20. Comparison of fecal coliform bacteria at IBW Palm Rookery from 2 May to 19 September 1991.

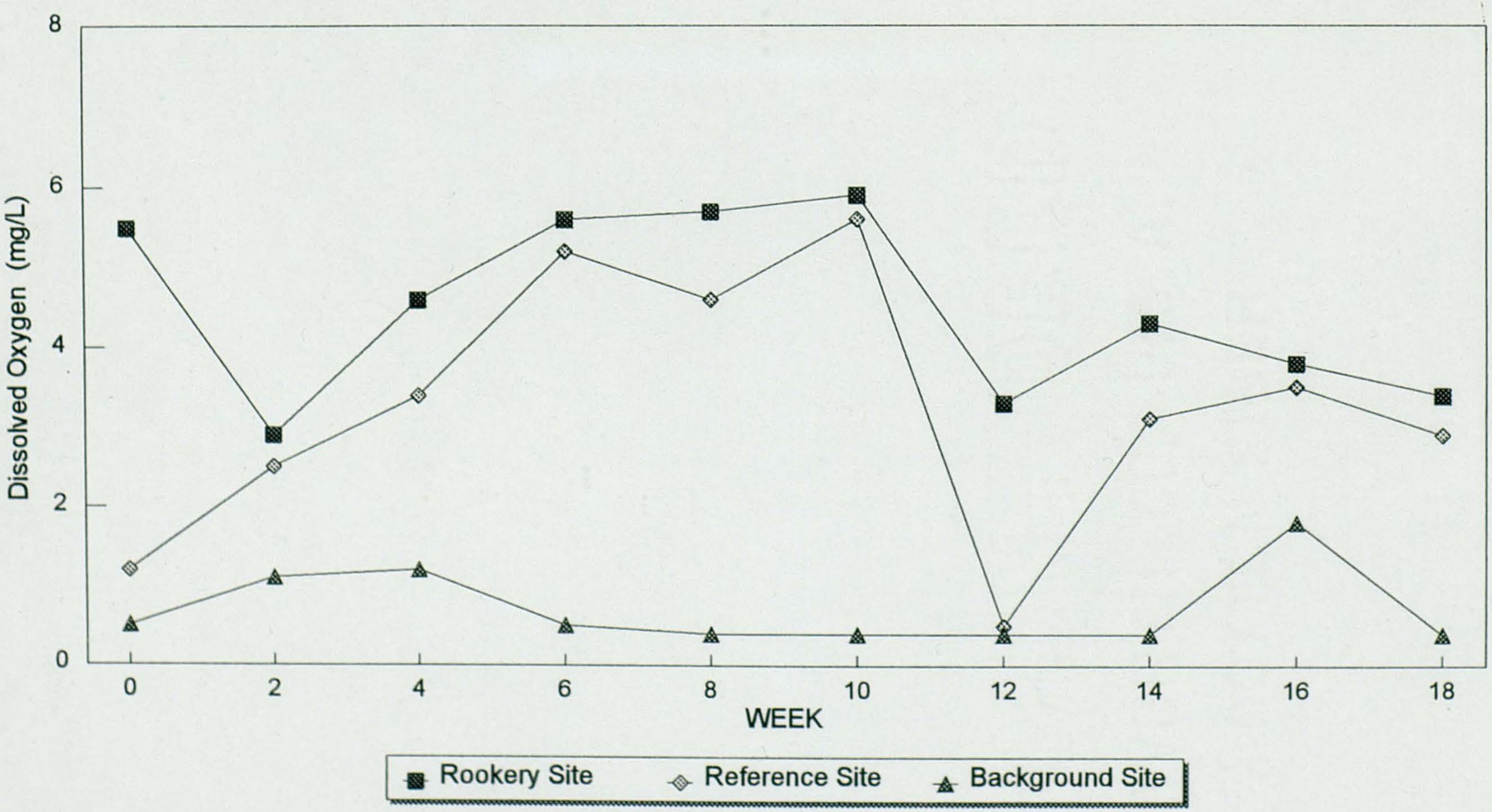

Figure 21. Comparison of dissolved oxygen at IBW Palm Rookery from 2 May to 12 September 1991.

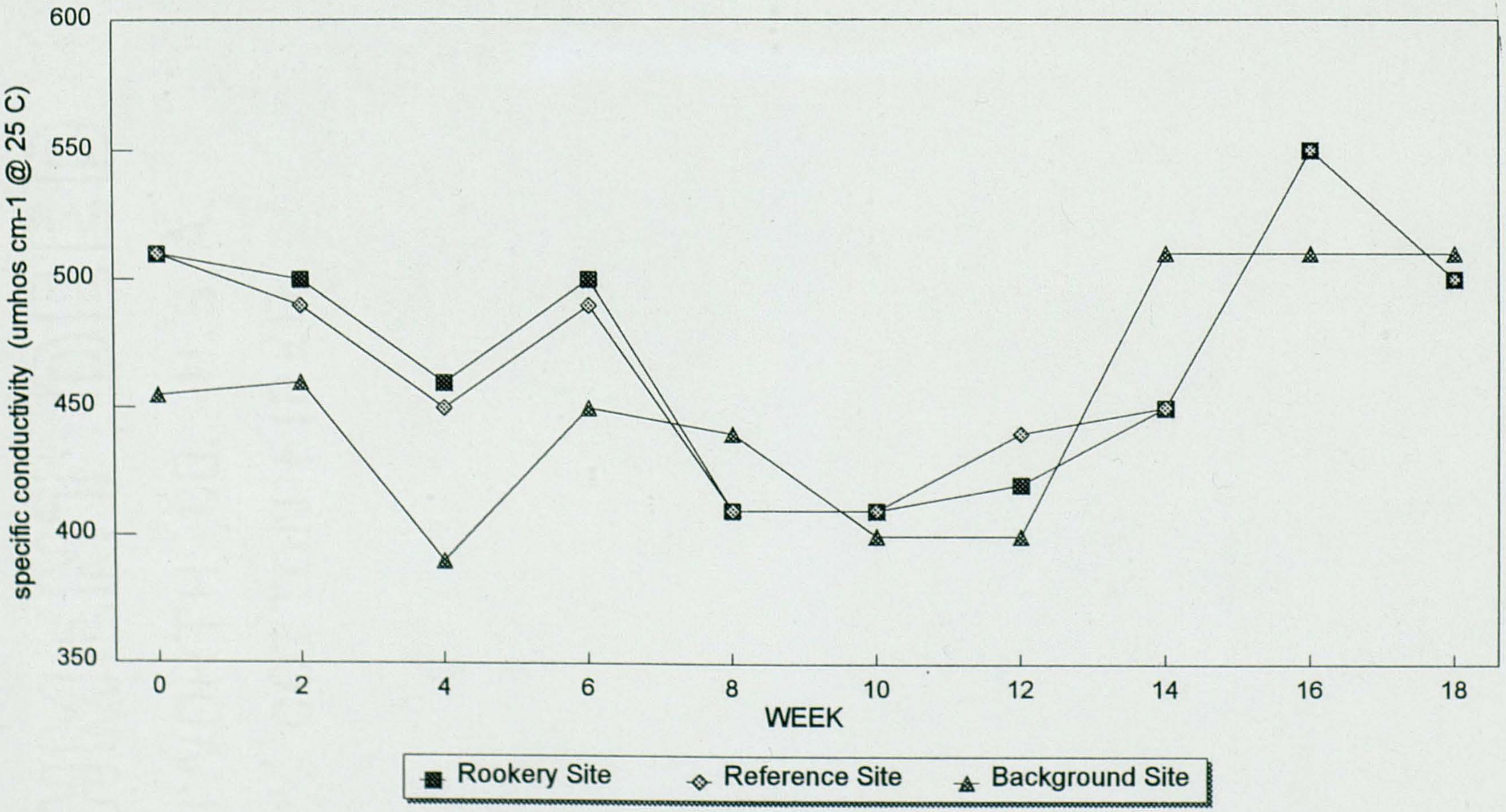

Figure 22. Comparison of specific conductivity at IBW Palm Rookery from 2 May to 12 September 1991.

