
RELATIONSHIPS BETWEEN HYDROLOGIC CONDITIONS
AND QUALITY AND QUANTITY OF FORAGING HABITAT FOR
ROSEATE SPOONBILLS AND OTHER WADING BIRDS IN THE C-111 BASIN

Final Report
to the
South Florida Research Center,
Everglades National Park,
Homestead, Florida
February 1994

Prepared by:

Robin D. Bjork¹
and
George V. N. Powell, Ph.D.²

National Audubon Society
Tavernier Science Center
115 Indian Mound Trail
Tavernier, Florida 33070

Current addresses:

¹P.O. Box 574
Tavernier, Florida 33070

²RARE Center for Tropical Conservation
Apartado 10165, San Jose 1000, Costa Rica

EXECUTIVE SUMMARY

Ninety percent of Florida's breeding population of Roseate Spoonbills nests in Florida Bay and forages in the transition or ecotone between the freshwater Everglades and estuarine Florida Bay. From the late-1970's to the mid-1980's, spoonbill nesting numbers in the Bay declined by approximately 40% and reproduction was typically poor. These changes prompted concern that the spoonbill population's difficulties may have been, at least in part, the result of water management of the C-111 canal which lies upstream of primary foraging grounds for spoonbills nesting in northeast Florida Bay.

The objectives of this study were to examine the relationships between surface water conditions on the foraging grounds and spoonbill habitat use and reproductive success and to evaluate the influence of C-111 canal management on the ecology of the foraging grounds and breeding of the spoonbills. We collected or compiled (from existing data) three primary data sets for the study: 1. hydrologic: surface water level and rainfall throughout the lower C-111 basin and canal discharge into the basin, 2. wading bird foraging distribution and abundance throughout the south Florida mainland ecotone, and 3. reproductive parameters of Roseate Spoonbills nesting in Florida Bay. Field work was conducted from November 1987 through March 1992. The period of study fell in a relatively dry period for south Florida; 3 of the 5 years experienced over 25% below normal rainfall during the wet season and 2 of the 5 years received below normal rainfall during the dry season.

Lower C-111 Basin Hydropatterns

The pattern of surface water fluctuation in the lower C-111 basin was a reflection of its juxtaposition between the freshwater Everglades to the north and the estuarine-lagoonal system of Florida Bay to the south. Differences in the hydropatterns of these large wetland systems produced a complex mosaic of water recession within the lower C-111 basin. Water level in the ecotone, a band about 5 km wide, was closely associated with Florida Bay hydropatterns and independent of freshwater hydropatterns, including C-111 canal discharges. In contrast, the 2-4 km band of freshwater marsh adjacent to the C-111 canal, was strongly influenced by freshwater hydropatterns.

The hydropattern of the C-111 basin ecotone was dominated by an annual fluctuation in Florida Bay and adjacent marine waters that was characterized by an approximately 40 cm decline in mean water level between October and December. The decline precipitated a rapid draining of the ecotone resulting in drying over much of the marsh surface and constriction of water into depressions, moats around tree islands and narrow creeks. This constriction of surface water into the deeper areas resulted in the concentration of fish populations where they were highly accessible as prey for spoonbills and other wading birds. This process occurred at a time when the freshwater marsh was still largely inundated.

Surface water levels in the freshwater marsh of lower C-111 basin also receded rapidly around

October but then stabilized in a flooded state on the surface until about February when they again receded rapidly to below average marsh surface. Therefore, based on differences in drying regimes, concentration of prey populations occurred later in the freshwater marsh relative to the ecotone.

The Ecotone as Wading Bird Foraging Habitat

The ecotone of southern Florida provided foraging habitat critical for nesting Roseate Spoonbills and was important for many other species of wading birds. The monthly number of Roseate Spoonbills foraging in the ecotone averaged between 280 to 1,032 birds ($0.5\text{--}2.0$ birds/ km^2). Federally Endangered Wood Storks foraged in the ecotone throughout the season during all 4 survey years. Monthly averages of 13 to 665 Wood Storks ($<0.1\text{--}1.3$ birds/ km^2) were recorded there. The ecotone was also an important foraging habitat for wintering American White Pelicans. The monthly average of American White Pelicans recorded in the ecotone varied between about 200-1,800 birds ($0.4\text{--}3.5$ birds/ km^2). Average monthly numbers of all wading bird species, combined, was 4,792 to 12,140 birds ($9.2\text{--}23.3$ birds/ km^2). These densities of aquatic birds were higher and more consistent than those documented in other regions of the system, including the central and southwestern freshwater Everglades.

In the eastern portion of the south Florida ecotone (Turkey Point to Seven Palms Lake), the lower C-111 basin was consistently the area that was most heavily used by wading birds, in general and Roseate Spoonbills, specifically. The southern portion of Taylor Slough was important foraging habitat late in the dry season; birds concentrated there in February. Also important were the ecotone wetlands east of U.S. Highway 1; these marshes were most often used in late-January and February. These wetlands are outside the boundaries of Everglades National Park. Radio-telemetry data demonstrated that spoonbills foraging in those areas nested on islands in northeast Florida Bay within the Park. The dependency of the Park's spoonbill population on habitat outside its boundaries amplifies the importance of increasing protection and restoration of these lands.

Spoonbills foraging in the lower C-111 basin showed a tendency to shift from the ecotone to the freshwater marsh as the nesting season progressed. We believe that this shift, which occurred in 3 of 4 years, was related to the heterogeneous seasonal hydropatterns within the basin (described above in Lower C-111 Basin Hydropatterns). The greater influence of the November decline in Florida Bay water levels on the ecotone allowed wading bird foraging habitat to be available earlier in the season than the freshwater marsh. The birds moved into the freshwater marsh as the drying proceeded there and new areas presumably became available for foraging.

Determinants of Spoonbill Reproductive Success

We used an 11-year reproductive record from the principal northeast Florida Bay spoonbill colony at Tern Key to evaluate 8 factors as predictors of productivity of spoonbills that forage in lower C-111 basin. Those factors were: rate of change in water level (January to March) and average

January water level in the freshwater marsh, rate of change in water level (November to January) and average December water level in the ecotone, and total rainfall, the number of days when temperature dropped below 11°C (52°F) and C-111 canal discharge during the 1-month period after nests hatched, and timing of nesting.

Only 2 of the parameters, rainfall and temperature (accounting for 80% and 10%, respectively), explained significant amounts of variance in reproductive success. Higher total rainfall and more days of low daily temperatures during the 4-week nestling period were correlated with lower productivity. Low temperatures have been shown to influence behavior of the small fishes that comprise the spoonbills' diet. Therefore the mechanism by which temperature affected productivity may have been from reduced prey availability to feed the nestlings during cold spells. The mechanism by which rainfall influenced spoonbill productivity was not identified. We do not know whether spoonbills are highly sensitive to rainfall irrespective of foraging habitat quality, or whether the northeast Florida Bay subpopulation is particularly sensitive to rainfall because those individuals are using marginal or degraded foraging habitat. However, analysis of reproduction from 1957-1962, when the spoonbill population foraged primarily in an area independent of Everglades water management, showed that rainfall did not negatively impact their productivity suggesting the later hypothesis.

Although 2 of the 8 parameters, rate of change in water level and average January water level in the freshwater marsh, did not significantly contribute to explaining variation in spoonbill productivity not accounted for by rainfall, they were correlated with rainfall. That correlation suggested that the effect of rainfall on spoonbill productivity was at least in part through a decline in foraging habitat availability in the freshwater marsh during higher rainfall years.

Evidence of the sensitivity of spoonbills to changes in water level on their foraging grounds was shown by a comparison of hydropatterns and spoonbill activities between 1990-91 and 1991-92 nesting seasons. In 1990-91 water levels in the freshwater marsh were consistently declining from mid-January through February, while in 1991-92, water levels in that region did not reach marsh surface and exhibited minor increases from mid-January through February. Aerial surveys of foraging spoonbills documented very little use of the lower C-111 basin in 1991-92 compared to 1990-91. As well, in 1990-91, radio-tagged adults traveled to foraging sites closer to the colony, returned to the colony more frequently (an indication of more frequent feedings of nestlings) and had significantly higher nest success compared to 1991-92.

Recommendations

We have organized 3 recommendations relative to water management into 2 categories, direct and indirect, relative to the potential routes through which regulation could affect spoonbills. In addition, we present 2 recommendations to afford spoonbills greater protection in other foraging areas and from direct human disturbance in their colonies and 5 recommendations for other research and

monitoring studies for future evaluations of the health of the system and success of restoration.

Water Management Recommendations

We evaluated water management practices with regards to habitat quality and quantity for Roseate Spoonbills, based on two potential routes through which regulation of canal discharges and stages could impact them: directly, through impacts on surface hydropattern that influence the availability of suitable foraging sites and indirectly through impacts on salinity and primary and secondary productivity in the foraging area.

Our capacity to assess the impacts was inhibited by a nearly complete lack of information on conditions in the lower C-111 basin under pristine conditions. Furthermore, we have no pre-drainage information on the use of the area by the spoonbill population. However, we know that as recently as the 1950's and 1960's, spoonbill reproduction in the area was significantly less susceptible to disruption by inclement weather than currently, an indication that the population was more robust at that time. As recently as the late 1970's the population was 40-50% larger in northeast Florida Bay than present. This information suggests that the status of the population has deteriorated in recent decades.

Direct Impacts of Water Management

RECOMMENDATION: Focus management on ecosystem restoration; proceed with proposals to raise water levels in the upper C-111 basin and increase canal discharges. Monitor spoonbill reproductive success during the later part of their nesting season (mid-January to March).

JUSTIFICATION: Our hydrological analysis of the ecotone, the primary foraging area for spoonbills, demonstrated that management of C-111 canal had little impact on the area's hydropattern, the principal mechanism for direct effects on spoonbills. Therefore the proposed management modifications should not affect habitat availability for the species. Only when the birds moved up into the vicinity of the canal, in mid-January and later, in response to water levels dropping below average marsh surfaces, would they be vulnerable to affects of the proposed changes. If that surface flooding parameter continues to be the spoonbills' foraging habitat selection criterion, under new management scenarios spoonbills will likely have reduced access to the freshwater marsh. However, if Everglades restoration results in more productive fish populations as we predicted, the reduced access may be compensated by greater prey densities.

Based on these findings we conclude that except during about mid-January to March, spoonbill reproduction should not be used as a basis for evaluating direct short-term effects of water management on the lower C-111 basin ecosystem. Because of their vulnerability to proposed changes during the later part of the nesting season, spoonbills' reproductive success should be monitored at that time to insure they can succeed in the new habitat conditions.

Potential Indirect Impacts of Water Management

The limited information regarding the historic conditions of the spoonbills in the lower C-111 basin and northeast Florida Bay, cited above, again makes it difficult to assess indirect impacts that decades of water management may have had on the population. We suggest, that the lack of growth and reproductive sensitivity to rainfall of the northeast Florida Bay spoonbill subpopulation has likely been caused, in part, by long-term disruptions of natural flow patterns of freshwater into this historically low-salinity habitat. We conclude that targets for the management of the area should be focused on recreating historic conditions as they can best be predicted. Toward that end, we make the following recommendations:

RECOMMENDATION: Model for salinity; focus management end points on the resultant downstream salinity regime.

JUSTIFICATION: Results from modeling salinity based on predictions of historic upper basin water levels and their relationships to salinity indicate that the ecotone now experiences far higher salinities than prior to the lowering of the water table in the headwaters of the C-111 basin and adjacent Taylor Slough. Corroborating evidence of a lower salinity ecotone is derived from comparison of reported distributions of freshwater plant communities in the 1940's and 1960's with current distributions.

Because the ecotone's salinity regime is such an important indicator of balance within the system, model endpoints should be focused more on the resultant downstream salinity patterns than upstream flow volumes. Consideration must be given not only to extending hydroperiod to lower maximum salinities to levels consistent with historical levels, but to eliminating the discharge-induced drastic swings in salinity that now characterize the area.

RECOMMENDATION: Establish water management/conservation areas to store excess water.

JUSTIFICATION: Unless groundwater stages are maintained closer to historic levels, surface water will not be available to downstream ecotone marshes and Florida Bay to maintain historic salinities. To achieve the goal of a more "natural" salinity regime, land in the Frog Pond must be reincorporated into the Taylor Slough/C-111 basin system. Although ideally the current C-111 impoundment (north of the canal) should be restored as part of the continuous ecotone, consideration should also be given to managing it to restore historic salinity regime to ecotone.

Other Habitat Management Recommendations

RECOMMENDATION: Protect and restore ecotone wetlands east of U.S. Highway 1.

JUSTIFICATION: During the process of developing management plans for Taylor Slough and C-111 basins, attention should be given to integrating the wetlands east of U.S. Highway 1 into the restoration plans. While this ecotone habitat is outside ENP, our research demonstrated that it

provides important foraging habitat for Roseate Spoonbills that nest in the Park. Therefore, successful restoration of northeast Florida Bay depends on protection and restoration of these wetlands.

Distribution and soil composition of the transverse glades upstream of this ecotone habitat, hammock orientations and historic drainage patterns suggest that much greater surface flow occurred to the east than currently. Culverting of U.S. Highway 1 and the proposed east-west spreader canal should be evaluated for their potential to increase freshwater surface flows to that region, but without sacrificing designated water needs of adjacent areas.

These wetlands comprise the Model Lands Basin Project which is a priority purchase for the SFWMD this year, and Dade County has recommended immediate acquisition under their Environmentally Endangered Lands program. This purchase should be completed.

RECOMMENDATION: Protect breeding colonies from human disturbance.

JUSTIFICATION: In response to the increasing recreational activity in Florida Bay, ENP Enforcement Division should be required to ensure that sufficient isolation is maintained between colonies and Park visitors. In particular, Porjoe and East Buchanan keys require additional protection.

Other Research and Monitoring Priorities

The poor level of understanding of even the most basic ecological processes in the ecotone is seriously impeding efforts to restore the greater Everglades ecosystem to historic conditions. We have 5 recommendations for research and monitoring in the ecotone/Florida Bay habitats.

RECOMMENDATION: Develop a greater understanding of determinants of primary and secondary productivity in the ecotone.

JUSTIFICATION: This goal will require vastly improving the capacity to monitor basic physical parameters, such as water level fluctuations, rainfall, surface and ground water flows, evapotranspiration and conductivity. Field studies, as well as studies that will allow laboratory manipulation of parameters (e.g. salinity concentrations and fluctuations, primary productivity) on fish growth, reproduction and larval recruitment are necessary.

RECOMMENDATION: Complete the topographical survey of the ecotone and survey water level recorders to the sea level datum.

JUSTIFICATION: These surveys must be completed to allow the integration of data from the ecotone with those of the freshwater marsh and Florida Bay. Furthermore, the influence of sea level rise on the ecotone cannot be evaluated without this information.

RECOMMENDATION: Model ecotone hydrology.