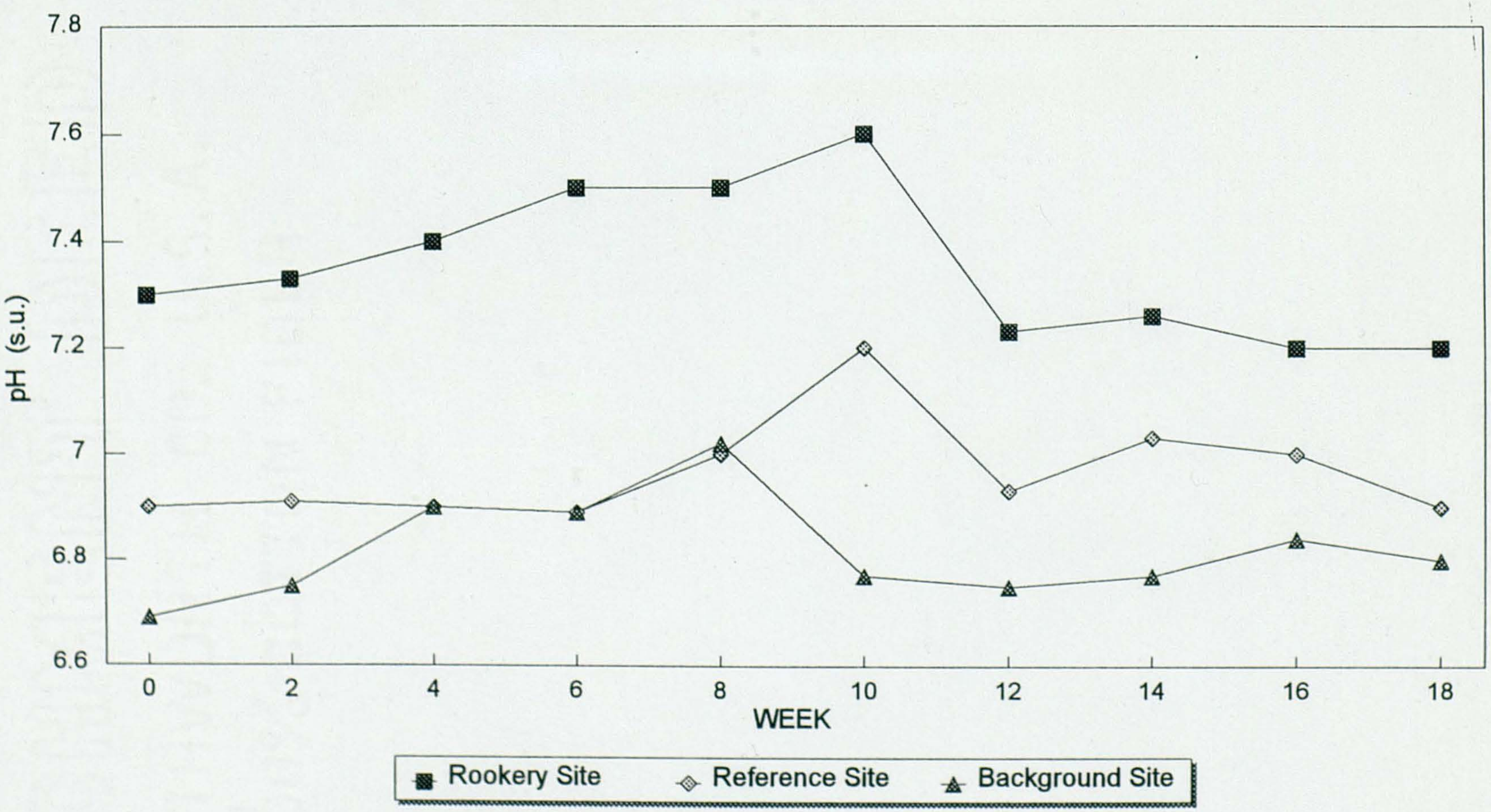

Figure 23. Comparison of pH at IBW Palm Rookery from 2 May to 12 September 1991.

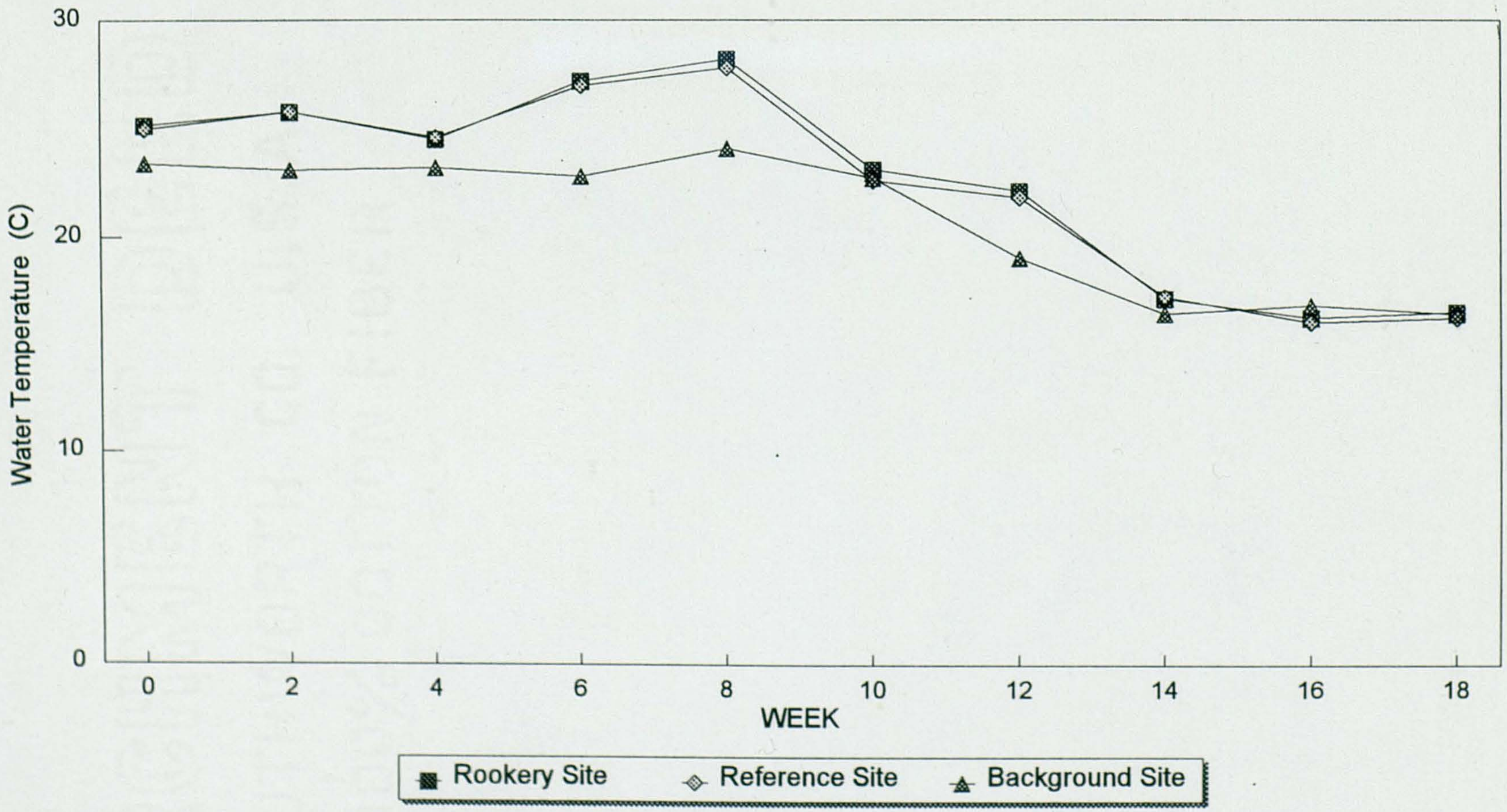

Figure 24. Comparison of water temperature at IBW Palm Rookery from 2 May to 12 September 1991.