JUSTIFICATION: Our analyses of ecotone hydropatterns are based on 3 years of hydrological data collected during a relatively dry period in south Florida from a small number of monitoring stations. During that time C-111 canal stages were <3.9 ft (dry season stages averaged much lower) and discharge events <6000 acre-ft. The relationship between ecotone hydropatterns, C-111 canal stage and discharge should be evaluated under a greater range of conditions and with a more complete data network.

RECOMMENDATION: Investigate level of mercury contamination in the ecotone.

JUSTIFICATION: Based on mercury concentrations in spoonbill nestlings in northeast Florida Bay colonies, further investigation into occurrence of mercury in fish populations in the eastern ecotone should be conducted.

RECOMMENDATION: Monitor annual spoonbill population size.

JUSTIFICATION: Although our analyses indicate that spoonbills generally are not directly impacted by canal discharges in the lower C-111 basin, the stability of their population will ultimately be influenced by the proposed changes. Along with lower C-111 basin, Taylor Slough provides important foraging habitat for the northeast Florida Bay nesting birds. Proposed structural and water management modifications to deliver more freshwater to the Bay will affect the ecological processes of both basins. Spoonbills are a Florida Species of Special Concern. Greater than 90% of the nesting population in Florida is concentrated in Florida Bay, about half of which depends on the southeastern ecotone for foraging. Monitoring spoonbill nesting distribution and abundance, therefore, is critical to assessing their status. The relatively low costs required to continue monitoring the size of the population make this data set a cost-effective measure of population status.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	i
Lower C-111 Basin Hydropatterns	i
The Ecotone as Wading Bird Foraging Habitat	ii
Determinants of Spoonbill Reproductive Success	ii
Recommendations	iii
Water Management Recommendations	iv
Direct	iv
Indirect	v
Other Habitat Management Recommendations	v
Other Research and Monitoring Priorities	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF APPENDICES	xv
ACKNOWLEDGEMENTS	xvi
HISTORICAL BACKGROUND/INTRODUCTION	1
OBJECTIVE	2
METHODS	3
Study Area	3
The C-111 canal system	3
Hydrology and foraging habitat research	3
Roseate Spoonbill nesting studies	3
Hydrological Analyses	4
Seasonal Rainfall During Period of the Study	4
Surface Water	4
Canal Discharge	6
Rainfall	6
Wading Bird Foraging Analyses	6
Wading Bird Foraging Distribution: Population Surveys	6
Roseate Spoonbill Foraging Distribution: Individual Surveys	7
Roseate Spoonbill Reproductive Analyses	8
Nesting Distribution and Abundance	8
Annual Reproduction	8
Determinants of Roseate Spoonbill Reproductive Success	9
RESULTS	10
Hydrological Analyses	10
Characterization of Ecotone Hydropatterns with Respect to Adjacent Marine and Freshwater Ecosystems	10
Effects of Canal Discharge on Water Level	12
Effects of Rainfall on Water Level	12
Long-term Record for the Freshwater Marsh	12

Long-term Record for the Marine System	13
Wading Bird Foraging Analyses	13
Wading Bird Foraging Distribution: Population Surveys	13
Roseate Spoonbill Foraging Distribution: Individual Surveys	15
Foraging Distribution of Spoonbills Relative to Hydropattern	15
Roseate Spoonbill Reproductive Analyses	16
Nesting Distribution and Abundance	16
Direct Human Disturbance at Two Colonies	16
Annual Reproduction: Colony Level	17
Mercury Contamination	18
Reproduction and Foraging Trips: Individual Level	19
Determinants of Roseate Spoonbill Reproductive Success	19
DISCUSSION	21
Hydrological Analyses	21
Implications of Water Management on Hydropattern	22
Implications of Water Management on Salinity	23
Wading Bird Foraging Distribution in the Ecotone	24
General Trends of Habitat Use During the Dry Season	24
Nesting Roseate Spoonbills' Foraging Habitat Use	25
Roseate Spoonbill Reproductive Analyses	25
Roseate Spoonbill Nesting Distribution and Abundance: Historical Trends	25
Annual Reproduction	28
Causes of Nestling Mortality	28
Mercury Contamination	29
Correlates of Wading Bird Habitat Use Patterns and Roseate Spoonbill Reproduction	29
Temporal Patterns of Habitat Use and Hydrology	29
Determinants of Roseate Spoonbill Reproductive Success	31
RECOMMENDATIONS	34
Direct Impacts of Water Management	34
Focus management on ecosystem restoration and monitor spoonbill reproduction	34
Potential Indirect Impacts of Water Management	36
Model for salinity	37
Establish water management/conservation areas	38
"The Frog Pond"	38
Impounded area between C-111 canal and U.S. Highway 1	38
Other Habitat Management Recommendations	38
Protect and restore ecotone wetlands east of U.S. Highway 1	38
Protect breeding colonies from human disturbance	39
Other Research and Monitoring Priorities	39
Develop a greater understanding of determinants of primary and secondary productivity ..	39
Complete the topographical survey of the ecotone and survey water level recorders	40
Model ecotone hydrology	40
Investigate level of mercury contamination in the ecotone	40
Monitor annual spoonbill population size	40
LITERATURE CITED	41

LIST OF TABLES

- Table 1. Description of independent variables used in multiple linear regression.
- Table 2. Standard deviations of mean daily water level differences between pairs of recorders (in a roughly north-south alignment) for the periods October-March, 1990-91 and 1991-92.
- Table 3. Statistics on radio-tagged adult Roseate Spoonbills.
- Table 4. Number of nesting pairs of Roseate Spoonbills in Florida Bay, 1987-88 through 1991-92, by colony.
- Table 5. Productivity of Roseate Spoonbills at three colonies in Florida Bay for five consecutive nesting seasons.
- Table 6. Summary of causes of mortality of nestling Roseate Spoonbills found dead in their nests.
- Table 7. Mercury concentrations (ppm, wet weight) in liver tissues of nestling Roseate Spoonbills collected in Florida Bay colonies (*from* Spalding and Forrester 1991).
- Table 8. Timing of nesting and productivity (young 3-5 weeks old/nest attempt) of Roseate Spoonbills estimated from field notes, unpublished reports and this study during the period 1974-75 through 1991-92.
- Table 9. Hydrologic/climatic data used in correlation and in multiple variable regression (**top**). Refer to Table 1 for description of variables. Table 8 lists spoonbill nesting initiation and productivity estimates. Pearson correlation matrix of hydrologic/climatic variables (**bottom**).
- Table 10. Spoonbill productivity (actual and predicted), total rainfall (NOAA Tavernier station) and ambient temperature data (as determined in Table 1) for 1957-58 through 1962-63 nesting season.
- Table 11. Salinities (ppt) recorded at 100 m intervals along the western N-S transect between the LJ and UJ water level recorders and along the eastern transect between the LH and UH water level recorders.

LIST OF FIGURES

- Figure 1. Number of Roseate Spoonbills nests in Florida Bay from 1935-36 through 1987-88.
- Figure 2. Regional distribution of Roseate Spoonbill nesting colonies in Florida Bay from 1955 through 1985.
- Figure 3. Overview of our primary study area, and the southern portion of the C-111 canal system, southeastern Florida.
- Figure 4. Map of distribution of dominant habitat categories and landscape features in our primary study area of southeastern Florida.
- Figure 5. Locations of surface water recorders used in analyses of hydropatterns in the lower C-111 basin.
- Figure 6. Transect pattern of wading bird/American White Pelican aerial surveys conducted over the southern end of peninsular Florida.
- Figure 7. Boundaries of zones used in summaries of bird abundance (based on aerial survey data) in the eastern region.
- Figure 8. Precipitation data from the NOAA Tavernier station (% departure from normal) for the wet (May-October) and dry (November-April) seasons for the 5 years of our study.
- Figure 9. Hydrographs of mean monthly water level for annual cycle (9a) and from November through January (9b) at the marine recorder, Key West (KW) and the freshwater marsh recorder, Craighead Pond (CP).
- Figure 10. Surface water hydrographs from continuous water level recorders in the ecotone of lower C-111 basin.
- Figure 11. Hydrographs from recorders along 2 north-south transects in C-111 basin, canal discharge (S-18C - S-197) and rainfall (EPR) for 2 dry seasons (from October through March).
- Figure 12. Effect of canal discharge events on change in water level (when there was no rainfall recorded at EPR or S-18C).
- Figure 13. Effect of rainfall on change in water level at freshwater marsh (EPSW), upper (UJ and UH) and lower (LJ and LH) recorders (when there was no canal discharge).

- Figure 14. Hydrographs from freshwater marsh water level recorders, G1251 and EPSW.
- Figure 15. Hydrographs from water level recorders G1251 and EPSW for 3 different rainfall and canal discharge events.
- Figure 16. Comparison of hydrographs of mean daily water level at the marine station, Key West (KW), and the Florida Bay station, Joe Bay (JB).
- Figure 17. Mean density of foraging wading birds by region, month and year.
- Figure 18. Mean density of foraging wading birds by species, region, month and year.
- Figure 19. Mean density of Roseate Spoonbills (19a) and Wood Storks (19b) by region, month and year.
- Figure 20. Distribution of Roseate Spoonbills (20a), other wading birds (excluding spoonbills and Wood Storks, 20b) and Wood Storks (20c) by zone in the eastern ecotone.
- Figure 21. Mean latitude of Roseate Spoonbills (21a) and all other wading birds (21b) in the C-111 basin, by survey and year.
- Figure 22. Distribution of Roseate Spoonbills in primary habitat categories during 3 nesting seasons.
- Figure 23. Distribution of wading birds (Roseate Spoonbills, RS; Wood Storks, WS; White Ibis, WI and Great Egrets/Great White Herons, combined, LW) in primary habitat categories in 1990-91.
- Figure 24. Locations of Roseate Spoonbills followed from 3 colonies to foraging sites during 2 nesting seasons.
- Figure 25. Foraging locations of radio-tagged Roseate Spoonbills nesting at Tern and Porjoe keys during 2 nesting seasons.
- Figure 26. Number of Roseate Spoonbill nests, by region. Refer to Table 4 for specific colonies and numbers within each region.
- Figure 27. Surface water hydrographs (top boxes) of freshwater marsh (recorder EPSW) and lower ecotone (recorder LJ) and mean latitude of Roseate Spoonbills in C-111/E and C-111/W Zones, combined, (bottom boxes) recorded during aerial surveys during 3 nesting seasons.

Figure 28. Water level trace from recorder LH (lower graph) and ground profile of cross section of the creek in the vicinity of the recorder (upper graph) showing under what water level conditions foraging wading birds moved into the area.

Figure 29. Percent cumulative nest initiations at 3 colonies in Florida Bay during 5 years.

Figure 30. Mean daily distances traveled from colony to foraging site per the number of foraging trips per day (an indication of the number of times the adult brought food to its young) of radio-tagged adults from northeast Florida Bay colonies during 2 nesting seasons.

Figure 31. Hydrographs of freshwater marsh (recorder G1251 in all years and recorder EPSW from 1986-87 through 1991-92), canal discharge (S-18C - S-197) and rainfall (S-18C and EPR) from October through March in all years with Roseate Spoonbill productivity data (young/nest).

Figure 32. Predicted salinities in Little Madiera Bay, northeastern Florida Bay.

Figure 33. Peak densities of foraging wading birds in 3 different habitats of south Florida (*adapted from* Frederick and McGehee 1992).

LIST OF APPENDICES

- Appendix A. Habitat categories for Roseate Spoonbill/wading bird aerial survey.
- Appendix B. Number of birds per species by region recorded during aerial surveys of the ecotone during the dry season in each of 4 years.
- Appendix C. Mean monthly density ($\pm$ S.D.) of birds (birds/km²) per species by region recorded during aerial surveys of the ecotone during the dry season in each of 4 years.
- Appendix D1. Distribution of Roseate Spoonbills recorded during aerial surveys of the eastern ecotone region.
- Appendix D2. Distribution of white wading birds and White Pelicans recorded during aerial surveys of the eastern ecotone region.
- Appendix E. Reproductive success of Roseate Spoonbills at three colonies in Florida Bay for five consecutive nesting seasons.
- Appendix F. Level of significance for differences in reproductive success for nestling periods 14 and 21 days among colonies (Sandy Key, Tern Key and Porjoe Key) within years.
- Appendix G. Level of significance for differences in reproductive success for nestling periods 14 and 21 days among years at each colony (Sandy Key, Tern Key and Porjoe Key).

ACKNOWLEDGEMENTS

Our work has been aided by assistance from Tony Berto, Robin Corcoran, S. Patrick Green, Steve Fowler, William McKelvy, Lori Oberhofer, Fred Schaffner, John Simon and Gene Young. They worked under demanding field conditions and their patience, fortitude, interest and suggestions have contributed directly to the quality of the research.

University of Florida graduate student Jerry Lorenz has developed fish sampling techniques in the ecotone and is conducting the sampling as part of a separate but associated study. Cooperation with and data from Jerry provided new insights into the secondary productivity of this little known realm of the ecotone. Marilyn Spalding, DVM with the Department of Infectious Diseases at University of Florida, conducted necropsies and pathological analyses on nestlings. Barbara Patty's summary of unpublished reports on Roseate Spoonbill nesting biology in Florida Bay for the 1960's and 1970's were invaluable for the historic analyses in this report. Night-vision equipment was provided by Alan Litman of StarTron Corporation. Dave Feder contributed crucial technical assistance in the fight against atrophy of electronics equipment in a saline environment. We thank Laura Quinn of the Wild Bird Center for her support.

In particular, we thank Robert Fennema, Peter Frederick, Jerry Lorenz, John C. Ogden, Mike Ross, Rick Sawicki, Marilyn Spalding and Allan Strong for their comments on and technical advice with various aspects of this study. We thank Tom McVicar who provided an insightful overview of the whole Everglades ecosystem. We thank all members of the National Audubon Research Department in Tavernier for their assistance with and discussion of this project, including Tom Bancroft, Wayne Hoffman, Laura Flynn, Jack Meeder, Joe O'Brien and Sandy Sprunt. Discussions with Sarah Bellmund DeToit, Rob Bennetts, Reed Bowman, Marty Fleming, Jim Fourqurean, Su Jewell, Robert Johnson, Curtis Kruer, Janet Ley, Bill Loftus, Carole McIvor, Pete Myers, Dewitt Smith, Dewey Worth and Peter David have improved various aspects of the study. We thank Nancy Paul who provided superior managerial and secretarial support necessary to carry out this project.

Hydrologic data were made available to us by the South Florida Research Center at Everglades National Park and the South Florida Water Management District. We wish to thank the Everglades National Park rangers, particularly District Rangers Hunter Sharp and Dave King for their cooperation. We thank Wyatt Aviation for expert, safe flying service and patience and flexibility with flight scheduling.

Funding for this study was provided by the South Florida Water Management District through a cooperative agreement (#CA 5280-9-8005) with Everglades National Park and funding from the Elizabeth Ordway Dunn and the John and Florence Schumann Foundations.

HISTORICAL BACKGROUND/INTRODUCTION

Ninety percent of the Roseate Spoonbills (*Ajaia ajaja*) breeding in Florida nest on mangrove islands in Florida Bay (Bjork and Powell in press) within Everglades National Park (ENP). At present, they are listed as a Species of Special Concern in Florida (Wood 1992).

Historic information on nesting numbers and distribution of spoonbills in Florida Bay is limited. Anecdotal accounts from Florida Bay and other parts of Florida indicate that a large population once existed in the state. However, spoonbills were virtually extirpated throughout Florida during the late 1800's and early 1900's (review in Powell *et al.* 1989) with only a single colony of about 15 pairs remaining on Bottle Key in Florida Bay by 1935 (Allen 1942). From that date, the nesting population grew exponentially, reaching a peak of over 1200 pairs in 18 colonies by 1978-79 (Figure 1; Allen 1963, Powell *et al.* 1989). No information is available for 5 years subsequent to 1978-79, but by 1984, surveys documented the total nesting population at approximately 450 pairs in 13 colonies, a 64% reduction from the 1978-79 peak. The population remained at that level through 1987-88 (Figure 1; Powell *et al.* 1989).

Until about the mid-1960's, almost all the Florida Bay spoonbills nested in the central and southern regions of the Bay and were thought to depend on wetland habitat on the upper "mainline" Florida Keys (those connected by U.S. Highway 1) for foraging (ENP Ranger Reports 1957 and 1962 unpubl. repts., Ogden 1978). Through the 1960's, coinciding with the rapid growth of the spoonbill population, much of the foraging habitat in the upper mainline Keys was lost (due primarily to commercial and residential development). Concurrently, there was a shift in the nesting population to keys in northern Florida Bay. By the mid-1970's, 75% of the breeding birds nested in northern Florida Bay and by the mid-1980's, 87% nested there (Figure 2), primarily concentrated in the northeast (Powell and Bjork 1990). With this shift grew a dependence of the spoonbill population on foraging in the brackish-water, mangrove-dominated ecotone between the freshwater Everglades and Florida Bay. Aerial surveys documenting foraging habitat use in 1973-1975 and 1977-1979 indicated that spoonbills were dependent on the eastern ecotone wetlands for much of their food resources during their breeding season, October-March (ENP unpubl. repts.).

In the late 1970's when the spoonbill nesting population reached its peak, spoonbills nesting in northeast Florida Bay and foraging in the eastern ecotone experienced poor reproductive success (ENP 1978, 1979). Furthermore, although the population was growing as a whole, the principal northeast colony (at Tern Key) declined from an average of 427 nests (1977-78 and 1978-79) to an average of 150 nests (1985-86 through 1987-88), while a northwest colony (at Sandy Key) increased from an average of 50 nests to an average of 130 nests, respectively (Powell *et al.* 1989).

Just upstream of the eastern ecotone lies C-111 canal. This canal, which was completed in 1967, forms the southern portion of a flood protection system for agricultural and residential areas of

southeastern Dade County and the final leg of the South Dade Conveyance System which connects with the extensive Shark Slough water management system to the north. The C-111 canal provides a gravity outlet for storm water runoff and surface water deliveries to the Taylor Slough and Eastern Panhandle drainages (Johnson and Fennema 1989). Both areas are important foraging habitat for spoonbills.

Because water deliveries down C-111 canal increased in the early 1980's as part of the Northeast Shark River Slough Water Delivery Experiment, we hypothesized that the timing and magnitude of the water deliveries down the canal might be causing the shifts in the location of nesting spoonbills in Florida Bay. Specifically, we hypothesized that too much fresh water entering the eastern ecotone in the dry season was reducing drying rates and consequently, decreasing the quality of the foraging habitat for the spoonbills.

Plans are currently underway to modify management of the C-111 canal, first through an interim plan developed by the South Florida Water Management District (SFWMD) and the Taylor Slough Demonstration Project (Van Lent *et al.* 1993) and, more permanently, through the C-111 General Re-evaluation Report being developed by the U.S. Army Corps of Engineers. Current knowledge of both the foraging habitat requirements of spoonbills and the impacts of C-111 canal operation on downstream conditions was too limited to use to assess future water management decisions on foraging habitat quality for spoonbills and other wading birds. Therefore, this study of the reproduction and foraging ecology of the Roseate Spoonbill was initiated.

OBJECTIVE

The objective of the study was to determine the influence of C-111 canal management on Roseate Spoonbill foraging habitat use and reproductive success. The information will ultimately assist in determining the best water management plan for the species. Furthermore, quantification of hydrologic parameters in the ecotone wetlands will provide a better understanding of their function for the development of ecosystem models of the area.

Our strategy to accomplish this objective was 2-parted. The first involved understanding surface water patterns in spoonbill foraging habitat south of C-111 canal, as a function of water level fluctuation, precipitation and canal discharge on the northern end of the study area, and of Florida Bay water level fluctuation on the southern end of the study area. The second part involved identifying which major spoonbill breeding colonies had birds feeding in the C-111 basin and then examining the relationships between surface water conditions on the C-111 foraging grounds, spoonbill foraging habitat use and reproductive success in those colonies.

METHODS

This study was conducted from November-March of 1988-89, 1989-90, 1990-91, and 1991-92. Hydrological data were collected year-round from December 1989 to April 1992. Data on reproductive success during 1987-88, which we collected in a preliminary study, are included in this report.

Study Area

The C-111 canal system provides a gravity outlet for storm water runoff from southeastern Dade County, Florida and discharges from basins further north via the South Dade Conveyance System. The canal provides water deliveries to the Taylor Slough and lower C-111 basin drainages (Figure 3; Johnson and Fennema 1989). Canal water is maintained at a designated stage; when water flow exceeds that criteria, flow to the southern part of the canal is increased. Water can be directed into canal L-31W and discharged into Taylor Slough or it can continue south in C-111 canal to the lower C-111 basin. After water passes through the control structure S-18C, it disperses into the marsh through gaps in the canal's southern spoil bank. During extremely high water levels in the canal, water is released through the southeast end of C-111 canal at control structure S-197, into Manatee Bay and Barnes Sound. The lower C-111 basin is bordered on the south by the shallow estuarine lagoonal system, Florida Bay.

Hydrology and foraging habitat research were focused in the lower C-111 basin from the southern leg of C-111 canal to the northern edge of Florida Bay and from the east at U.S. Highway 1 to Taylor River on the west (Figure 3). The habitat gradates from the freshwater Everglades in the north, with hammocks dominated by buttonwood (*Conocarpus erectus*) in a matrix of sawgrass (*Cladium jamaicense*) to the seagrass (*Thalassia testudinum*)-dominated estuary to the south. The polyhaline area, dominated by scrub red mangrove (*Rhizophora mangle*) and open flats of spike rush (*Eleocharis cellulosa*), constitutes the transition or ecotone between these 2 major ecosystems. A habitat map (Figure 4) was generated from 1987, 1:10,000 scale false-color positive transparencies (provided by ENP) which were digitized into a geographic information system, CAMRIS (Computer Aided Mapping and Resource Inventory System, Ford 1987). We did not ground-truth this map, however, aerial surveys conducted in 1993 (J. Lorenz unpubl. data) substantiated that our habitat delineations were accurate. This map provides a general picture of the complexity of the habitat types (Figure 4). Bird density and distribution data were also collected throughout the southern ecotone, an approximately 5 km wide band along the southern end of peninsular Florida from Turkey Point Nuclear Power Plant on the east to Northwest Cape Sable on the west.

Roseate Spoonbill nesting studies were conducted in nesting colonies which are located on small, mangrove-dominated islands or keys in Florida Bay. Nests in these colonies are constructed, often over water, primarily in red mangrove or black mangrove (*Avicennia germinans*) trees growing

along small intra-island creeks or interior ponds.

Hydrological Analyses

Seasonal Rainfall During Period of the Study

We summarized monthly precipitation and departure from normal for the Tavernier, Florida station (NOAA Climatological Data) to characterize the general seasonal rainfall patterns for the period of this study. Departure from normal was calculated based on the monthly means for the period 1951-1980.

Surface Water

We used hydrographs from 2 sites outside the lower C-111 basin to examine the difference in hydropatterns between the freshwater and marine ecosystems adjacent to our study area. Recorder CP, located in Taylor Slough, was used to represent the freshwater marsh and recorder KW, located in Key West, was used for the marine representation.

We analyzed hydrologic information in the lower C-111 basin based on data compiled from 10 continuous water level recorders in or immediately adjacent to the basin (Figure 5). We installed and monitored four of these recorders:

LJ (Lower Joe): 1 km north of Joe Bay

80° 31.85', 25° 14.73'

UJ (Upper Joe): 2.2 km north of LJ

80° 31.93', 25° 15.83'

LH (Lower Highway): 1.5 km north of the east end of Long Sound near Highway Creek

80° 27.64', 25° 15.16'

UH (Upper Highway): 1.7 km north of LH

80° 27.43', 25° 15.99'

*Longitude and latitude estimated from USGS 7.5' quadrangles.

These 4 recorders were arranged along 2 transects in conjunction with 4 existing ENP recorders: the Highway Creek (or eastern) transect from north to south included canal recorder, CT3; upper recorder, UH; lower recorder, LH; and bay recorder, LS. The Joe Bay (or western) transect from north to south included canal recorder, CT50; upper recorder, UJ; lower recorder, LJ; and bay recorder, JB.

Recorder EPSW, intermediate between the two transects and intermediate between the canal and upper recorders, was used to represent the freshwater marsh of the lower C-111 basin in hydropattern analyses. Water level data from recorder G1251, located 10 km northwest of EPSW, began in 1974 and was used to obtain a characterization of water patterns in the freshwater marsh of

lower C-111 basin prior to the EPSW record.

To date, our 4 recorders and those in Florida Bay have not been referenced to the sea level datum which is standard for the rest of the recorder network. Therefore, only comparisons of relative water depth among sites were possible. In the absence of the sea level datum, we calibrated our 4 recorders (which were centrally located in creeks) to the average marsh surface adjacent to the recorder at each site. Therefore, hydrograph data displaying water level at 0 indicates that water was at marsh surface but still remained in creeks and depressions. Water depth on the marsh surface was calculated as follows. A 100 m east-west transect was established 25 m to the north and south of each water level recorder. Water depth to sediment surface was measured at 25 m intervals along each transect during flood stage at the same time as a reading was taken from the recorder. Average water depth for the transect (on the flats) was used as a representative water depth for the surrounding marsh flats. Each water level recorder was set to zero when average water depth on the marsh flats was zero. For recorders EPSW and G1251, values of 30.2 cm and 85.0 cm, respectively, were subtracted from the water level data set to calibrate each recorder to its surrounding marsh flats (R. Johnson and R. Fennema pers. comm.).

We installed staff gauges at 100 m intervals between the lower and upper recorders on the Highway Creek and Joe Bay transects to obtain a general overview of variation in water depth between our ecotone recorders. Water level and ground surface, as well as salinity (ppt, using a refractometer, beginning in September 1991) were recorded at each site every 30-45 days.

To examine the relationships among hydrographs throughout the lower C-111 basin, we calculated correlations (Pearson correlation, Wilkinson 1990) between hydrographs from recorders along each of the 2 transects (Highway Creek and Joe Bay). For these correlations, we used daily change in water level at the recorders calculated by subtracting water level the day before from water level that day. We compared hydrographs for temporal lags of 0, 1, 2, and 3 days. For example, with a 2-day south to north lag from a bay recorder to a lower recorder, change in water level at bay recorder on day 1 was correlated with change in water level at lower recorder on day 3. Correlations were calculated for October-March in 1990-91 and 1991-92.

Correlation between hydrographs from recorders EPSW and G1251 was performed for the period 1986-1991 to determine the validity of using data from G1251 to characterize freshwater hydropattern conditions in lower C-111 basin prior to the record for EPSW. The period of record for G1251 was 1965 through present. For graphical comparison of those hydrographs, both data sets were normalized (i.e. each data set was adjusted to zero by subtracting each daily value from the long-term mean).

Hydrographs of mean daily water levels from the NOAA recorder at the Key West station (KW) and from the ENP recorder at Joe Bay (JB) were graphically compared to determine if the Key

West data could be used to represent hydropatterns of Joe Bay. If these hydrographs were similar, it would allow us to extend back the record of water level conditions in northeast Florida Bay. To smooth out daily tidal fluctuations at KW, 10-day running averages of mean daily water level were calculated.

Canal Discharge

Records of discharge through S-18C and S-197 (Figure 5) were provided by ENP and the SFWMD. We computed canal discharge into lower C-111 basin by subtracting daily flow (acre-feet) through S-197 from flow (acre-feet) through S-18C. We analyzed the effect of discharge on change in water level in the basin using linear regression (General linear model, Wilkinson 1990); total discharge for the period of a discharge event was the independent variable and the maximum change in water level during the event was the dependent variable. A discharge event was the sum of daily discharge over consecutive days with discharge >50 acre-ft and there was no rainfall reported at EPR or S-18C.

Rainfall

Rainfall data from S-18C and EPR (located at EPSW; Figure 5) were provided by ENP and the SFWMD. In addition, we collected rainfall data at each of the 2 lower recorder sites, LJ and LH, with Belford Chart Recorders. We examined the effect of rainfall on water level fluctuation using linear regression (General linear model, Wilkinson 1990); total daily rainfall was the independent variable and change in water level between the day after the rain and the day of the rain was the dependent variable. Only days with rainfall >0 and no canal discharge were included in the analyses. For these analyses, rainfall from EPR was correlated with EPSW, UH and UJ water level data; rainfall at LH and LJ was correlated with water level data from water level recorders at those sites.

Wading Bird Foraging Analyses

Wading Bird Foraging Distribution: Population Surveys

To quantify foraging habitat use by Roseate Spoonbills during the breeding season, we developed a systematic flight survey technique that allowed quantification of patchily distributed birds in a narrow band of habitat. The technique differed from the Systematic Reconnaissance Flight Surveys (SRF) used for other wading bird studies in Everglades National Park (Hoffman *et al.* 1992) in that our flight pattern was designed to provide nearly complete aerial coverage (except directly below the aircraft). Flight lines were flown at 1 km intervals in generally east-west trajectories over the entire southern width of the Everglades-Florida Bay ecotone from Turkey Point to Northwest Cape (Figure 6). Navigation along the pre-determined route was accomplished using Loran C or a Global Positioning System coupled with visual orientation to major landscape features. Flights were made in fixed-wing aircraft flying approximately 80 nautical miles per hour at a fixed altitude of 91 m (300 feet). Through the period November to March, in 1988-89, the survey was flown weekly and in 1989-90, 1990-91, and 1991-92 it was flown biweekly; in 1991-92, only the eastern half of the transects were flown. Two observers, seated in the back of the plane, recorded the locations on 7.5 minute

USGS quadrangles, behaviors (i.e. foraging, standing, roosting, flying), and specific habitats (Appendix A) of all wading birds and American White Pelicans (*Pelecanus erythrorhynchos*) that were observed.