TABLE 13

STATISTICAL VALUES USED IN COMPARING WATER QUALITY MEANS FOR 1991 ANOVA COMPARISONS

Parameter	RS to ReS [1]	RS to BS
Ammonia Nitrogen	[2] 0.05; 36; 1; 12.1; 4.08	0.05; 32; 1; 9.4; 4.17
Total Kjeldahl Nitrogen	0.05; 36; 1; 5.1; 4.08	0.05; 32; 1; 43.9; 4.17
Total Phosphorus	0.05; 36; 1; 1.6; 4.08	0.05; 32; 1; 17.5; 4.17
Fecal Coliform Bacteria	0.05; 36; 1; 17.2; 4.08	0.05; 32; 1; 14.9; 4.17
Dissolved Oxygen	0.05; 36; 1; 8.0; 4.08	0.05; 32; 1; 123.7; 4.17
Specific Conductivity	0.05; 36; 1; 0.01; 4.08	0.05; 32; 1; 2.3; 4.17
pH	0.05; 8; 1; 69.5; 5.32	0.05; 8; 1; 202.9; 5.32
Water Temperature	0.05; 36; 1; 0.1; 4.08	0.05; 32; 1; 2.4; 4.17
Secchi Depth	0.05; 36; 1; 6.0; 4.08	No Comparison
Chlorophyll-a	0.05; 36; 1; 0.7; 4.08	0.05; 32; 1; 23.5; 4.17

1 Null Hypothesis: RS mean = ReS or BS mean.
2 Alpha; denominator df; numerator df; test statistic; rejection region.

Average total phosphorus concentrations (mg/ L) of 0.14, 0.09 and 0.05, were recorded at RS, ReS, and BS, respectively, but the concentrations were not significantly ($p > 0.05$) different between RS and ReS. However, there was a significant ($p < 0.05$) difference between concentrations at RS and BS. Furthermore, the results also indicated that ReS concentrations differed from those at BS, but this difference was not statistically tested. Total phosphorus concentrations at RS did not appear to follow reported population trends of the rookery, and were consistently greater than or equal to ReS and BS values (Figure 19). Total rookery population and total phosphorus concentration at RS were not significantly ($p > 0.05$) correlated, $r^2 = 0.21$. TP concentrations at ReS were also greater than BS values, with the trend through time resembling that of RS. TP concentrations at RS and ReS appeared to reach or approach background conditions (BS value) by the end of the study period. Maximum concentrations (mg/L) at RS, ReS, and BS were 0.42, 0.34, and 0.11 , respectively.

Average densities of fecal coliform bacteria (no. colonies/100 ml) were 2266, 173, and 75 for RS, ReS, and BS, respectively. Fecal coliform bacteria densities were significantly ($p < 0.05$) different between RS and ReS and between RS and BS. The results also indicated that ReS densities differed from those at BS, but this difference was not statistically tested. Fecal coliform bacteria density at RS was much greater than at ReS and BS (ranging from 5 to 9310) during the entire study period, and appeared to follow observed rookery population trends (Figure 20). Fecal coliform bacteria density appeared to reach background conditions (ReS and BS values) by early September (wk 16). A maximum bacteria density of 9310 colonies/100 ml was recorded at RS during early June (wks 6 and 7). Maximum coliform counts at ReS and BS were 864 (wk 8) and 193 (wk 14), respectively. Total rookery population and fecal coliform bacteria density at RS was not significantly correlated, $r^2 = 0.37$.

Average dissolved oxygen (DO) concentrations (mg/L) of 4.3, 2.9, and 0.7 were reported at RS, ReS, and BS, respectively. The DO concentrations were significantly ($p < 0.05$) different between RS and ReS and between RS and BS. The results also indicated that the DO at ReS differed from that at BS, but this difference was not statistically tested. DO concentrations at RS (ranging from 2.6 to 5.9 mg/L) were consistently greater than observed values at ReS and BS throughout the study period (Figure 21). The observed DO concentration at RS appeared to increase during June and July (wks 6 to 10) and then steadily decrease through the end of the study period. DO values at ReS followed a similar trend, with increased values (5.1 -5.7 mg/L) during June and July (wks 6 to 10). DO concentrations at RS and ReS appeared to be approaching background conditions by the end of the study period. Maximum DO concentrations at RS and ReS recorded during early July (wk 10) were 5.9 and 5.6, respectively. The maximum DO at BS was 1.9 (mg/L), recorded during late August (wk 16). Total rookery population and dissolved oxygen concentration at RS was not significantly correlated, $r^2 = 0.02$.

The average specific conductivity (micromhos/cm at 25 C) was 460, 460 and 440 at RS, ReS, and BS, respectively, but there was not a significant ($p > 0.05$) difference between RS and ReS and between RS and BS. The results also indicated that specific conductivity at ReS differed from that at BS, but this difference was not statistically tested. The specific conductivity at RS closely tracked that of ReS throughout the study period and both RS and ReS exhibited trends and values similar to background conditions at BS (Figure 22). The overall trend for all three sites appeared to be a decrease in observed values from May (wk 1) to a low in early July (wk 10), followed by a steady increase through the end of the study (wk 18). Maximum values at RS, ReS, and BS recorded during late August (wk 16) were 550, 550, and 510, respectively. Total rookery population and specific conductivity at RS was not significantly correlated, $r^2 = 0.01$.

Average pH values (s.u.) were 7.39, 7.01 and 6.81, at RS, ReS, and BS, respectively. The pH at RS was significantly ($p < 0.05$) higher than that at ReS and BS. The results also indicated that there was not a difference in pH between ReS and BS, but this observation was not statistically tested. The pH measurements at all three sites remained steady throughout the study, but values at RS were consistently greater (Figure 23). However, a slight peak (0.12 and 0.16 s.u. increase) did occur during early July (wk 10) at Rs and ReS, respectively. The pH at RS and ReS appeared to approach background conditions (BS value) by the end of the study period (wk 18). Maximum pH values (s.u.) at RS and ReS were recorded during late June and early July (wks 9 and 10), measuring 7.60, 7.20, and 7.02, respectively. Total rookery population and pH at RS was not significantly correlated, $r^2 = 0.37$.

The average water temperature (C) was 23.1, 22.6, and 20.6 at RS, ReS, and BS, respectively. There was not a significant ($p > 0.05$) difference in water temperature between RS and ReS and between RS and BS. Surface water temperature followed a similar trend at all three sites, but RS and ReS were more closely correlated (Figure 24). However, water temperature at RS and ReS appeared to have reached background conditions (BS value) by the end of the study. Maximum values of 28.2, 27.8, and 23.4 were recorded during mid June (wk 8) at RS, ReS, and BS, respectively. Total rookery population and surface water temperature at RS was significantly correlated, $r^2 = 0.45$.

Unlike the other parameters, water depth (cm) and Secchi depth (cm) were measured only at RS and ReS (Table 14). The water depth at both RS and ReS fluctuated slightly through the study period, but that of RS was consistently greater. Secchi depth measurements (cm) at RS decreased in relation to water depth from mid June to mid July (wks 7 to 11) and appeared to inversely track observed population trends of the colony. However, by late July (wk 12) there was no observed difference between water and Secchi depth. Secchi depth measurements at ReS did not decrease in relation to water depth during the study period. In addition, the average difference between water and Secchi depth at each site was significantly ($p < 0.05$) greater at RS, but total rookery population and the difference between water and Secchi depths at RS was not significantly correlated, $r^2 = 0.14$.

Sediments

Sediments under the rookery exhibited a decrease in nitrogen from 4880 mg/kg on 30 May 1991 (at the onset of rookery activity) to 1130 mg/kg on 9 September 1991, approximately one month after rookery abandonment (Table 15). Similarly, phosphorus decreased from 206 mg/kg on 30 May 1991 to a post-rookery measurement on 9 September 1991 of 75 mg/kg.

TABLE 14

COMPARISON OF WATER DEPTH AND SECCHI DEPTH DIFFERENCES FOR THE PALM ROOKERY FROM MAY TO SEPTEMBER 1991

	Rookery Site			Reference Site		
WEEK	Water Depth (cm)	Secchi Depth (cm)	Difference (cm)	Water Depth (cm)	Secchi Depth (cm)	Difference (cm)
1	41	41	0	44	44	0
2	39	39	0	36	36	0
3	46	46	0	43	43	0
4	46	46	0	43	43	0
5	39	39	0	36	36	0
6	36	36	0	33	33	0
7	42	39	3	39	39	0
8	43	40	3	43	43	0
9	45	40	5	43	43	0
10	47	43	4	46	46	0
11	47	44	3	42	42	0
12	39	39	0	36	36	0
13	36	36	0	33	33	0
14	43	43	0	38	38	0
15	37	37	0	34	34	0
16	39	39	0	33	33	0
17	39	39	0	33	33	0
18	40	40	0	35	35	0
19	41	41	0	36	36	0
Average			1			0

TABLE 15

SEDIMENT NUTRIENT CONCENTRATIONS AT THE ROOKERY SITE
FOR THE PALM ROOKERY - 1991

DATE	Total Phosphorus (mg/kg)	Total Nitrogen (mg/kg)
30 May 1991	206	4880
10 July 1991	117	2740
9 September 1991	75	1130

Phytoplankton Productivity

The average chlorophyll$_a$ content (mg/m^3) was 17.45, 14.03, and 1.44 at RS, ReS, and BS, respectively. There was not a significant ($p > 0.05$) difference in chlorophyll$_a$ content between RS and ReS, but a significant ($p < 0.05$) difference existed between RS and BS (Table 13). The results also indicated a difference between ReS and BS content, but this was not statistically tested. Chlorophyll$_a$ content followed a similar, fluctuating trend at RS and ReS, but was typically greater at RS (Figure 25). Peak high concentrations of 37.83 and 40.35 at RS and ReS, respectively, were recorded during mid June (wk 8) and values of 42.21 and 40.35 were recorded in mid July (wk 12), respectively. A peak low concentration of 0.10 mg/m^3 was recorded at both RS and ReS during early July (wk 10). Maximum values of 42.21, 40.35, and 4.12 were recorded in week 12 at RS, ReS, and BS, respectively. Total rookery population and chlorophyll$_a$ content at RS was not significantly correlated, $r^2 = 0.01$.

Aquatic Macroinvertebrate Community Structure

Aquatic organisms collected on the artificial substrate samplers at stations located at the Rookery (RS) and Reference (ReS) Sites during June and September 1991 are in Tables 16 and 17, respectively. Fifteen species of organisms were identified at the rookery and thirteen species at the Reference Site on 13 June 1991. Species of the family *Chironomidae* were dominant at both sites. Twelve species were identified at the rookery and eight at the Reference Site on 5 September 1991. In addition, eight species were identified at a background marsh site in the extreme western portion of Cell 14. Again, chironomid species were dominant at all three sites.

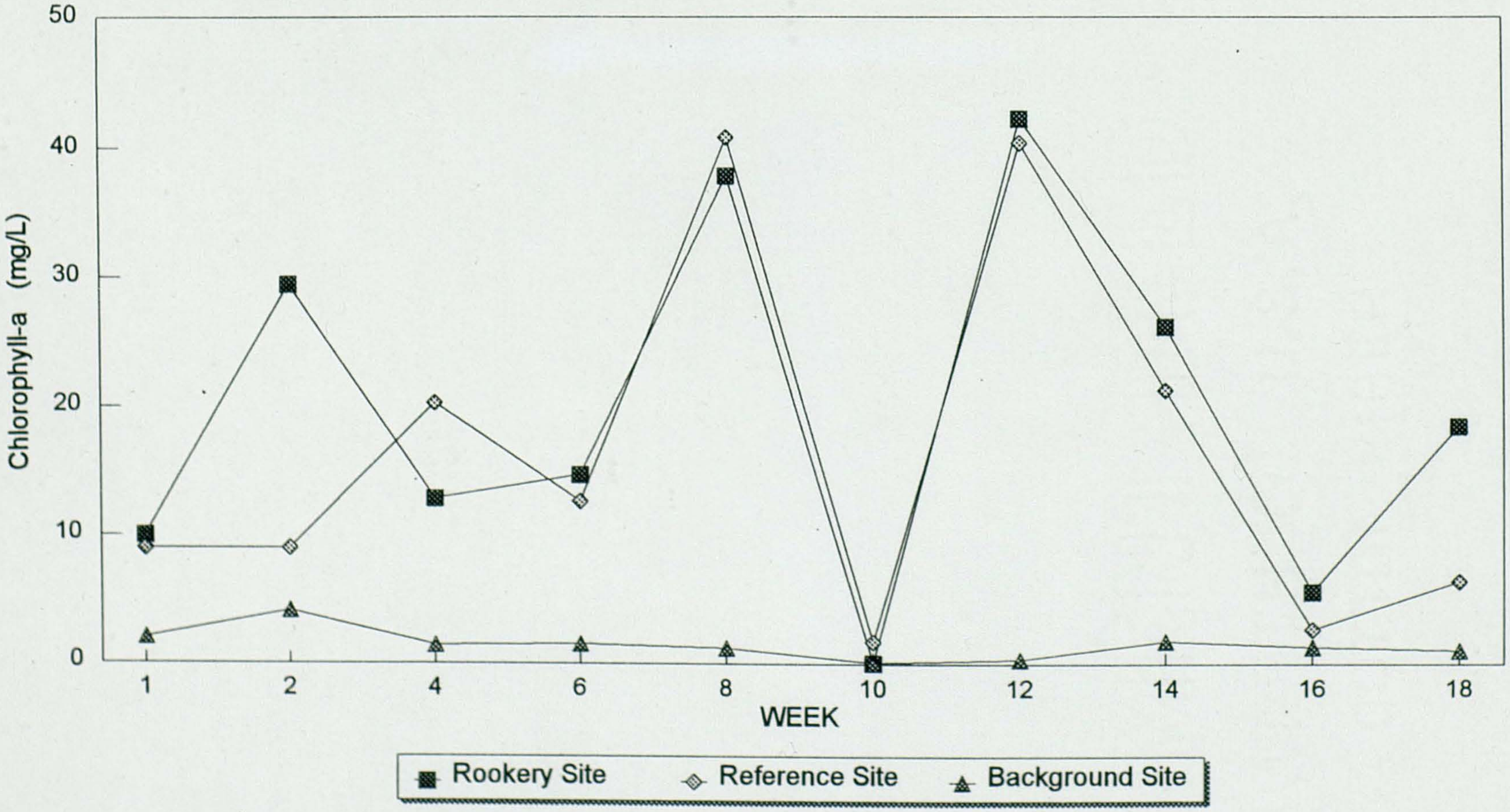

Figure 25. Comparison of chlorophyll$_a$ content at IBW Palm Rookery from 2 May to 12 September 1991.

TABLE 16

AQUATIC MACROINVERTEBRATE SPECIES COLLECTED DURING THE PALM ROOKERY STUDY, 13 JUNE 1991

ROOKERY SITE (15 species)	CONTROL SITE (14 species)
Nematoda (unidentified sp.)	Nematoda (unidentified sp.)
Annelida	Annelida
Oligochaeta	Hirudinea (unidentified sp.)
Naididae	
Dero nivea	Mollusca
	Gastopoda
Hirudinea (unidentified sp.)	Ancylidae
	Hebetancylus excentricus
Mollusca	
Gastopoda	Pilidae
Ancylidae	Pomacea paludosa
Ferrissia hendersoni	
Hebetancylus excentricus	Planorbidae
	Planorbella duryi
Pilidae	
Pomacea paludosa	Arthropoda
	Crustacea
Planorbidae	Amphipoda
Planorbella scalaris	Hyalellidae
	Hyalella azteca
Arthropoda	
Crustacea	Insecta
Amphipoda	Ephemeroptera
Hyalellidae	Caenidae
Hyalella azteca	Caenis diminuta
Insecta	Diptera
Ephemeroptera	Ceratopogonidae
Caenidae	Bezzia sp.
Caenis diminuta	Chironomidae
	Chirinomini
Tricoptera	Asheum beckae
Hydroptilidae	Dicrotendipes simpsoni
Orthothichia sp.	Glyptotendipes testaceous
	Geoldichironomus carus
Diptera	Parachironomus sp.
Chironomidae	
Chirinomini	
Asheum beckae	
Dicrotendipes simpsoni	
Glyptotendipes testaceous	
Geoldichironomus carus	
Parachironomus sp.	