When groups of spoonbills or large groups (> approximately 100 individuals) of other wading birds were encountered, the pilot circled them until observers achieved a consistent count. Some wading bird groups encountered during the aerial surveys could not be reliably distinguished to species and therefore, were categorized as small white waders (White Ibis, *Eudocimus albus*; Snowy Egret, *Egretta thula*; and juvenile Little Blue Herons, *E. caerulea*) or large white waders (Great Egret, *Casmerodius albus*; and Great White Heron, *Ardea herodias occidentalis*). Identification of White Ibises occurring in monospecific groups was possible and they were placed in a separate category. Although small blue waders (Little Blue Heron and Tricolored Heron, *E. tricolor*) were counted during the surveys, their relatively cryptic coloration made it difficult for aerial observers to obtain an accurate indication of numbers and distribution and we therefore eliminated this category from our summaries.

The physical features (e.g. coastline, lakes, major roads) of the survey area were digitized into a geographic information system, CAMRIS (Ford 1987), and the distribution of birds, by survey, were overlaid on the digitized area. The areas of eastern and western regions (Figure 6), 258 km² and 263 km², respectively (used for calculations of birds/km²), were calculated from the total area covered by the survey minus unsurveyed sub-areas (lakes and bays). The eastern region was divided into 5 zones (Figure 7) in order to compare the distribution of birds within the eastern region thought to have different drainage patterns (J. C. Ogden pers. comm.). Mean latitude of bird locations within the C-111/E and C-111/W, combined, was calculated for each survey to examine variation in seasonal patterns of movement of Roseate Spoonbills and of other wading birds (combined) within the ecotone.

Roseate Spoonbill Foraging Distribution: Individual Surveys

Two methods were used to analyze foraging habitat use on an individual level. During the 1989-90 and 1990-91 nesting seasons, we followed spoonbills in fixed-wing aircraft from breeding colonies to their foraging sites. A distance of at least 200 m was maintained between the aircraft and the birds to avoid influencing their flight path. Parameters recorded were departure time, group size, landing time, location, and habitat type; and size and composition of wading bird assemblages at the landing sites. When a flock was followed from a colony, one individual was selected as the target individual to be followed if the flock separated in flight. Birds were followed from northeast colonies at Tem, North Park, South Park and Porjoe keys and from a northwest colony at Sandy Key.

During 1990-91 and 1991-92 nesting seasons, we measured habitat use of individuals by locating radio-tagged adult spoonbills on the foraging grounds. Nesting adults with small young were captured at the nest using a nest trap (Frederick 1986). The birds were weighed and held for approximately 10 min while radio transmitters (weighing 6 g or 0.4% body mass of a bird) were glued to their back feathers (Fleming and Scheuch 1990, F. Schaffner pers. comm.) before they were

released. Radio-tagged birds were located at least 1 time per day on 2 to 3 days each week.

Automated telemetry monitoring systems were installed at Tern and Porjoe keys colonies in 1990-91 and 1991-92. The systems logged presence or absence of radio-tagged birds in the colonies at 10-minute intervals. From these data it was possible to determine nest visitation patterns including timing and number of trips each adult made to the colony (indication of number of times the adult brought food to its young). The colony monitoring data were combined with aerial monitoring data to analyze relationships between number of trips per day and mean daily distance flown to foraging sites (km).

Roseate Spoonbill Reproductive Analyses

Nesting Distribution and Abundance

All islands that historically contained spoonbill colonies were visited (usually during early nestling stage) and all nests were counted. As we traveled throughout Florida Bay, note was made of islands where spoonbills were observed. Subsequently, these sightings were investigated for nesting activity.

Annual Reproduction

Reproductive data were collected from the three largest spoonbill colonies (Sandy, Tern and Porjoe keys; Figure 6) during the 1987-88 through 1991-92 breeding seasons, except during 1989-90 and 1990-91 when only Sandy and Tern keys colonies were monitored. A representative sample of nests was monitored along routes established through each colony. Nests were individually marked with plastic numbered tags; each colony was visited every four to six days and the contents of each nest were recorded. Information on clutch size, duration of nesting, reproductive success and cause of nest failure was collected for each nest.

At Tern and Porjoe colonies, nests were generally placed in individual trees or small clumps of trees making it possible to locate the young spoonbills at least until 21 days after they hatched. In the Sandy Key colony, the unique combination of nest distribution and habitat structure made it impossible to enter the colony without causing excessive disturbance after nestlings reached an average age of 14 days. Thus, it became necessary to mark nests with large numbered tags placed below the nests and to observe them from blinds placed approximately 25 m from different sections of the colony. We analyzed nestling survival data (number of young/nest) for both the 14-day and 21-day periods because these are the two standards that are typically presented in studies of wading bird reproduction.

Estimates of reproductive success for each colony were calculated using the Mayfield (1961, 1975) method which prorates survival of repeatedly visited nests for the entire reproductive cycle and allows the sample to be extrapolated to estimate success of the entire colony (see Frederick and Collopy 1988). Survival rates of nests were estimated for three periods: 1) egg laying/incubation

lasting 23 days (incubation lasts 22 days beginning with the day after the first egg is laid, White *et al.* 1982), 2) nestling to 14 days of age and 3) nestling to 21 days of age. Overall nest success was calculated for 2 periods; a nest was considered successful if at least one young survived to 14 days of age and to 21 days of age, respectively. Statistical comparisons (Hensler and Nichols 1981, Hensler 1985) were made among survival estimates for 14-day and 21-day nestling periods among the 3 colonies.

All dead Roseate Spoonbills found in the colonies were collected for detailed necropsy and examination by Marilyn Spalding, DVM. Fresh liver tissue was used for mercury analysis (described in Spalding and Forrester 1991). The carcasses and pathological analyses are pending.

Determinants of Roseate Spoonbill Reproductive Success

We analyzed data on 2 scales: a fine scale, using the reproductive and foraging habitat use data from this study to examine responses of spoonbills to more subtle changes in hydrology on their foraging grounds, and a long-term, relatively gross scale that included less precise reproductive and hydrology data.

For the long-term data set, spoonbill productivity (number of young/nest attempt) and timing of nesting at Tern Key was estimated for 6 years during the 12-year period prior to this study, where sufficient ground count data were available. The estimation of productivity was made based on the total number of "fledged young" observed (a count which included young between 3-6 weeks old that were observed in nests and tree branches in the colony) divided by the total number of nests counted in the colony. In addition, each estimate was corroborated with field biologists' impressions of success of the colony from their field notes. Productivity data (number of 21-day old young/nest attempt) at Tern Key from 1987-88 to 1991-92 nesting seasons (collected during this study) were also included in the long-term data set.

We evaluated 8 factors (Table 1) as predictors of spoonbill productivity at Tern Key using stepwise multiple linear regression (General linear model, Wilkinson 1990). One assumption of multiple linear regression (MLR) is that the independent variables are not interrelated or highly correlated. Therefore, all independent variables were first analyzed for the strength of association (Pearson correlation, Wilkinson 1990). In cases where variables showed high correlation with each other (Pearson correlation coefficient $> \pm 0.60$), the MLR was computed with each of the correlated variables in the absence of the others to determine the best model. Using forward stepwise MLR, variables were entered based on a tolerance level of 0.05 and were selected beginning with the variable which had the highest standardized coefficient.

RESULTS

Hydrological Analyses

The period of our study fell in a relatively dry period for south Florida (Figure 8). Three of the 5 years experienced over 25% below normal rainfall during the wet season months, May through October. Two of the 5 years received below normal rainfall during the dry season months, November through April, the time during which spoonbills nest. The dry seasons of the 3 remaining years were near average. The drought years resulted in lower overall water levels in the basin. Consequently, our analyses are based on a weather period that is not fully representative of rainfall and water depth conditions and we could only extrapolate to more hydrophitic conditions.

Characterization of Ecotone Hydropatterns with Respect to Adjacent Marine and Freshwater Ecosystems

Comparisons of the annual water level cycle of freshwater (CP) and marine (KW) hydropatterns in south Florida, demonstrated the temporal difference in drying and flooding between the 2 regions. Both hydropatterns showed a major decline in water level occurring in the dry season (October-May, Figure 9a). However, marine water levels declined more quickly in November and December compared to the freshwater system (Figure 9b). In contrast, around January, marine water levels began to stabilize and then increase while water levels in the freshwater marsh began a more rapid decline (Figure 9a).

Figure 10a-b shows the annual pattern of surface water fluctuation in the lower C-111 basin as depicted along the two north-south transects we established for the study. Hydropatterns varied relative to position along the transect, but all followed a roughly sigmoid curve with high levels during summer months and lows in winter and early spring. Following 4 to 5 months of continuously flooded conditions throughout the lower C-111 basin, June to October, the seasonal decline in surface water began in October or early November and lasted until between January and May depending on position in the basin. Beginning in May, water levels again began increasing throughout the basin.

Between October and March, the period that concentrations of spoonbills foraged in the lower C-111 basin, there was an overall decline in water level of between 30 and 50 cm. The extent and timing of the decline was not homogeneous from north to south (Figure 11a-d). At the lower recorders (LJ and LH), a decline of 40-50 cm was documented. In contrast water level at the upper western recorder (UJ) declined 30-40 cm. Comparison of 1991-92 hydrographs along the Joe Bay (western) transect illustrate the differences in timing of decline (Figure 11d). Water levels in Florida Bay and coastal areas (LJ and JB recorders) dropped precipitously in November, with marsh surfaces becoming exposed early to mid-December. Freshwater marsh (EPSW) water level had an initial rapid recession in November but then receded slowly; marsh surfaces at that site were not exposed until mid-March.

Another characteristic of the water level recession that differed along the transect was the constancy of decline (Figure 11a-d). The freshwater site, EPSW, and upper recorder, UJ, displayed a relatively constant water level decline between October and March, while throughout the lower portion of the basin the water recession was not a continuous event. Instead, the long-term drying trend was periodically overridden by short-term reversals of an average of 10 cm (range 2-32 cm) over 2-18 day ($\bar{x}=7$ days) cycles. Nine short-term reversals occurred in the lower sites (LH and LJ) over the 6-month period in both 1990-91 and 1991-92.

Through the use of the water level recorder network and correlations between hydrographs, we characterized hydropatterns in the ecotone relative to the influence of water level fluctuations in the adjacent freshwater Everglades and Florida Bay ecosystems (Table 2). On the eastern side of the basin, represented by the Highway Creek transect of recorders, hydropatterns at both the upper and lower recorders (UH and LH), closely paralleled the Florida Bay recorder at Long Sound (LS). Secondly, influences on the upper recorder varied depending on water level in the freshwater marsh and intensity of flooding from the Bay. In detail, in 1990-91, the greatest similarities were between upper (UH) and lower (LH) recorders ($r=0.83$) and bay (LS) and lower (LH) recorders ($r=0.74$). Other comparisons that showed relatively high, but decreasing similarity were the bay (LS) and upper (UH) recorders with a 1-day south to north lag ($r=0.60$) and canal (CT3) and freshwater marsh (EPSW) recorders ($r=0.61$). Upper recorder (UH) also showed similarity to freshwater marsh (EPSW) recorder ($r=0.57$), especially when water levels in the freshwater marsh were relatively high. For example, at the end of the wet season in 1990, the site also displayed some influence from the freshwater marsh hydropattern by exhibiting fluctuations intermediate between the bay, and freshwater marsh recorders (e.g. November 1990, Figure 11a). In 1991-92, the greatest similarity in hydrographs was again between lower (LH) and upper (UH) recorders ($r=0.83$), bay (LS) and lower (LH) recorders ($r=0.66$), and bay (LS) and upper (UH) recorders with a 1-day south to north lag ($r=0.55$).

In contrast to the east side of the C-111 basin, a strong Florida Bay influence did not extend to the upper recorder on the western side, as represented in data from the Joe Bay transect, except during high Bay flooding coupled with low freshwater marsh water levels (e.g. 5-15 February 1992, Figure 11d). The upper recorder (UJ), in this area, was more similar to freshwater (EPSW) and canal (CT50) recorders. In detail, in 1990-91, freshwater (EPSW) and upper (UJ) recorders were the most similar ($r=0.70$) and canal (CT50) and freshwater marsh recorders ($r=0.70$). The upper recorder (UJ) also showed similarity to the canal recorder (CT50) with a 1-day north to south lag ($r=.50$) and to the bay recorder (LJ) with about a 1-day south to north lag ($r=0.59$). There were insufficient data to use the lower recorder (LJ) in comparisons during the 1990-91 period. In 1991-92, trends were similar. Although there was not a strong a relationship between canal (CT50) and upper (UJ) recorders ($r=0.30$), upper (UJ) and freshwater marsh (EPSW) recorders ($r=0.61$) were similar. There was strong correlation between bay (JB) and lower (LJ) recorders ($r=0.87$). As in 1990-91, the upper recorder (UJ) was also similar to the bay recorder (JB) with a 1-day south to north lag as well as to the lower recorder (LJ) ($r=0.55$).

In summary, the relative influence of freshwater marsh and Florida Bay hydropatterns during the dry season varied within the ecotone. On both Highway Creek and Joe Bay transects, the lower ecotone recorders closely tracked Florida Bay fluctuations, with a lag of about 1 day. The upper ecotone recorder on the Highway Creek transect also tracked Florida Bay fluctuations while the upper ecotone recorder on the Joe Bay transect did not. Although the upper ecotone recorder on the Highway Creek transect (UH) was predominantly influenced by Florida Bay patterns, it exhibited some similarity to freshwater marsh patterns as well, particularly when water levels were relatively high in the freshwater marsh. The upper recorder on the Joe Bay transect (UJ) closely followed the canal and freshwater marsh recorders (CT50 and EPSW). On both the Highway Creek and Joe Bay transects, when water levels became low in the upper region of the basin, Florida Bay's influence was more pronounced at both of the upper recorders (UH and UJ).

Effects of Canal Discharge on Water Level

The effect of canal discharge on change in surface water level in the lower C-111 basin varied relative to the location of the water level recorder within the basin (Figure 12). There was a significant positive correlation of C-111 canal discharge with change in water level only in areas relatively close to the canal, including upper recorder, UH ($r^2=0.67$ $P<0.005$) located about 2.5 km from the canal and freshwater marsh recorder, EPSW ($r^2=0.73$ $P<0.005$) located about 3 km from the canal. Although there was no linear correlation at either canal recorder, CT50 ($r^2=0.19$ $P>0.05$) and CT3 ($r^2=0.22$ $P>0.05$) located just below the canal, a strong effect was apparent. Water levels at these recorders were elevated with all discharge events >1000 acre-ft independent of amount of release. There was no significant linear correlation between discharge and change in water level at upper recorder UJ ($r^2=0.06$ $P>0.05$) located 5 km from the canal, or at either lower recorders, LJ ($r^2=0.12$ $P>0.05$) and LH ($r^2=0.01$ $P>0.05$) which are both located in the lower portion of the ecotone, approximately 8 and 5 km away from the canal, respectively.

Effects of Rainfall on Water Level

The direct effects of rainfall on change in water level in the lower C-111 basin contrasts with those of canal discharge (Figure 13). With one exception (LJ, $r^2=0.004$ $P>0.05$), rainfall was significantly correlated with water level increases at ecotone and freshwater marsh sites (EPSW, $r^2=0.50$ $P<0.01$; UJ, $r^2=0.61$ $P<0.005$; UH, $r^2=0.51$ $P<0.01$; LH, $r^2=0.29$ $P<0.01$). During these days of rainfall, water level tended to rise almost equal to the equivalent of accumulated precipitation (slope ranged from 0.70 to 1.44). Rainfall at the LJ recorder was apparently dissipated in the creek (where that recorder was located) rapidly enough to eliminate a significant water level increase at that site.

Long-term Record for the Freshwater Marsh

The representative water level recorder for the freshwater marsh in the lower C-111 basin, EPSW, is limited to only 6 years (since 1986). To extend the length of the record for that region and allow an extended comparative analysis of water patterns and spoonbill productivity, we needed a hydrology database for the region that had been operational since the 1970's. Therefore, we compared

EPSW water level data with those from G1251, a recorder with a longer database to determine if it could be used as a representation of freshwater marsh patterns in lower C-111 basin prior to the EPSW record.

The G1251 record had 2 potential sources of divergence from the EPSW record; it measures below ground water level (whereas EPSW measures surface water) and it is situated to the west of the C-111 canal in contrast to EPSW which is located directly south of it (Figure 5). Hydrographs from EPSW and G1251 recorders were highly correlated ($r=0.88$, Figure 14), however differences existed in their responses to rainfall and discharge events (Figure 15a-c). Recorder G1251 did not directly respond to C-111 discharge at S-18C, whereas discharge events reversed drying trends at EPSW. The differential influence of discharge on the 2 sites is clearly illustrated in late November 1990 (Figure 15a), where there was a discharge event of 12 days totaling 4200 acre-ft followed by a steady daily discharge of about 115 acre-ft through December; during that period, water level at G1251 maintained a steady recession while EPSW exhibited a reversal of 2 cm followed by stable water levels for the period. In another example (December 1986-January 1987, Figure 15b), water level at EPSW increased over 20 cm over the period of a discharge event totaling 13,775 acre-ft (>1000 acre-ft/day), whereas G1251 responded rapidly to a 4 cm rainfall with an increase in water level of 8 cm but then exhibited relatively little increase during the period of the discharge. An example of the influence of rainfall on the 2 sites is illustrated in January 1989 (Figure 15c), when about 1 cm of precipitation fell at both sites; G1251 displayed a rapid 8 cm below ground reversal whereas EPSW showed no reversal. Although these minor differences existed between the 2 sites, the general patterns in timing and extent of water recession on an annual basis were similar for both sites. Therefore, G1251 was used as an indicator of general characteristics of the freshwater marsh hydropattern for the long-term analysis.

Long-term Record for the Marine System

Similar to the situation in the freshwater marsh in lower C-111 basin, hydrology data for Florida Bay are extremely limited. The Joe Bay recorder (JB), which has the longest available record for northern Florida Bay, covers only 3 dry seasons (1989-90 through 1991-92). Therefore, we again sought another recorder that could be used to extend the length of the record. Hydrographs from Key West (KW) and Joe Bay (JB) showed a high degree of similarity during all 3 dry seasons, both in overall range of change for the period and in major water level fluctuations (Figure 16). Differences did exist in the magnitude of fluctuations where, in some cases, JB displayed greater fluctuations, but the differences were relatively minor. Therefore, we used the KW data set to extend the length of the Florida Bay hydrologic record beyond the 3 years that the Joe Bay recorder had been operational.

Wading Bird Foraging Analyses

Wading Bird Foraging Distribution: Population Surveys

Based on aerial surveys, the density of all wading birds (excluding American White Pelicans) using the ecotone between November and February ranged from about 9 birds/km² to 23 birds/km²

(Appendices B and C provide total number of birds per survey and birds/km² per month, respectively, for each species by region and year). Comparison of total number of birds in the eastern region (Turkey Point to Seven Palms Lake) and the western region (Seven Palms Lake to Northwest Cape) indicate that although numbers were consistently less in the eastern region they were a significant proportion of the total birds recorded in the ecotone (Figure 17). White Ibises, and large and small white waders comprised the majority of birds observed in both the eastern and western regions (Figure 18).

Density of Roseate Spoonbills in the ecotone ranged from 0.1-2.2 birds/km² (Figure 19a). Densities of spoonbills in all years showed an increasing trend through the breeding season. Numbers of spoonbills were higher in the western region compared to the eastern region, but the eastern region comprised 35-50% the total numbers recorded. Wood Storks were found throughout the ecotone ranging from 0.1-1.4 birds/km² (Figure 19b). Unlike all other species, density of Wood Storks in the eastern region was about equal to the western region.

Within the eastern region (Turkey Point to Seven Palms Lake), the C-111 basin (C-111/E and C-111/W Zones) was the area most heavily used for foraging by the wading birds; 50-68% of the Roseate Spoonbills, 37-72% of the Wood Storks and 44-66% of the other wading birds used the basin during the 4 years of this study (see Figure 7 for delineation of zones). The eastern portion of the basin (C-111/E Zone) received the highest use by spoonbills and other wading birds (Figure 20a,b,c). Generally, Taylor Slough Zone followed C-111/E Zone in spoonbill and other wading bird use. However, in 1991-92, the Turkey Point Zone had greater bird use than the C-111/E Zone (Figure 21a,b). The C-111/W, Triangle and Turkey Point Zones were used less than 20% by spoonbills (Figure 20a). For Wood Storks, the Taylor Slough and C-111/W zones received between 10-40% use with the Triangle and Turkey Point Zones used less than 20% in each of 4 years (Figure 20c).

We analyzed the aerial survey data from the eastern region for seasonal differences in distributions (Appendix D1, D2). Early in the season (November-December), coastal foraging sites were used primarily, while later in the season (January-February), the birds were more often in freshwater marsh sites in lower C-111 basin, Taylor Slough, the impoundment north of C-111 canal or ecotone habitat to the east of U.S. Highway 1. Within the C-111/E and C-111/W Zones, combined, a plot of average latitude of spoonbills per survey in each of 4 years showed that trend with the shift north occurring about early to mid-January (Figure 21a). A less pronounced shift north was also evident in wading bird species combined as a group (Figure 21b).

A summary of the habitats used by Roseate Spoonbills in the eastern region based on aerial survey observations (Figure 22) showed that Vegetated Creeks (VC) and Dwarf Open Mangroves (DO) were used most heavily in all 3 years data were collected. Comparison of habitat use by other wading bird species (only 1990-91 analyzed) showed that Wood Storks and large whites (Great Egrets and Great White Herons) used Vegetated Creeks and Dwarf Open Mangrove habitats most heavily for

foraging (Figure 23). Both of these habitat types, along with Moats (MO) are deeper than surrounding habitat, such as Dwarf Uniform (DU), Closed Mangrove (CM), or Freshwater Marsh (FM). White Ibises did not appear to follow the same habitat-use pattern as the other species. Instead, they used Dwarf Uniform (DU) more than the other habitat types (Figure 23).

Roseate Spoonbill Foraging Distribution: Individual Surveys

The sites used by 192 birds followed from colonies to foraging sites corroborated the aerial survey data in that breeding spoonbills depended on the ecotone as their primary foraging habitat (Figure 24). Spoonbills from the major colonies tended to forage in habitats closest to their respective colonies with relatively little overlap among colonies; birds from the Sandy Key colony in northwest Florida Bay foraged in the western ecotone while birds from the northeastern colonies foraged in the eastern ecotone.

The 29 radio-tagged individuals nesting at Tern and Porjoe keys colonies in the 1990-91 and 1991-92 (Table 3) seasons showed similar patterns. Generally, these birds were observed foraging in ecotone habitat close to their respective colonies, though there was considerable overlap between the regions (Figure 25). Birds from both colonies foraged in ecotone wetlands from U.S. Highway 1 to Taylor River. However, wetlands east of U.S. Highway 1 were primary foraging habitat for Porjoe Key birds which also made use of the open flats in the Boggies (the narrow strip of land joining mainland Florida with the Florida Keys, just southwest of U.S. Highway 1). In rare cases, individuals from both colonies flew to western sites, over 40 km away from their respective colonies.

Foraging Distribution of Spoonbills Relative to Hydropattern

The seasonal shift in distribution of spoonbills from the lower region of the ecotone to freshwater marsh habitat in the lower C-111 basin appeared to be related to the heterogeneous character of water recession within the basin (Figure 26a-d).

During the 4 spoonbill nesting seasons, 1988-89 through 1991-92, water levels in the ecotone decreased rapidly in November through December. At that time, the marsh flats were exposed and water was concentrated in the creeks, moats and deeper depressions throughout the marsh. For example, in the vicinity of our LH water level recorder, we found that foraging wading birds, including spoonbills, moved into the area when water levels had declined just to the level of the banks of the moats and creeks (Figure 27). In all 4 years, spoonbills fed exclusively within the lower regions of the ecotone during this time. In 1988-89 and 1989-90, water levels within the ecotone remained below the marsh surface throughout the nesting period. The extended dryness tended to eliminate those areas as foraging habitat later in the season. In contrast, during the other 2 years, 1990-91 and 1991-92, the ecotone hydropattern was characterized by cycles of flooding and recession.

In 1988-89 and 1989-90, the recession of water in the freshwater marsh began in late December. However, once water levels began to recede, they receded rapidly and constantly

throughout the nesting season. Concurrent with the rapid recession, spoonbills moved from lower in the ecotone into the upper region of the ecotone and adjacent freshwater marsh (including the impoundment north of C-111 canal). The third season, 1990-91, water recession in the freshwater marsh began in mid-January, about a month later than the 2 previous years, and water level did not drop to marsh surface until the end of February. Spoonbills remained longer in the lower portion of the ecotone compared to 1988-89 and 1989-90 and they shifted north when ecotone water levels became high and the freshwater marsh water to recede. The fourth season, 1991-92 was characterized by a sharp water level recession in the freshwater marsh during November followed by a stabilized period lasting the rest of the nesting season when water levels remained about 7 cm above the marsh surface; there was no water recession. The hydropattern of the ecotone at that time was marked by cycles of flooding and recession. The birds fed at sites outside the lower C-111 basin.

Roseate Spoonbill Reproductive Analyses

Nesting Distribution and Abundance

The spoonbill nesting population in Florida Bay ranged from about 500 to 900 pairs/year and from 16 to 21 colonies/year during the period of this study (Table 4). Overall, nesting abundance increased through the period of this study; 1991-92 levels were 43% higher than levels in 1987-88. The increase in number of nests was primarily associated with increases in the central and northwest regions of Florida Bay.

Data since 1984 showed significantly increasing trends in nesting numbers in the northwest ($r^2=0.85$ $P<0.001$) and central ($r^2=0.74$ $P<0.001$) regions (Figure 28). There was no change in the nesting abundance over time in the northeast region ($r^2=0.06$ $P<1.0$, Figure 28).

Direct Human Disturbance at Two Colonies

Nesting numbers at Porjoe Key colony declined by about 65% for 2 consecutive seasons following the 1987-88 season, while concurrently, the number of pairs nesting in all other northeast colonies increased (Table 4). In 1990, the island was posted by ENP rangers to prevent approach of boating traffic within less than 100 feet. In the 1990-91 and 1991-92 seasons, nesting at Porjoe Key increased back to about the 1987-88 level.

Since the 1987-88 nesting season, the East Buchanan colony has consistently had a small number of spoonbill nests (1-19), however, in the 1991-92 colony survey, there were no active nests. That season was also marked by nesting abandonment of other bird species including Brown Pelicans, Double-crested Cormorants and Great White Herons which consistently nested around East Buchanan's interior pond. During the colony survey at East Buchanan in 1991-92, we observed that large red mangrove branches overhanging the side channel that leads to the interior pond had been sawed off, allowing boat access into the heart of nesting area. Residents of the Florida Keys mentioned the occurrence of sight-seeing trips into the East Buchanan colony. These observations strongly suggest

human interference had caused the colony abandonment.

Annual Reproduction: Colony Level

Although timing of nesting tended to be highly synchronized within years at each colony, there was considerable variation among colonies (Figure 29). For example, Tern and Porjoe keys colonies initiated nesting as much as 3 to 5 weeks earlier than Sandy Key colony. Porjoe Key colony, which is located only 8 km east-southeast of Tern Key colony, consistently initiated nesting later than Tern Key colony.

There was also considerable interannual variation in timing of nest initiation particularly in the eastern colonies. Tern Key varied by almost 2 months between colony initiation in 1990 and 1987. Colony dynamics data were not collected for Porjoe in 1989 and 1990 because of the decline in nesting numbers we observed in the 1987-88 season (see above). Variation in colony initiation dates for the three remaining years suggest a range similar to that of the Tern Key colony. In contrast, at Sandy Key, the date of colony initiation was more consistent among most years. The single exception was 1987 when the colony formed 3 weeks later than normal.

Mean clutch sizes ranged from 2.8 to 3.7 eggs/nest (Table 5). Productivity of spoonbills at Tern, Porjoe and Sandy keys colonies was high all 4 years of this study ranging from 1.1 to 2.4 21-day old young/nest attempt. In all colonies except Porjoe Key in 1991-92 more than 1 young per nest attempt was produced (Table 5). Mayfield estimates of reproductive success for each of 3 periods, egg, nestling to 14-days old and nestling to 21-days old and for overall success at Tern, Sandy and Porjoe keys colonies are listed in Appendix E. Estimates for the egg stage should be interpreted with some caution because we did not begin monitoring nests until late in egg stage. Therefore, we do not know if nest lost was consistent throughout the incubation period. Overall nest success, which is the product of the egg and nestling periods, should also be interpreted with caution for the same reason.

Generally, there was little sign of egg predation at any of the colonies during the 5 seasons of monitoring. However, we occasionally found depredated spoonbill eggs at Sandy Key though they apparently had not been taken from the nests we were monitoring. Sandy Key had a resident pair of Common Crows, (*Corvus branciarancus*, common predators of wading bird eggs), that we occasionally observed in the colony.