TABLE 17

AQUATIC MACROINVERTEBRATE SPECIES COLLECTED DURING THE PALM ROOKERY STUDY, 5 SEPTEMBER 1991

ROOKERY SITE (12 species)	REFERENCE SITE (8 species)	BACKGROUND SITE (8 species)
Platyhelminthes	Platyhelminthes	Annelida
Turbellaria	Turbellaria	Hirudinea (unidentified sp.)
Dugesia tigrina	Dugesia tigrina	
		Mollusca
Nematoda (unidentified sp.)	Annelida	Gastropoda
	Hirudinea (unidentified sp.)	Planoribidae
Annelida		Planorbella duryi
Oligochaeta	Arthropoda	
Naididae	Crustacea	Arthropoda
Dero nivea	Amphipoda	Crustacea
	Hyalellidae	Amphipoda
Hirudinea (unidentified sp.)	Hyalella azteca	Hyalellidae
		Hyalella azteca
Arthropoda	Insecta	
Crustacea	Ephemeroptera	Insecta
Amphipoda	Caenidae	Ephemeroptera
Hyalellidae	Caenis diminuta	Caenidae
Hyalella azteca		Caenis diminuta
	Diptera	
Insecta	Chironomidae	Diptera
Ephemeroptera	Chirinomini	Chironomidae
Caenidae	Asheum beckae	Chirinomini
Caenis diminuta	Glyptotendipes testaceous	Asheum beckae
		Dicrotendipes simpsoni
Tricoptera	Odonata	Glyptotendipes testaceous
Polycentropodidae	Zygoptera	Goeldichironomus carus
Cyrnellus fraternus	Coenagrionidae	
	Ischnura ramburi	
Diptera	unidentified sp.	
Chironomidae		
Chirinomini		
Asheum beckae		
Glyptotendipes testaceous		
Geoldichironomus carus		
Odonata		
Zygoptera		
Coenagrionidae		
Ischnura ramburi		
Unidentified sp.		

A summary of aquatic macroinvertebrate community structure during June and September 1991 is presented as Table 18. The average species richness (12), average total number of organisms (374), and average diversity index (2.16) under the rookery are all greater than those recorded for the Reference Site (9, 178, and 1.93, respectively). Sample evenness was approximately equal at both sites. Similarly, the measured community parameters were also greater under the rookery during September 1991. In addition, the measured parameters were greater, with the exception of average total organisms under the rookery (451), at both sites during June.

TABLE 18

AQUATIC MACROINVERTEBRATE COMMUNITY STRUCTURE DURING THE PALM ROOKERY STUDY ON 13 JUNE AND 5 SEPTEMBER 1991

	13 June 1991							
	Rookery Site				Reference Site			
Parameter	RS-1	RS-2	RS-3	**Average**	ReS-1	ReS-2	ReS-3	**Average**
Total Organisms	262	434	425	**374**	202	151	180	**178**
No. of Organisms	12	11	13	**12**	7	8	12	**9**
Diversity	2.39	1.79	2.31	**2.16**	1.99	1.95	1.84	**1.93**
Eveness	0.67	0.52	0.62	**0.60**	0.66	0.65	0.51	**0.61**

	5 September 1991							
	Rookery Site				Reference Sites			
Parameter	RS-1	RS-2	RS-3	**Average**	ReS-1	ReS-2	ReS-3	**Average**
Total Organisms	NS	467	435	**451**	128	72	99	**100**
No. of Organisms	NS	11	10	**11**	7	7	7	**7**
Diversity	NS	2.05	2.08	**2.07**	1.64	1.55	1.58	**1.59**
Eveness	NS	0.57	0.59	**0.58**	0.55	0.55	0.54	**0.55**

DISCUSSION

To minimize redundant deliberations of the 1990 and 1991 studies, the discussion section will not follow the same format as the preceding sections. Rather, both study years will be discussed simultaneously in the same subsections.

Life History

Rookery Phenology

The 1990 and 1991 breeding colonies at IBW exhibited life history patterns for cattle egret and anhinga compatible with those described by others (Perrins 1987; Cassidy 1990; and Kale and Maehr 1990). Anhinga occupation of both rookeries was initiated in late March and early April, preceding that of cattle egret by two to three weeks (Figures 6 and 15). The number of anhinga nests peaked in early May and again in mid June during both study seasons, although the 1990 Willow Rookery supported a greater number of nests (and consequently a greater number of individuals). It was unclear whether the peak in mid June was a result of late season nesting pairs or pairs nesting for a second time. However, smaller peaks in nesting activity during late August during both seasons were attributed to repeat nesting. A quantitative analysis of breeding success was not conducted in either year, but it appeared that two to four nestling anhingas remained in the nest until space constraints forced them onto adjacent branches after approximately 2.5 weeks. The anhinga juveniles then began feeding on their own after another two weeks. The above scenario was true for both the 1990 and 1991 rookeries. Foraging activity within rookery areas was not noticed, but juveniles did appear to "practice" diving from the branches and swimming techniques. Most of the fledged young appeared to return to the 1990 Willow Rookery to roost each night. However, this behavior was not observed for the 1991 Palm Rookery, most probably due to greatly reduced suitable roosting areas. Rookery abandonment by adults and fledglings occurred during late August or early September at both study rookeries.

Cattle egret phenology of the Willow and Palm Rookeries was markedly different and warrants separate descriptions for 1990 and 1991 seasons (Figures 7 and 16). Cattle egret nesting was initiated at the Willow Rookery (1990) in mid April. The primary activity of adults at this time appeared to be the establishment and defense of nesting sites. Both sexes were active in nest construction, but copulation was not observed at the rookery site. Both adults also appeared to be active at the nest for the duration of the breeding season. Nests were primarily constructed from green willow branches that were stripped in proximity to the nest site, resulting in a severely denuded willow head by the end of the nesting period.

On the average, four eggs per nest were present within one and one-half weeks of rookery occupation and hatching began approximately two weeks after the eggs were laid. Nestlings seemed to display strict nest fidelity for approximately two and one-half weeks. After this time, juveniles (offspring no longer confined to the nest) spent the majority of their time on adjacent branches. The juveniles were highly mobile, but were kept within the immediate vicinity of their nest by vigorous attacks from neighboring adults. Juveniles seemed to remain dependent on the parents for approximately two weeks after moving to the branches. There was late-season nesting occurring through early August, but it was not determined if this were the result of late first-time nesting or pairs producing a second clutch. A quantitative analysis of breeding success was not conducted, but it was estimated that only two to three offspring per nest successfully fledged the Willow Rookery. Most of the fledged juveniles returned to the rookery at night, but both adults and juveniles had completely abandoned the willow head by late September, leaving behind less than five percent coverage of living willows.

As previously described, the Palm Rookery was established in a permanently inundated palm and hardwood snag stand approximately 125 m southeast of the Willow Rookery site. During the 1990 study season a small number of cattle egret (less than 25 pairs) nested at this location and it is believed that the 1991 Palm Rookery was established in response to the loss of the willow head due to stress from previous breeding colonies (nest construction) and the permanent inundation of the willows.

In the Palm Rookery, adults began arriving in mid-April, but as at the Willow Rookery, copulation was not observed and both adults seemed to participate in nest construction. The nests were placed primarily in the dead branches (boots) of sabal palms and constructed of dead and live twigs collected from nearby woodlands and forested ditch banks. Due to the low number of palms and the limited area provided by each tree, the majority of suitable nesting sites were occupied by the beginning of May. Nests were arranged completely around each palm, with trees on the perimeter of the rookery containing as many as 11 nests. A limited number of nests were located in live oak snags, but most of the branches suitable for supporting nests had already been lost.

Egg laying was initiated approximately two weeks after nest completion with typically four eggs per nest. Eggs began to hatch after approximately two and one half weeks. These observations correspond with other life history descriptions (Bull and Farrand 1977 and Kale and Maehr 1990). Hatchlings displayed strict nest fidelity for roughly two weeks, after which, the larger nestlings began to move out from the nest. Unlike willows, the sabal palms offered little space other than the actual nest sites. Therefore, juveniles that temporarily left the nest had little room to negotiate and were assaulted by neighboring adults. As a result, juvenile activity was primarily restricted to the actual nests. Juveniles fledged the nest approximately two weeks after beginning to move between the nest and proximate branches. There was a limited amount of late-season nesting occurring through early August, but it was not determined if this were the result of late first-time nesting or pairs producing a second clutch. A quantitative analysis of breeding success was not conducted, but it was estimated that only one to two offspring per nest successfully fledged the Palm Rookery. Most of the fledged juveniles did not return to the rookery at night and both adults and juveniles completely abandoned the Palm Rookery in early September 1991.