We focused our evaluations of Roseate Spoonbill nesting success on the nestling periods, because this is the time of highest food demands for breeding pairs. Elevated food demands would tend to accentuate differences in foraging habitat quality between eastern and western colonies. Sandy Key colony consistently experienced the highest nest success during the nestling period among the 3 colonies. In 3 of the 4 years, birds on Sandy Key colony experienced greater than 95% nest success during the 21-day old nestling period; in the fourth year success was 87%. Success rates at Tern and Porjoe keys colonies were similar in 2 of 3 years (1987-88 and 1988-89) with 71-86% nest success

during the 21-day nestling period. In 4 of 5 years, Sandy Key colony had significantly greater nest success during the nestling periods than Tern Key colony (Appendix E and F). Only in 1991-92, was nest success during the nestling period significantly greater at Tern Key colony compared to Porjoe Key colony (Appendix E and F).

We also compared colony nest success during the 14-day and 21-day nestling periods among years (Appendix E and G). Only one colony showed a significant difference in nest success between years during the 14-day nestling period. Porjoe Key colony experienced greater success in 1988-89 compared to 1991-92. However, during the 21-day nestling period, nest success was highly variable among years. At Tern Key colony, success probabilities were similar in 1988-89, 1989-90 and 1990-91. Nest success in 1987-88 and 1991-92 was lower than in 1988-89, 1989-90 and 1990-91. At Porjoe Key colony, comparisons among years were limited because nest success data were not collected in 1989-90 and 1990-91. However, the Porjoe Key colony experienced greater success in 1987-88 and 1988-89 compared to 1991-92 during the 21-day nestling period. Sandy Key colony also experienced greater success in 1988-89 compared to 1991-92.

Causes of mortality, as indicated from 110 necropsies of dead nestlings were varied (Table 6). While primary cause of mortality varied from year to year, the 3 principal factors were predation (35%), malnutrition (21%), and disease (20%).

Bald Eagles (*Haliaeetus leucocephalus*) breed throughout Florida Bay and have been observed to take nestling spoonbills (J. C. Ogden pers. comm.). While no Bald Eagle predation was observed during our study, radio-transmitters from 2 radio-tagged juvenile spoonbills were found in a Bald Eagle nest at Sandy Key in 1990, indicating that eagles were responsible for at least part of the predation we recorded. However, characteristics of injuries sustained by surviving and depredated nestlings suggest that Turkey Vultures (*Cathartes aura*) were responsible for most of the predation. Lacerations on these animals conformed with vulture attack techniques documented in photographs in a Florida Bay spoonbill colony (J. Bangma unpubl. data). Evidence from the carcasses of the depredated spoonbills indicated that they were killed rather than scavenged by the vultures; the tissues exhibited good nutritional condition and their stomachs, which were usually left intact, were full of food (M. Spalding unpubl. data).

Disease was the major cause of death in only 1 of the 5 nesting seasons (1989-90), during which it accounted for nearly half of the known causes of death. Malnutrition was a relatively constant cause of mortality with the exception of 1990-91 when it accounted for only 1 of 6 deaths.

Mercury Contamination

Mercury concentrations in liver tissue (ppm, wet weight) from spoonbill nestlings found dead in the colony ranged from 0.16 to 5.38 ppm (Table 7, *adapted from* Spalding and Forrester 1991). Sample sizes were small, however, mercury concentrations tended to be higher in northeastern colonies

compared to northwest colonies in Florida Bay.

Reproduction and Foraging Trips: Individual Level

Nest success (nest producing at least 1 young to 21 days) for radio-tagged adults was 90% (n=10) in 1990-91 and 50% (n=16) in 1991-92. These values are comparable to estimates of the larger sample of nests followed in those years: 88% at Tern Key in 1990-91 and 71% and 51% at Tern and Porjoe Keys respectively in 1991-92 (estimated nest success probability for nestling period to 21 days, Appendix E).

In 1990-91, there was little variation in the distances radio-tagged birds traveled to foraging sites throughout the season and distances were relatively short ($\bar{x}=12$ km $\pm$ 2.8, N=47). Consequently, there was no difference ($r^2=0.02$ $P>0.05$) in mean daily distance to foraging sites relative to the number of trips to the colony per day (Figure 30a). In 1991-92, there was greater variability in the distances traveled to foraging sites throughout the season and distances were greater ($\bar{x}=16$ km $\pm$ 12.0, N=72) compared to 1990-91. There was a significant trend of fewer trips to the colony/day with longer mean daily distances to foraging sites ($r^2=0.29$ $P<0.001$, Figure 30b). The mean number of trips to the colony was higher (representing more frequent feedings) in 1990-91 ($\bar{x}=2.1$ $\pm$ 0.7, N=102) compared to 1991-92 ($\bar{x}=1.4$ $\pm$ 0.9, N=72). There was no significant difference in the length of time that nesting adults were gone from their colony between years; mean time away was 4.6 hours (SD=1.93, N=139 trips) in 1990-91 and 4.9 hours (SD=1.96, N=24) in 1991-92.

Determinants of Roseate Spoonbill Reproductive Success

A historical record of colony productivity (young/nest attempt) at Tern Key colony provided a long-term measure of reproductive variability within the largest northeast colony. Although productivity was consistently high at Tern Key during the 5 years we monitored reproduction, it was highly variable during the past 17 years. During that period, success ranged from nearly complete failures in 1977-78, 1978-79, 1982-83, 1983-84, and 1986-87 to relatively successful years in 1974-75, 1987-88, 1988-89, 1989-90, 1990-91 and 1991-92 (Table 8).

We examined the 11 years of reproductive success data at Tern Key as a function of timing of nesting and 7 environmental parameters (Table 1) using stepwise multiple linear regression (MLR) to determine the combined contribution of these variables in predicting spoonbill productivity in northeast Florida Bay. Because the influence of water management on the foraging grounds was the focus of this study, water patterns on the foraging grounds and primary factors influencing water patterns were the parameters used in these analyses.

A graphical view of water level in the freshwater marsh, canal discharge (cfs), and rainfall plotted with the estimated period of nesting for each year used in the MLR analysis are presented in

Figure 31. In the 3 years that spoonbills experienced total reproductive failure (1977-78, 1982-83 and 1986-87), water levels underwent relatively large flooding events during months that spoonbills had young. Colony failure occurred soon after major water level reversals (January 1983: G. Powell, field notes; and January 1987: R. Bjork, field notes) when most nests had young. In 1 (1986-87) of 3 (1977-78, 1982-83), rainfall and canal discharge contributed to water level reversal. In 1977-78, there was relatively little discharge and high rainfall; there was no water recession and there were several reversals throughout the nesting period. Reproductive failure occurred at all stages in the nesting cycle (ENP 1978). Relatively large discharges prior to spoonbills hatching, which did not result in water level reversals were not a major negative influence on spoonbill productivity. For example, in 1987-88, there were large discharges early in the dry season and even some smaller discharges during the nestling period, yet spoonbill productivity was good. From 1987-88 through 1991-92, spoonbills experienced high reproductive success. For 3 of these seasons, 1987-88, 1989-90 and 1988-89, gradual recession of water level coincided with high productivity. In 2 of the 6 seasons of high productivity, there were no major reversals, however, water level recession was minimal.

Correlation of all independent variables used in the MLR revealed a high correlation (>0.60) among the 3 variables total rainfall, rate of change of water level and average January water level in the freshwater marsh (Table 9). Rate of change in freshwater marsh water level was also correlated with rate of change in marine water level and average marine water level in December (Table 9).

Eighty percent of the variability in spoonbill productivity was explained by rainfall; the greater the rainfall, the lower the productivity ($P<0.001$). An additional 10% was explained by temperature; the more days of temperature below 11°C (52°F), the lower the productivity ($P<0.005$). The model created was: Spoonbill productivity = $2.082 + (-0.090 * \text{rainfall}) + (-0.054 * \text{temperature})$.

We used spoonbill productivity, rainfall and temperature data from 1957-1962 (Table 10) to test the relevance of the model during a period when the Florida Bay spoonbill population was growing and foraged primarily in the mainline Florida Keys (ENP Ranger Reports 1957 and 1962 unpubl. repts., Ogden 1978), an area largely independent of impacts of Everglades water management. For these years, productivity was significantly greater than predicted by the model ($P<0.05$, Wilcoxon signed-rank Test, Wilkinson 1990). In addition, we used these 6 years of productivity data as the dependent variable and total rainfall and ambient temperature data (derived as in the original model, Table 1) as the independent variables. In contrast to the strong influence of rainfall and temperature as determined in the original model, these 2 variables did not significantly influence productivity in the earlier years ($r^2=0.56$, $P>0.09$). Of the 2 years that had relatively high rainfall and low temperatures during the estimated 4-week period after hatching, the model predictions were well below the field census data (Table 10).

DISCUSSION

Hydrological Analyses

The hydrology of the lower C-111 basin reflects its juxtaposition between two major aquatic ecosystems, the freshwater Everglades and marine-dominated Florida Bay. Seasonal water levels of these 2 systems are primarily affected by different factors (Blaha 1984, Walters *et al.* 1992) and consequently have different patterns of annual water level fluctuation. Analysis of data from the 10 surface water recorders within and adjacent to our study area demonstrated that water level in the southern portion of C-111 basin, a band about 5 km wide which we have referred to as the ecotone, was closely associated with Florida Bay hydropatterns. Increases and decreases in water level in northeastern Florida Bay were reflected at the ecotone recorders within about 1 day. Consequently, the two periodicities of water level fluctuation within the Bay, annual (Allen *et al.* 1980, Schomer and Drew 1982) and short-term wind-driven (Holmquist *et al.* 1989), had major impacts on the amount of flooding within this area.

Annually, the ecotone became flooded by rising Florida Bay water level in summer (June-July) and remained flooded until early fall (about November). The flooding produced large shallow areas that remained inundated throughout the summer. The recession of marine water levels in the fall (October-November) precipitated an associated decline in water level in the ecotone. This decline (up to 50 cm during the years of our study) resulted in large-scale drying off of the extensive marl flats and the restriction of water to deeper depressions, primarily ponds, moats surrounding tree islands and narrow creeks.

Short-term fluctuations in Florida Bay water level also exerted impacts on the ecotone. Winter storm events, predominantly passing cold fronts, have been documented to follow a distinct pattern of one to several days of wind from the southwest followed by a shift around to the northwest and finally to the north as the cold front passes. The winds from the southeast and southwest cause water levels in Florida Bay to rise while winds from the northwest cause the Bay to fall (Holmquist *et al.* 1989). During our study, these short-term Florida Bay fluctuations concurrently caused the ecotone to be flooded and drained. Short-term flooding events in the lower ecotone, averaging 10 cm in magnitude lasting an average of 7 days, occurred 9 times in each of 2 seasons (November through March).

While the ecotone was dominated by water level fluctuations in Florida Bay, the influence of the marine system was reduced at more interior sites, particularly on the transect of recorders that ran north from Joe Bay. Here, the hydropattern of the 2-4 km band immediately adjacent to the C-111 canal was strongly influenced by freshwater hydropatterns and only occasionally, when relatively major storm events occurred, did the Florida Bay hydropattern influence this zone.

Implications of Water Management on Hydropattern

Little is known about hydrologic conditions in the lower C-111 basin prior to water flow records to the area which were first collected in the 1960's, well after extensive drainage of the western Coastal Ridge (Van Lent *et al.* 1993). It is likely that the drainage of the Everglades and Coastal Ridge and subsequent creation of the C-111 canal greatly affected hydropattern in the lower C-111 basin with a general lowering of water levels. Simulation output from the Natural System Model (NSM) showed that much of the Eastern Panhandle basin retained surface water throughout the dry season whereas the South Florida Water Management Model (SFWMM), simulating managed conditions, showed a complete drydown in the basin (ENP 1993). Data from our transects in the ecotone substantiated that the upper limits of the ecotone and freshwater marsh between the ecotone and the C-111 canal can dry out during the dry season (G. Powell and R. Bjork unpubl. data).

Another way water management practices influenced the hydropattern of the freshwater marsh in the lower C-111 basin was through canal discharges independent of local rainfall. Discharge events resulted in water level increases in the freshwater marsh. For example, discharge events of 5000-6000 acre-ft were associated with increases in water level of 3-5 cm in the freshwater marsh EPSW recorder, 3 km south of the canal. Barratta and Fennema (in prep) reported a strong correlation ($r > 0.9$) between S-18C stage (tailwater) and water level at the EPSW recorder.

In contrast, canal discharges had little or no impact on marsh water levels further from the canal. Our analyses showed that there was no correlation at our uppermost western recorder, UJ, the one that most reflected hydropatterns of freshwater marsh. Similarly, there was no correlation between discharge and change in water level at either of our lower ecotone recorders. Mazzotti and Brandt (1989) also concluded that canal discharge had little impact on surface water level in 2 creeks in the lower ecotone (Trout and Mud Creeks). Johnson and Fennema (in prep) analyzed water level fluctuations and water conductivity in Highway Creek and Long Sound as a function of rainfall, canal discharge, freshwater surface water level as indicated by tailwater level below S-18C and wind direction and velocity. They also found that canal discharges showed little correlation with water level changes in the large bays that comprise the interface between Florida Bay and the lower ecotone in northeast Florida Bay. These bays are adjacent to the ecotone of the lower C-111 basin. Their analysis focused particularly on discerning correlates of water level changes during storm events. The graphical representation of the primary event they used to illustrate their findings demonstrated that water levels in the bays actually rose slightly before the canal discharge was initiated and even before ground water began to rise at their freshwater marsh site. Again, these results indicated that the water level rise in the Bay was independent of discharges. The finding that canal discharge did not directly affect change in water level throughout most of the basin has major management implications because it means that even relatively substantial discharges through the C-111 canal will not cause flooding or reversals throughout much of the lower C-111 basin ecotone which is the primary foraging habitat for spoonbills.

Implications of Water Management on Salinity

While surface water patterns in the ecotone are largely independent of canal management, the opposite is true of salinities. Tabb (1967) documented a strong negative correlation between water level in upper C-111 basin and salinity in the large bays at the interface between the ecotone and the Bay. Based on concurrent measures of both parameters, he calculated an $r^2=0.8$ ($P<0.01$) between water levels at the Homestead Well and salinity at locations in the northeastern bays (Joe and Madera bays). That relationship was later corroborated by Sculley (1986) who concurred with Tabb that the relationship tended to break down when water levels in the upper basin reached very low levels. White (1983) used the equation to generate a plot of monthly salinities at the entrance to Little Madera Bay (Predicted Managed System, Figure 32) and then compared predictions with measured values that exist in the literature. The exercise demonstrated the relatively high level of accuracy of those predictions (Figure 32) and consequently of Tabb's model.

To assess the magnitude of changes that water management modifications in the upper C-111 basin have produced in the salinity regime of the ecotone, we compared the salinity predictions for Little Madera Bay under the managed system generated by White (1983) with predictions for the same period and location under a "natural" system, or one without water management structures. We generated the natural system predictions based on water levels at the Homestead Well site using the Natural System Model (Version 3.6 provided by R. Fennema) and Tabb's (1967) regression equation for Madera Bay salinities (Figure 32). The results indicated that major changes have occurred in the salinity regime of the ecotone in conjunction with a general lowering of the water table in the upper C-111 basin. Historically, salinity levels apparently fluctuated in a pattern that is similar to current trends, but at salinity concentrations 20 to 30 ppt lower than they have been in recent times. The impact of the lowering of the water table in the C-111 basin has likely been compounded by documented sea level rise in south Florida (Lidz and Shinn 1991). However, in the absence of critical data including a topographic/bathometric profile for the region and the ecotone and Florida Bay recorders surveyed to the sea level datum, the impact of sea level rise cannot be evaluated.

Reduced dry season flows and poor distribution of flows through the C-111 canal gaps may be allowing higher salinities to persist well up into the ecotone, as well. We recorded hypersaline conditions in the ecotone, as high as 37 ppt at the eastern upper recorder (UH), located about 4 km inland from Long Sound and as high as 56 ppt at the lower recorder (LH), located about 2 km inland of Long Sound (Table 11).

The significance of these changes in salinity to the biota of the ecotone is largely unknown. The absence of predrainage descriptions of submerged vegetation or fish and invertebrate populations in the area precludes comparisons with existing conditions. However, Egler (1950) mapped the distribution of major plant communities in the area based on data he collected in 1945; Tabb (1967) described the plant communities in that area for 1967. Their maps show sawgrass prairie and *Eleocharis* marshes extending into the lower reaches of the ecotone where red mangrove dominates

today. The dominance of sawgrass and *Eleocharis* indicates that the area was a low salinity habitat that would also have supported a rich periphyton community.

Little is known about relationships between salinity and primary and secondary productivity in the ecotone. Quantifying those relationships will be a major step towards evaluating the impacts of human-induced changes in the ecotone on wading bird populations. Current research on the dynamics of fish populations in the ecotone being supported by the SFWMD and ENP (Lorenz and Powell 1992) will provide a first step towards that evaluation. Preliminary analyses from this study have shown that the prey base fishes reach much higher densities and biomass in heavily-vegetated sites compared to sparsely-vegetated sites (Lorenz 1993a). Lorenz (1993a) hypothesized that herbaceous marshes provide better habitat for these fishes compared to dwarf red mangrove marshes. A decline in herbaceous marshes in the ecotone, now dominated by red mangrove would therefore result in a decline in the prey base. Research focused on examining the influence of habitat type on the prey base, in addition to experimental analysis of the impacts of high salinities and rapid fluctuations in salinity on recruitment and growth of these small estuarine fishes should be conducted.

Wading Bird Foraging Distribution in the Ecotone

General Trends of Habitat Use During the Dry Season

The ecotone of southern Florida provides foraging habitat critical for nesting Roseate Spoonbills and is important for many other species of wading birds. Federally Endangered Wood Storks foraged in the ecotone throughout their traditional breeding season during all 4 survey years. Generally, peak numbers (between 50-200 birds) occurred in the eastern region in December and January and in the western region in January and February. The ecotone is also an important foraging habitat for wintering American White Pelicans. The number of American White Pelicans recorded in the surveys averaged 353 +/-308 birds in the eastern region and 982 +/-359 birds in the western region. In a recent comparison of wading bird densities in south Florida habitats which used the data collected in this study to represent the southern ecotone, Frederick and McGehee (1992) found that foraging densities in the ecotone were higher and more consistent than central and southwest freshwater Everglades (Figure 33, *adapted from* Frederick and McGehee 1992).

While the ecotone supports the highest densities of wading birds, present day use of that habitat can only be a shadow of historic conditions. All of the major historic colonies of wading birds, including Wood Storks, that bred in large numbers in south Florida were located within ecotone habitat (Ogden 1994). The virtual abandonment of those colony sites, coupled with the dramatic declines in breeding populations of those species in south Florida since the 1930's (Frederick and Collopy 1988, Ogden 1994), must translate into greatly reduced use of the ecotone by breeding wading birds. Many of the historic colony sites remain intact, leading us to conclude that declines in foraging habitat quality have been responsible for the abandonment.

In the eastern survey region, the lower C-111 basin was consistently the area most heavily used by wading birds and specifically Roseate Spoonbills. Plans to restore the historic hydrology of Taylor Slough call for increased water flow to that area which, at present design, would require reduction of water into lower C-111 basin. The historic model for lower C-111 basin is not yet complete, however, historic vegetation and salinity data indicate that the area is already receiving less water than under pre-drainage conditions. In view of this concentration by wading birds in the lower C-111 basin, we urge that care be taken that it is not further degraded by reductions to existing water delivery patterns.

Nesting Roseate Spoonbills' Foraging Habitat Use

The foraging flight data clearly demonstrated that birds nesting in a colony flew to adjacent ecotone habitats to forage. Birds in the Sandy Key colony in northwest Florida Bay fed in mangrove areas in the western part of the range while birds in the northeast colonies generally fed in the lower C-111 basin and surrounding areas. Foraging distribution of adults that were radio-tagged in northeast colonies reinforced that finding. In addition, those data allowed further definition of spatial use by colony members and showed differential use of areas even between the two major northeast colonies. Although there was overlap in regional habitat use among these colonies, birds nesting on Tern Key concentrated their foraging in wetlands north and west of Joe Bay while individuals nesting on Porjoe Key concentrated on wetlands outside ENP to the east of U.S. Highway 1.

The wetlands east of U.S. Highway 1 to Turkey Point have been cut off from most surface water flow by the U.S. 1 and from traditional ground and surface water inputs due to the draining of the Coastal Ridge. These wetlands comprise the Model Lands Basin Project which is a priority purchase for the SFWMD this year (B. Helfferich pers. comm.) and Dade County has recommended immediate acquisition under their Environmentally Endangered Lands program. In view of the importance of these wetlands to wading birds, this purchase should be completed and the area's hydrologic characteristics should be restored. Culverting of U.S. Highway 1 and the proposed east-west spreader canal should be evaluated for their potential to increase freshwater surface flows to that region, but without sacrificing designated water needs of adjacent areas.

Roseate Spoonbill Reproductive Analyses

Roseate Spoonbill Nesting Distribution and Abundance: Historical Trends

We have no information on numbers of spoonbills nesting in Florida Bay or their distribution and use of foraging habitat prior to modifications that began in the early 1900's. Growth of the Roseate Spoonbill nesting population in northeast Florida Bay between the 1930's and 1970's coincided with recovery of the Florida Bay population as a whole (Powell *et al.* 1989), the loss of mainline Florida Keys foraging habitat (Powell and Bjork 1990), and the heavy human modifications to the Everglades which culminated in the construction of C-111 canal. Therefore, we do not know the extent to which they foraged in C-111 basin under historic, "natural system" conditions. We know

that the spoonbill was a common wide-spread species in southern Florida (Allen 1963, Powell *et al.* 1989). We can also use the tendency of spoonbills to be associated with large aggregations of other wading bird species to hypothesize about their historical distribution. As the historic distribution of other wading bird species that spoonbills generally associate with was concentrated in the ecotone, it is likely that the spoonbills depended on those areas as well. Therefore, the ecotone has probably always been a major foraging habitat for the species.

The Roseate Spoonbill population in Florida Bay continued to increase through the 1970's before reaching a peak in the 1978-79 nesting season. No information is available for the 5 years following 1978-79, but by the 1984-85 nesting season, surveys documented a 64% decline in the nesting population (Powell *et al.* 1989). Much of the decline occurred in the northeast colonies. We suggest that the decline was due to repeated reproductive failure between 1977-78 and 1983-84. Reproductive data available for 4 of the 8 years indicate few young were produced during those years (0 young/nest in 1977-78, 0.6 in 1978-79, 0 in 1982-82 and 0.5 in 1983-84). Predictions of reproductive success for the remaining years (1979-80 through 1981-82), derived from our predictive model, indicate low productivity for 2 of the 3 years (0.7 young/nest for 1979-80, 0.2 in 1980-81 and 1.3 in 1981-82). Based on a typical mortality rate of 10 to 20% per year of adult wading birds (Henny 1972), this 7 years with little recruitment would be enough to explain the recorded population decline that occurred between 1979 and 1984.

Since about 1987-88, the Florida Bay spoonbill population as a whole has increased from the low in the mid-1980's, to levels again approaching those of the mid-1970's. This steady population growth is probably a reflection of recruitment of young birds from the successful reproductive attempts for 6 of the past 7 years. Much of the population growth that was recorded during the past 5 years occurred in western colonies, where the number of nesting pairs increased from 65 in 1984 to an average of 250 in the last 3 years. Nesting abundance in the northeast colonies has varied around the same mean since 1984 despite the years of successful reproduction. The large colony on Tern Key that contained between 300 and 600 pairs during the late 1970's fluctuated between 100 and 200 pairs, but showed no significant increase in size (the 1992-93 nest count at Tern Key was 102, less than counts from the last 5 seasons, Table 4). The lack of increase in colony size at a time of high reproductive success suggest that the northeast habitats are at carrying capacity. If so, that carrying capacity is substantially below (40%) that of the mid- to late 1970's.

The smaller size of the spoonbill population in northeast Florida Bay, makes it more vulnerable to declines or even extirpation during another extended period of poor reproductive success. Our attempts to understand the reasons for the relative decline in use of that area by breeding spoonbills and, particularly, how anthropogenic alteration of their foraging area contributed to that decline, have been only partially successful. While it remains to be determined whether relatively poor secondary productivity in the eastern ecotone accounts for this apparent shift, it is certainly a tenable hypothesis which should be fully tested. Preliminary comparison of densities of prey eaten by

spoonbills between eastern and western foraging sites show much greater food resources in the west (Lorenz 1992, J. Lorenz unpubl. data). Some of the potentially important parameters that relate directly to the resource base for spoonbills are currently being addressed by the ongoing companion study of fish community dynamics in the ecotone (Lorenz and Powell 1997). That field study, as well as needed studies that will allow laboratory manipulation of parameters (e.g. salinity, primary productivity) related to fish growth and reproduction, will provide important insights into the determinates of productivity in the ecotone.

Direct Human Disturbance

Allen (1941), who studied Roseate Spoonbills following a period of heavy persecution, suggested that even mild human disturbance at any time in the nesting cycle could lead to failure of the colony. However, a later study of nesting Roseate Spoonbills in Texas (White *et al.* 1982) found high reproductive success both at colonies visited weekly throughout the nesting period and a colony which was visited only twice. We saw no evidence that our presence in the colony negatively affected spoonbill nesting; reproductive success at Sandy Key was close to 100% in 3 of the 5 years we carried out research activities there, including monitoring nesting success at 4- to 6-day intervals and radio-tagging juveniles. Similarly, reproductive success at Tern Key was 88% during the year we intruded most heavily in that colony to radio-tag adults and juveniles as well as to monitor nests at 4- to 6-day intervals. Our disturbance to these colonies did not begin until late in the incubation period, well after the birds were settled into the nesting cycle and we limited our length of disturbance while checking nests to less than 1 hour and only during mild climatic conditions.

While disturbance from our research presence did not appear to negatively affect spoonbill colonies, major changes in nesting numbers in two colonies appeared to be related to recreational traffic. At Porjoe Key colony, nesting numbers declined sharply (70% decline for 2 consecutive years compared to the previous 4-year average) concurrent with substantial boating activity (e.g. bird watching, fishing) adjacent to the colony which caused repeated and sustained flushing of nesting birds (G. Powell pers. obs.). Colonies more isolated from human traffic by virtue of their location in the interior of the island and distance from the mainline Florida Keys, did not show these same trends of changes in abundance, further implicating disturbance as a factor contributing to the decline. In response to the decline, ENP rangers posted a 100-foot no-access-zone around the island and increased patrols. The following year nesting numbers more than doubled.

East Buchanan Key also showed indications of greatly increased human disturbance in conjunction with abandonment of the colony by spoonbills and several other waterbird species. On that key, in 1991 large branches of red mangroves had been cut to allow boat access through a small channel that leads to the center of the colony site. That colony, which had been active every year for at least 20 years (S. Sprunt IV, pers. comm.) was completely abandoned that year.

Annual Reproduction

Overall, reproductive success for spoonbills nesting in Florida Bay was high in all years of this study (1987-88 through 1991-92). Success during this period was comparable to productivity estimates during the 1950's and early 1960's when spoonbills were nesting primarily on the central Florida Bay keys (Allen 1963). On average, productivity in Florida Bay from 1987-88 through 1991-92 was higher than that of the only other site, coastal Texas (White *et al.* 1982), where Roseate Spoonbill reproductive success was monitored in the 1980's (89% and 27% of the nests in Florida Bay and in Texas, respectively, produced > 2 14-day old young/nest attempt).

Although productivity at Tern and Sandy keys colonies was high during this study, differences in reproductive success existed. In four of five seasons, Sandy Key colony had significantly greater nest success during the nestling periods than Tern Key colony. At this point, it is not possible to fully analyze the role that differences in food resources may have played in differential reproductive success. However, preliminary data comparing densities of small fishes that constitute the primary prey of spoonbills show much greater (e.g. 15 times biomass and 88 times densities, December 1991 and 2.8 times the biomass and 13 times the density in December 1992) food resources in the western than in the eastern foraging sites (Lorenz 1992, J. Lorenz unpubl. data), possibly contributing to higher spoonbill productivity in that region. Furthermore, daily tidal fluctuations in western Florida Bay may provide greater foraging options to spoonbills nesting at Sandy Key, especially when foraging conditions are not suitable in the ecotone. Bancroft *et al.* (1990) found that tidal estuarine habitats were used for foraging by nesting *Egretta sp.* when freshwater habitats were unsuitable.

Causes of Nestling Mortality

Mortality of juvenile spoonbills during the past 5 years was low and no single cause of mortality emerged as a major influence on reproductive success. Most causes of mortality were attributed to predation, malnutrition and disease which varied in importance each year. Bald Eagles were identified as predators at Sandy Key when, on two occasions, a radio-transmitter of a juvenile spoonbill was found in an eagle nest (Powell and Bjork 1990). Although we never directly witnessed Turkey Vulture predation during this study, evidence strongly implicated vultures as a major predator of young that were in good nutritional condition and without evidence of disease (Spalding and Bjork, unpubl. data). A photograph, taken in the mid-1980's of a Turkey Vulture attacking a 3-week old nestling spoonbill, showed a capture technique that produced wounds matching those we observed on nestlings found injured or killed at Tern and Porjoe keys during this study. Vulture predation on living nestling spoonbills was noted in 1977-78 and was attributed to poor feeding conditions which led to prolonged absence of adults from nests (ENP 1978). In the case of our study, the analysis of spoonbill carcasses indicated the nestlings were in good nutritional condition and without evidence of diseases. Therefore, we conclude that vultures attacked healthy nestlings as well as those that were in weakened conditions. In 1991-92, when predation was the primary cause of mortality, adult spoonbills made fewer trips to the colony and traveled longer distances to foraging sites but they did not remain away from the colony for longer periods than in 1990-91. Therefore, factors other than or in addition

to periods of adult absence from the colony influenced predation pressure.