Mortality

Although a quantitative analysis of mortality was not undertaken, observations on the causes of cattle egret mortality were recorded during 1990 and 1991.

The primary cause for cattle egret mortality in the Willow Rookery during 1990 was competition for food among siblings. Supporting evidence consisted of the presence of typically one weak, malnourished nestling in most of the nests with more than two nestlings. Predation was also an observed (directly and indirectly) cause of mortality in the Willow Rookery. The most frequent example of observed predation was initiated by adults attacking stray juveniles and knocking them from the rookery. Upon striking the water, the fallen juveniles were taken by one of several American alligators (*Alligator mississippiensis*) that had become resident under the rookery at the onset of avian hatching. The alligators were absent prior to hatching and vacated the rookery site after avian abandonment. Indirect evidence of predation was the discovery of cattle egret remains along grassy berms and in wooded areas adjacent to the colony. The remains along the berms had evidence of predation by fox, while the remains in the woods were found in and alongside owl pellets and droppings.

The fundamental cause for cattle egret mortality within the Palm Rookery during 1991 was the overall poor-quality nesting habitat provided by the palms and oak snags, expressed in terms of limited nesting space. The increased mortality (decreased breeding success) observed for the Palm Rookery was attributed to sibling competition for food and space, inter-nest competition for space, juvenile accidental death, and predation. As in the Willow Rookery, sibling competition for food was evidenced by the presence of at least one malnourished nestling in most of the nests.

Unlike the Willow Rookery, extreme competition for space between juveniles from all nests resulted in elevated instances of accidental death and predation. The most common observation of accidental death was the entrapment of juveniles in the palm branches, typically resulting in suffocation or starvation. Consumption by alligators following dislodgement by attacks from adults was the most commonly observed example of predation. Indirect evidence of predation was exemplified by the presence of shed ratsnake skins in the lower palm branches and the presence of cattle egret remains along adjacent berms.

Nutrient Transport and Loading

The suggestion that avian breeding colonies represent point source inputs of nutrients (Ganning and Wulff 1969; and McColl and Burger 1976; and Stinner 1983;) was supported by results of the 1990 study. The results indicated that 5.2 $g/m^2/day$ TN and 0.4 $g/m^2/day$ TP were excreted from the Willow Rookery on 5 June 1990. A total, one day input of 12.6 kg N and 0.97 kg P was calculated for the entire 2420 m^2 rookery on that day (Table 5). An estimation of total nutrient addition from the rookery for the entire breeding season was not attempted due to differing contributions to the total rookery excreta between age classes and the low number of sampling events. Although rookery deposition during the breeding season represented a notable, localized addition of nutrients (based on the 5 June 1990 estimate), inputs were considered nominal when compared to other natural sources of nutrient deposition into the entire 485 ha wetland. For instance, total phosphorus concentration in rainfall of south Florida was estimated to be 0.03 mg/l (Davis, 1994). Using this estimate, 204.0 kg of TP would be deposited annually into the wetland by rainfall, assuming 140 cm of rainfall into the 485 ha system.

Given that the Willow Rookery was shown to be a point source input of nutrients, the two cattle egret-dominated rookeries also supported the suggestion that avian breeding colonies act as nutrient transport mechanisms between ecosystems (Bildstein et al. 1992 and Powell et al. 1991). Because cattle egret typically forage arthropod and small vertebrate prey from roadsides, pastures, and other agricultural areas (Collopy and Jelks 1989), the 1990 and 1991 Rookeries represented classic examples of nutrient transport from uplands to wetlands. The nutrient flow was believed to be unidirectional (from uplands to wetlands) because upland prey items were assumed to be the source of nutrients excreted from the birds.

Marsh Enrichment

The suggestion that avian breeding colonies affect biotic and abiotic characteristics of the wetlands in which they have become established (Onuf et al. 1977; Powell et al. 1991; and Frederick and Powell 1994) was supported by the results of the 1990 and 1991 studies, indicating that the trophic condition of the IBW marsh associated with the rookeries was altered. As will be discussed separately, evidence supporting increased nutrient enrichment included significant ($p < 0.05$) differences in water quality between rookery and reference stations, sediment nutrient concentration trends at rookery stations, significantly ($p < 0.05$) increased phytoplankton production at rookery stations, and differing aquatic macroinvertebrate community characteristics between rookery and reference stations.

Water Quality

Water quality has been used extensively as a means to classify surface waters into three general trophic categories (Hutchinson 1957; Wetzel 1975; Clark 1977; and

Vollenweider and Kerekes 1982): oligotrophic, mesotrophic, and eutrophic. Oligotrophic water bodies are typically characterized as unproductive systems demonstrating low nutrient concentrations (<0.001 mg/L P). Conversely, eutrophic water bodies are characterized as highly productive systems with high nutrient concentrations (0.04-0.1 mg/L P and >0.30 mg/L inorganic nitrogen, comprised of nitrate-N, nitrite-N, and ammonia-N) and dissolved oxygen levels greater than 1.5 mg/cm^3/month (Wetzel 1975; Clark 1977; and Vollenweider and Kerekes 1982). Varying degrees of eutrophication are also recognized, ranging from eutrophic (<0.1 mg/L P) to hyper-eutrophic (>0.1 mg/L P) conditions (Vollenweider and Kerekes, 1982). Mesotrophy is considered an intermediate condition characterized by moderate nutrient levels (0.01-0.04 mg/L P) and dissolved oxygen concentrations ranging between 1.0 and 1.5 mg/cm^3/month (Wetzel 1975).

Assuming the above criteria, most surface waters in Florida have nutrient concentrations in the high mesotrophic to eutrophic range (0.03-0.1 mg/L P and >0.30 mg/l inorganic nitrogen), mainly due to high productivity in response to seasonal influences and average annual water temperature (>13.0 C), high organic inputs, and the effects of phosphatic substrates (Hulbert 1990). The comparisons of mean water quality values between rookery stations (RS) associated with the 1990 and 1991 rookeries and marsh reference (ReS) and background stations (BS) indicated that the study area within the IBW was classified as eutrophic (Tables 6 and 11, respectively) based on the previously described criteria. Because the study area was considered to be in a eutrophic state, further discussion will be in terms of increased enrichment of a single trophic state (eutrophic) rather than shifts between trophic levels.

The 1990 and 1991 comparisons in Tables 6 and 11 also indicated statistically significant ($p < 0.05$) differences between rookery stations (RS) and both reference (ReS) and marsh background (BS) stations for all water quality parameters except specific conductivity and water temperature. In addition, the comparisons indicated that observed mean values (mg/L) of total ammonia nitrogen (NH_3N), total kjeldahl nitrogen (TKN), total phosphorus (TP), and dissolved oxygen (DO) at the rookery stations (RS) were all significantly ($p < 0.05$) greater than marsh reference (RS) values for at least one of the study years. These results provided evidence that abiotic factors within portions of the marsh associated with the rookeries were exhibiting definitive signs of increased nutrient enrichment (Wetzel 1975; Clark 1977; and Vollenweider and Kerekes 1982).

In addition to water quality values typically associated with increased nutrient enrichment, significant ($p < 0.05$) differences in fecal coliform bacteria density also indicated rookery influences on the receiving wetland. For example, mean fecal coliform bacteria counts at the 1990 and 1991 Rookery Sites (2266 and 989 colonies/100 ml, respectively) were significantly ($p < 0.05$) greater than the corresponding Reference Sites (173 and 61 colonies/100 ml, respectively). Moreover, the mean fecal bacteria density at both rookeries also greatly exceeded Florida Department of Environmental Protection Class III surface water quality standards of monthly average bacteria counts not to exceed 200 colonies/100 ml $H_2 0$. Although fecal coliform bacteria are not intestinal pathogens, they are used as indicators of pathogenic species discharged in the feces of warm-blooded animals (Clark 1977). Therefore, the most serious wetland impact of high bacterial loading was increased health hazards to both wildlife and humans (Geldrich 1976).

Additional evidence of water quality alterations by fecal inputs was significantly ($p < 0.05$) increased pH levels at the 1990 and 1991 Rookery Sites. For example, the mean pH at the 1990 and 1991 Rookery Sites (7.39 and 7.23 s.u., respectively) were significantly ($p < 0.05$) greater than mean values at the corresponding marsh Reference Sites (7.01 and 6.94 s.u., respectively). These differences were primarily due to calcium inputs (present in the rookery excreta) increasing the pH of the rookery waters (Wetzel 1975). Stinner (1983) has shown that a change in pH effects many other water quality characteristics, but it was not known what effects the increased pH had on the IBW treatment wetlands. However, these pH influences may explain, in part, the low correlation coefficients (r^2) between rookery population and recorded water quality measurements.

Correlation coefficients (r^2) between rookery population (directly proportional to excrement loading) and several water quality parameters for the 1990 Willow Rookery indicated that rookery occupation could only explain between 6 and 64% of the variability in water quality measurements (Table 7). Rookery population was most closely identified with fecal coliform density ($r^2 = 0.64$) and an adjusted TP concentration ($r^2 = 0.61$). The TP correlation was adjusted by matching each weekly TP value with the rookery population three weeks prior to compensate for an anticipated lag period between excrement introduction and nutrient liberation. The influence of water flow on nutrient liberation and availability was considered negligible because measured flow was typically low (approximately 0.01 m/s). Rookery population was not significantly ($p < 0.05$) correlated with recorded NH_3N ($r^2 = 0.06$) and un-adjusted TP concentrations ($r^2 = 0.06$).

In spite of the predomonantly insignificant ($p > 0.05$) correlation coefficients between rookery population and water quality parameters, it was interpreted that the primary influence on water quality was excrement loading from the rookery. In addition to rookery population, recorded water quality measurements were also influenced by other factors (both biotic and abiotic), including: phytoplankton production; microbial metabolic processes; precipitation; flow rate; wind direction and velocity; and other water quality characteristics. These are considered to be potential influences only; experimentation to link them to recorded measurements was not conducted.

Correlation coefficients (r^2) between rookery population and several water quality parameters for the 1991 Palm Rookery indicate that rookery occupation could only explain between 1 and 45% of the variability in water quality measurements (Table 12). Unlike the 1990 study, rookery population was most closely identified with water temperature ($r^2 = 0.45$), pH ($r^2 = 0.37$), and fecal coliform density ($r^2 = 0.37$).

Rookery population was not correlated with recorded specific conductivity ($r^2 = 0.01$) and TP concentrations ($r^2 = 0.01$) and correlation coefficients for the 1991 Palm Rookery study were generally less than those for the Willow Rookery, 1990. In spite of the variable (and decreased) correlation coefficients between rookery population and water quality measurements at RS, it was interpreted that the primary influence on water quality was still derived from excrement loading from the rookery population. The impacts of rookery loadings during the 1991 study were modified or moderated by other factors (both biotic and abiotic), including: phytoplankton production; microbial metabolic processes; precipitation; flow rate; wind direction and velocity; and other water quality characteristics. As with the 1990 study, these are considered to be potential influences only and experimentation to link them to recorded measurements was not conducted.

Sediment Nutrients

Given the complexity of wetland soil dynamics, the results of the sediment nutrient concentration analyses for 1990 and 1991 provide weak evidence for nutrient enrichment from the rookeries. A more detailed sediment monitoring program and clarification of assumptions will be required to utilize sediment nutrient content as evidence to fully support the suggestion that nutrient loading from rookeries influences associated sediments. However, some level of evidence of nutrient enrichment included slight sediment nutrient level increases through time (approximately 10 mg/kg/month TP and 115 mg/kg/month TN) under the 1990 Willow Rookery (Table 10). Although increases in sediment phosphorus levels were not as great as might be expected (based on the estimated loading rate for 5 July 1990), it was believed that these slight increases did evidence rookery effects. One possible explanation for lower than expected sediment phosphorus concentrations was that phytoplankton productivity utilized phosphorus liberated from excreta before it could be incorporated into the sediments (Stinner 1983). The measured response of phytoplankton to nutrient additions in 1991 supports this view and will be discussed later in this section.

The results of the 1991 sediment analysis indicated a different trend (Table 15). The trend for both total phosphorus and total nitrogen was a decrease from rookery initiation (30 April 1990) through abandonment (19 September 1991). Two possible, inter-related explanations for the observed trend are forwarded: (1) the physical structure of the palms intercepted much of the excreta, thereby reducing the actual "interface" of solid excreta and sediments; and (2) phytoplankton productivity utilized phosphorus before its incorporation into the sediment. Stinner (1983) investigated the nutrient content of branch "leachate" and concluded that nutrients from excreta do enter the wetlands through branch runoff. Because the nutrient-rich runoff enters the wetlands as an aqueous solution rather than in solid form, it was assumed that nutrients were more readily available for utilization by phytoplankton. Results of the phytoplankton investigation, identifying significantly greater ($p < 0.05$) chlorophyll$_a$ content of 1991 Rookery water, supported this suggestion.

Phytoplankton Productivity

Biotic evidence to support the view that the IBW rookeries altered portions of the marsh included the results of the phytoplankton productivity investigation. This investigation was not based on taxonomic considerations; rather, total phytoplankton productivity was estimated at Rookery (RS), Reference (ReS), and Marsh Background (BS) stations by measuring the concentration of chlorophyll$_a$ during the 1991 study season (Table 11). The use of chlorophyll$_a$ content as a measure of productivity was justified based on the findings of Hosseini and van der Valk (1989) that chlorophyll$_a$ concentration and phytoplankton productivity had a positive correlation coefficient (r^2) of 0.87.

Significant differences were not observed ($p > 0.05$) between mean chlorophyll$_a$ content (mg/m^3) at the 1991 Rookery Site (17.45 mg/m^3) and Marsh Reference Site (14.03 mg/m^3), but significant ($p < 0.05$) differences were observed between the Background Site (1.44 mg/m^3) and the Rookery Site. This comparison indicated that rookery influences extended beyond the immediate vicinity of the rookery (spatial limitations will be discussed in a subsequent sub-section). Further evidence that rookery nutrient inputs increased phytoplankton productivity was that the maximum values of 27.7-42.2 mg/m^3 were recorded immediately following the period of peak rookery population (wks 4-8). Measurements recorded at this time were characteristic of hyper-eutrophic conditions (Vollenweider and Kerekes 1982).

Although the correlation coefficient between rookery population and $chlorophyll_a$ content was not significant ($p > 0.05$), nutrient deposition was still believed to be the primary factor influencing phytoplankton productivity. This view was also supported by Stinner 1983, during her investigation of rookery influences on the Okeefenokee Swamp. The low correlation coefficient between rookery population and phytoplankton production indicated that rookery nutrient addition effects were perhaps overshadowed by other contributing factors; such as: solar irradiance (Hosseini and van der Valk 1989), dilution (ibid), flow rate and velocity, and zooplankton grazing (Timms and Moss 1984).

Sechhi measurements conducted for the 1990 Palm Rookery study seemed to comply with the 1991 $chlorophyll_a$ evidence suggesting that phytoplankton productivity was increased by rookery nutrient depositions. Because the 1990 study was a preliminary investigation, $chlorophyll_a$ content was not measured. Instead, water and Secchi depths were measured at the Rookery and Reference Sites (Table 9). Although Secchi measurements are affected by other factors, such as turbidity and water color, it was assumed that phytoplankton density was the primary influence on Secchi readings and was inversely proportional to Secchi depth. Evidence to support this assumption includes increased DO concentrations at the rookery site and the determination that there was not a significant ($p < 0.05$) difference between water and Secchi depths at reference sites. The difference between water and Secchi depths was calculated for each week and averaged at both stations for statistical comparison. There was a significant ($p < 0.05$) difference between mean Secchi readings at the Rookery and Reference Sites (10 and 0 cm, respectively). Once again, the results indicated increased phytoplankton density (increased enrichment) at the Rookery Site.

Although the correlation coefficient ($r^2 = 42$) between rookery population and $chlorophyll_a$ content (representing primary production) was lower than expected, the discrepancy may be explained by the modifying effects of previously mentioned factors influencing phytoplankton productivity (solar irradiance, dilution, flow rate, and zooplankton grazing), as well as other influences on Secchi measurements.

These results (as well as the results of other water quality comparisons) indicated that rookery influences were affecting rookery waters (and the 1991 Reference Site) and are consistent with abiotic evidence that avian colonies were creating areas of nutrient enrichment within IBW.

Aquatic Macroinvertebrate Community Structure

Biotic evidence of marsh enrichment by IBW rookeries also included the results of aquatic macroinvertebrate community structure comparisons between rookery and marsh reference stations as part of the 1991 study (Table 18). The results of the June sampling event indicated that the average number of total organisms collected at the rookery sites (374 individuals) was greater than that of reference sites (178 individuals). Average species richness, or the number of species recorded at the rookery (12 species) was also greater than that at the reference sites (9). Sample evenness, or the measure of the distribution of individuals among taxa in a sample (Pielou 1966), was similar for rookery and reference sites averages (0.60 and 0.61, respectively). Evenness values range from 0 to 1, with the lowest values indicative of dominance by only a few species and high values indicative of relatively equal distribution between taxa in a single sample. The evenness value and species richness represent the two variables used to calculate diversity index values. Therefore, the average species diversity index calculated for the rookery sites (2.16) was greater than that for the reference sites (1.93). The diversity index used for this study was the Shannon-Weaver formula, in which the comparative quality of a community is quantified based on the number of taxa in a sample and the numerical distribution of individuals among those taxa (Shannon and Weaver 1949). In this index, 0 represents the lowest diversity (one species present) and 4 the highest diversity.

The results of the September sampling event indicated that the average number of total organisms collected at the rookery sites (451 individuals) remained greater than that of reference sites (100 individuals). Average species richness at rookery sites (11 species) also remained greater than that at reference sites (7). Sample evenness was similar for rookery and reference sites averages (0.58 and 0.55, respectively). The average species diversity index calculated for the rookery sites (2.07) was once again greater than that for the reference sites (1.59). It was evident from these data that portions of the wetland associated with the rookery were still exhibiting signs of increased enrichment.

In addition to quantitative analysis of macroinvertebrates at rookery and reference sites, a qualitative analysis of collected species was conducted for the June and September sampling events. The qualitative analysis was based on a proposed lake condition index in which commonly collected aquatic organisms are separated into three classes based on trophic conditions of a waterbody (Hulbert 1990). The three classes were: Class A- species found in unaltered systems; Class B- species found in slightly altered systems; and Class C- species found in highly altered systems.

A wetland condition index was not calculated for rookery or reference sites. Rather, the Hulbert classification scheme was used to categorize the recorded species presented in Tables 16 and 17. Many of the species collected were not included in the classes because they are found too rarely or too little ecological information is known for meaningful classification. It was determined from this evaluation that two species in Class B (*Hyalella azteca* and *Caenis diminuta*) and two species in Class A (*Glyptotendipes* sp. and *Orthothicia* sp.) were collected at the rookery site during the 13 June sampling event. This was interpreted to be important because it appeared that the rookery area was not enriched to the point that organisms sensitive to highly eutrophic systems were eliminated.

The evaluation of the 5 September sampling data presented in Table 17 indicated that one Class A organism (*Glyptotendipes* sp.) and two Class B species (*Hyalella azteca* and *Caenis diminuta*) were collected at rookery and reference stations. Again, this was determined to be important information because it indicated that species sensitive to high trophic levels were still present at the end of the avian breeding season. However, It was unclear to what extent the reduced number of species and individuals collected during the

September event were due to seasonal influences (Wetzel 1977).

The observed differences between rookery and reference sites (primarily numbers of individuals and species richness) during both the June and September sampling were indicative of expected macroinvertebrate community responses to increased nutrient enrichment (Wetzel 1975). Thus, they also supported the suggestion that avian breeding colonies influence biotic wetland characteristics.

Rookery Enrichment Limits

Temporal Limits

Water quality trends during the 1990 Willow Rookery investigation, presented in Figures 8 through 14, indicated that an increased state of enrichment existed for the duration of the 1990 breeding season (April to August) at the Rookery Site. It was also apparent that the trend for most of the water quality parameters (5 of the 7) at the Rookery Station (RS) was a gradual return to background conditions towards the end of rookery occupation. Evidence to support this interpretation included total phosphorus levels dropping from 0.45 mg/L during late July (wk 14) to 0.20 during late September (wk 22), approximately two weeks after rookery abandonment. Fecal coliform bacteria density (3600 colonies/100ml in early July, week 11) and pH levels (7.70 s.u. in late June, Week 9) also reached or closely approached background conditions by the end of the 1990 study period (40 colonies/100 ml and 7.15 s.u.) at RS.

Similar water quality trends were also observed for the Rookery Station (RS) during the 1991 study (Figures 17 through 24). Water quality at the Reference Station was also influenced by the rookery. However, all but one of the RS and ReS parameters (DO) demonstrated trends in which background conditions were approached or reached by the end of the study period. Dissolved oxygen concentration exhibited a slight decrease through time, but the RS value remained approximately 3.0 mg/L greater than background conditions (ReS and BS) at the end of the study period.

The observed trends of phytoplankton production also indicated that rookery effects were transient. Evidence to support this included chlorophyll$_a$ content of the 1991 Rookery and Reference Sites approaching marsh background (BS) values by the end of the breeding season.

The 1990 and 1991 data were interpreted to mean that the enrichment effects of the rookeries on biotic and abiotic conditions were primarily restricted to the period of rookery site occupation. This is not to say that lingering effects of residual nutrients do not exist. Rather, that measured values were comparable, although not statistically equal in all cases, to background conditions by the end of the breeding season.

Spatial Limits

Comparisons of average water quality values between sample sites during the 1990 Willow Rookery study indicated that significant differences existed between the Rookery and Reference Stations in Cell 14 (Table 6). These differences were interpreted as evidence that rookery influences were limited spatially, as well as temporally. The average flow (0.01 m/s) for the study period was considered to be sufficiently low as to allow the detection of rookery influences at the Reference Site (RS), located approximately 150 m west (up-flow) of the Willow Rookery. Because there were significant ($p < 0.05$) differences in most water quality values between RS and ReS, located at a distance of 150 m, it was interpreted that rookery influences extended less than 150 m to the west.

Water samples were not collected immediately down-flow from the rookery, but samples were collected from a site (HS9) located approximately 450 m down-flow as part of another independent investigation. There were no significant ($p < 0.05$) differences between TP, NH_3N, and fecal coliform density at BS and HS9. Therefore, it was interpreted that rookery influences extended less than 450 m down-flow.

Summary

The results of this two year investigation indicated that cattle egret-dominated rookeries at the Iron Bridge Wetlands Nutrient Removal System represented point-source inputs of nutrients, creating spatially and temporally limited areas of nutrient enrichment (eutrophication) within the wetland system. Nutrient loading estimates for 5 July 1990 were considered as evidence supporting the suggestion that IBW rookeries were depositing nutrients into the wetland system.

Abiotic evidence to support the suggestion that the rookeries created areas of enrichment included significant ($p < 0.05$) differences between water quality measurements at Rookery Sites and both Reference (Cell 14) and Background (Cell 13) Sites during the 1990 and 1991 study seasons. Biotic evidence supporting this view included significant ($p < 0.05$) differences between fecal coliform bacteria density and aquatic macroinvertebrate community structure between rookery stations (RS) and reference stations (ReS) in Cell 14 during either the 1990 or 1991 study season. Additional biotic evidence consisted of the significant ($p < 0.05$) difference between $chlorophyll_a$ content (representing phytoplankton productivity) at the 1991 Rookery Site and Marsh Background Site.

In summary, the significant differences of abiotic and biotic conditions between the rookery (RS) and reference stations (ReS and BS) during both study seasons indicated that rookery influences were spatially limited, less than 150 m up-flow and less than 450 m down-flow. The results also indicated that rookery influences were transient, with rookery water quality values reaching or approaching background conditions by the end of the breeding season in 1990 and 1991.

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