Mercury Contamination

Although not directly implicated in nestling mortality, mercury contamination is a potentially serious problem for the Florida Bay spoonbill population. Measurable levels of mercury were detected in all nestlings sampled ($n=14$) and concentrations in 2 individuals from northeastern Florida Bay were high enough to have potentially affected their survival. One nestling had 5.38 ppm wet weight of liver tissue, a level that has been associated with emaciation, disease and weakness in Great White Heron fledglings (Spalding and Forrester 1991). Interestingly, these nestlings probably obtained the mercury from the small fish and aquatic invertebrates brought in by adults that were feeding predominantly in the southeastern ecotone. These birds provide the first evidence that mercury contamination has reached the southeastern ecotone.

Correlates of Wading Bird Habitat Use Patterns and Roseate Spoonbill Reproduction

Temporal Patterns of Habitat Use and Hydrology

The complex pattern of regional habitat use that was revealed during our study appeared to be a response to temporal differences in hydropatterns of freshwater marsh and ecotone habitats.

During the 4 spoonbill nesting seasons, 1988-89 through 1991-92, water levels in the ecotone decreased rapidly in November through December. At that time, the marsh flats were exposed and water was concentrated in the creeks, moats and deeper depressions throughout the marsh. In all 4 years, spoonbills fed exclusively within the lower regions of the ecotone during this time. In 1988-89 and 1989-90, water levels within the ecotone remained well below the marsh surface throughout the nesting period. The severity of these water recessions would have produced highly concentrated sources of fish in remnant pools, moats and creeks throughout the ecotone early in the season, but the extended dryness would have tended to eliminate those areas as foraging habitat later in the season. During the other 2 years, 1990-91 and 1991-92, the initial water recession in the ecotone was followed by cycles of reflooding and recession, thereby allowing fish to persist in the ecotone later into the nesting season.

In 1988-89 and 1989-90, the recession of water in the freshwater marsh began in late December. However, once water levels began to recede, they receded rapidly and constantly throughout the nesting season. The spoonbills apparently responded to the appearance of new foraging habitat by moving from lower in the ecotone into the upper region of the ecotone and adjacent freshwater marsh (including the impoundment north of C-111 canal). The latitudinal shift by both spoonbills and other wading bird species was most pronounced during 1988-89 and 1989-90 when the water recession in the freshwater marsh was greatest.

The next year, 1990-91, water recession in the freshwater marsh began in mid-January, about a

month later than the 2 previous years, and water level did not drop to marsh surface until the end of February. At the same time, the water recession in the ecotone was interrupted by reflooding and redrying. Spoonbills remained longer in the lower portion of the ecotone compared to 1988-89 and 1989-90 and they shifted north at a time when ecotone water levels were high and the freshwater marsh was beginning to recede.

The fourth year, 1991-92, was characterized by a sharp water level recession in the freshwater marsh during November followed by a stabilized period lasting the rest of the nesting season when water levels remained about 7 cm above the marsh surface. Consequently, there was no water recession and presumably little or no concentration of food resources in the marsh while the spoonbills were feeding nestlings. The birds fed primarily at sites outside the lower C-111 basin.

Interestingly, spoonbills appeared to be more sensitive to water level fluctuations in the freshwater marsh than in the ecotone (which typically experienced several reversals when birds were foraging there). There are two ecological processes that we speculate may account for the birds' differential sensitivity to fluctuations. First, the birds tended to forage in the ecotone early in the nesting season when the food demands of raising young would be relatively low. Later in the season, when the birds tended to feed further inland, their nests had larger young and food demands presumably were higher, making them more dependent on concentrated food resources. Second, there appeared to be tremendous heterogeneity of foraging sites in the ecotone due to differential drying and reflooding of sites with varying degrees of isolation from the system of creeks that interfaces the bay with the ecotone. Moderate water recession of short duration concentrated fish in refugia, but allowed them to redistribute with reflooding (Lorenz 1993b) before oxygen depletion or excessive drydown eliminated the refugia. Therefore, short-term reversals in the ecotone, which would result from winter storms, effect the area differentially depending on the storm's intensity. A water recession of short duration would likely produce a mosaic of sites with a pronounced water level decline in the creeks interspaced by more isolated depressions and moats that will remain flooded longer. On a megascale, that condition prevailed between lower ecotone sites which dried out quickly in response to marine declines and the freshwater marsh which dried out more slowly.

Like spoonbills, Wood Storks also historically foraged in the south Florida coastal ecotone wetlands in November-January and shifted to freshwater foraging sites in February-May (J. C. Ogden in prep., Kushlan *et al.* 1975). In that era, the storks had large productive colonies located in the ecotone. Since the 1970's, timing of Wood Stork nesting initiation has shifted from November-December to much later in the dry season (January-May), often resulting in nesting failure because the onset of the rainy season refloods marshes and disperses food supplies while the birds are still feeding nestlings (J. C. Ogden in prep.). Bancroft *et al.* (1994) showed that nest initiation in the freshwater Everglades by Great Egrets and White Ibises usually began near large concentrations of foraging birds. They concluded that nesting was initiated in association with a concentrated prey base near a suitable nesting site. If Wood Storks similarly initiated nesting in response to a concentrated food resource in

the ecotone, their recent shift in location and timing of nesting is likely an indication that the early food resource concentrations when the ecotone dries out are no longer sufficient to stimulate nesting. We suggest, therefore, that degradation of the ecotone may help account for the loss of Wood Stork breeding population in south Florida.

The repeated failures of Wood Stork nesting attempts in the southern ecotone conforms with our conclusions that the spoonbill population in northeast Florida Bay is in a tenuous condition. It is critical to restoration efforts, that a greater understanding be developed of the processes that regulate productivity in the ecotone. Those findings must be incorporated into the Everglades restoration designs to ensure that the prescribed changes are effective in the coastal habitats.

Determinants of Roseate Spoonbill Reproductive Success

According to the multiple linear regression (MLR), only 2 of the 8 parameters used in the analysis, rainfall and temperature, explained significant amounts of variance in reproductive success. The mechanism by which rainfall and temperature would lead to nesting failure is undetermined. Winter storms with depressed temperatures and rainfall may influence reproductive success either directly, by stressing incubating or brooding adults or nestlings, or indirectly by influencing prey availability.

Rainfall may have affected spoonbill success, at least in part, through its effects on the hydropattern of the foraging grounds, presumably which would impact food availability. Average water level in January and rate of change in water level in the freshwater marsh, both correlated with rainfall, are two parameters that reflect the impact of rainfall on foraging habitats of the spoonbills. Higher rainfall was associated with deeper water in January and less rate of decline in water level in the freshwater marsh. Evidence of the sensitivity of spoonbills to changes in water level on their foraging grounds was shown by a comparison of hydropatterns and spoonbill activities between 1990-91 and 1991-92 seasons. There was little rainfall and no major reversals in the freshwater marsh in the 1990-91 and 1991-92 nesting seasons. However, in 1990-91 water levels in that area were consistently declining from mid-January through February, while in 1991-92, water levels in that region did not reach marsh surface and exhibited minor increases from mid-January through February. Aerial surveys documented very little use of the lower C-111 basin in 1991-92 compared to 1990-91. In 1990-91, radio-tagged adults traveled to foraging sites closer to the colony, returned to the colony more frequently and had significantly higher nest success compared to 1991-92.

Although the 2 freshwater marsh variables (average water level in January and rate of change in water level) were correlated with rainfall, they did not significantly contribute to explaining variation in spoonbill productivity that was not accounted for by rainfall. Those model results indicated that rainfall influenced spoonbill productivity through more than its impact to foraging habitat availability. Though 5 years that had the lowest productivity (1977, 1978, 1982, 1983 and 1986 with ≤ 0.6 young/nest) tended to have higher water levels in the freshwater marsh ($\bar{x} = 6.8$ cm,

range: 2.6 to 13.1 cm) than the more productive years ($\bar{x}$ = -9.5 cm, range: 1.7 to -27.3 cm), there were 2 years of relatively high water levels associated with high productivity. As well, during the three years that spoonbills experienced complete failure, water level declined very little or increased (-0.2 to 0.2 cm/day), yet there were years with similar rates of change in water level and high spoonbill productivity (Table 9).

Water recession of freshwater wetland habitats has historically been considered to be the primary determinant of wading bird success in south Florida (Kushlan 1976, Ogden *et al.* 1980, Bancroft *et al.* 1994). Kushlan *et al.* (1975) concluded from their study of foraging ecology of the Wood Stork, that a consistent marsh water recession was necessary to allow that species to successfully reproduce. Kahl (1964) found that in the southern Everglades, Wood Storks must have high densities of prey concentrated by declining water levels to trigger and sustain nesting. Because spoonbills feed by a similar non-visual, tactile method (Allen 1942), we expected that the freshwater marsh water recession would be the primary determinant of reproductive success for that species. However, at least during some years, such as 1991-92, spoonbills were able to find alternative foraging habitat when water levels in the freshwater habitat did not recede.

The other variable contributing to predicting spoonbill success was temperature, with more days of cold temperatures associated with lower productivity. Ogden (1978) suggested that unseasonably cold weather in January, 1973 resulted in nesting failure due to nest abandonment. Frederick and Loftus (in press) found that some of the fish that spoonbills depend on seek vegetation or burrow down into the marl substrate during periods of cold temperatures. They hypothesized that during extended periods of cold, it could become difficult for adult wading birds to obtain sufficient prey for nestlings, thereby contributing to reproductive failure. In their multivariate models they found that low daily temperature was the most significant variable in predicting nest success for Great Egrets, a species that is dependent upon visual detection of its prey and therefore requires that the organism be active. In contrast, the dominant foraging behavior of spoonbills is nonvisual, which may make them less dependent on prey activity and consequently less affected by low temperatures.

During the period of this study, there was a freeze in south Florida in December 1989 (Olmsted *et al.* in press) and 90% of the mangroves north of Joe Bay were killed (Lorenz 1993a). At that time, spoonbills in northeast Florida Bay were in the late incubation-hatching stage, a period when incubation of eggs and brooding of young is the dominant activity of nesting adults. Spoonbill productivity was not affected by this freeze as evidenced by the high reproductive success at the Tern Key colony. Probably because food demands are relatively low at this stage in nesting and the cold temperatures were not combined with high rainfall, there was little impact to the nesting birds.

The parameters that did not explain additional variance included several that we had initially expected would be important and therefore warrant additional discussion. The potential negative effects of increased C-111 canal discharge on wading bird habitat in the C-111 basin was a primary

reason for initiating this study. The lack of correlation between canal discharge and spoonbill productivity is consistent with the finding that during the dry season moderate discharges from the canal had no detectable impact on surface water levels throughout most of the ecotone. Instead, water levels in that area were associated with water level fluctuations in the marine system and local rainfall. Because spoonbills fed primarily lower in the ecotone during the first half of the breeding season, their access to foraging habitat was independent of discharge from C-111 canal at that time. Most years (10 of 11 years) included in the analysis had less than 6000 acre-ft of discharge during the nesting period. Only large canal discharges after mid-January, when the birds tend to move up into the freshwater marsh and around the canal itself, would be likely to have a negative impact on foraging habitat availability.

The extent to which potential flooding of foraging habitat caused by proposed raising of canal stages would influence spoonbill productivity is not known. While our analyses are based on nest survival up to 21 days after young hatch, we do know from radio-tagged fledglings that spoonbill young remain in the colony for approximately 2 months after hatching (White *et al.* 1982, Powell and Bjork 1990) and are fed by their parents throughout that period (Powell and Bjork unpubl. data). Therefore, productivity measurements for nests 21 days after hatching greatly under-represent the length of time adults are dependent on productive foraging habitat close to the colony.

Another factor that has been found to correlate with reproductive success for other species of wading birds nesting in south Florida is the timing of colony initiation. Timing of nesting was a significant variable associated with reproductive success of Great Egrets in the freshwater Everglades (Frederick and Loftus in press). The authors suggested that early nests tended to fail because they were more likely to encounter cold and rainy late winter storm events. In a study of White Ibis in the freshwater Everglades (Frederick and Collopy 1988), date of nesting initiation was the most significant correlate of nesting success. Again, nesting failures were attributed to rainfall patterns where later nests tended to fail because of the onset of rainy season. For the 11 years that we have data, spoonbill colony initiation varied by as much as 47 days, and although productivity had a pronounced negative correlation with rainfall, it was independent of initiation date. Periodicity of dry season precipitation during the spoonbill nesting period was variable, and nesting was completed well before the arrival of the rainy season in May or June.

The annual decline of marine waters adjacent to the ecotone is the main phenomenon that leads to the water recession in the ecotone at that time. We believe that this process is largely responsible for the concentration of resident small fish populations in the ecotone, as shown in data collected by Lorenz and Powell (1992) and Lorenz (1993b), providing accessible food resources before the freshwater marsh has substantially dried down. We therefore expected the marine water level decline to be an important correlate of reproductive success of the spoonbills. However, it did not enter into our MLR. The 5 years that had the lowest productivity (1977, 1978, 1982 1983 and 1986 with ≤ 0.6 young/nest) tended to have less of a water recession ($\bar{x}$ rate = -0.8 cm/day, range: -0.02 to -

1.17) than the more productive years ($\bar{x}$ rate = -1.0, range: -0.55 to -1.61). However, there were low rates of decline associated with high productivity and therefore it apparently was not a limiting factor of spoonbill productivity among those years (Table 9).

What we do not know is whether spoonbills are highly sensitive to rainfall irrespective of foraging habitat quality, or whether the northeast Florida Bay subpopulation is particularly sensitive to rainfall because those individuals are using marginal or degraded foraging habitat. Analysis of reproduction from 1957-1962, when the spoonbill population foraged primarily in an area independent of Everglades water management, showed that the strong influence of rainfall and temperature on spoonbill productivity, as determined in the original model, were not significant factors in these earlier years, therefore favoring the later hypothesis. As hypothesized by Frederick and Spalding (1994), the dependence of wading birds in the Everglades system on water recession rates may be an indication of "the degradation of the prey base, rather than as a historically necessary component of nesting. Given more robust prey populations, wading birds might be far less constrained by weather, hydrological variables, and season in their breeding attempts".

RECOMMENDATIONS

The strong dependence of the Florida Bay population of spoonbills on the eastern ecotone led us to focus our analyses of water management implications primarily on that area. As the spoonbills move up into the freshwater marsh between the ecotone and the C-111 canal late in the breeding season, we also assessed the impacts of management on that area.

To establish a basis for evaluating water management practices with regards to habitat quality and quantity for Roseate Spoonbills, we recognized two potential routes through which regulation of canal discharges could impact them: directly, through impacts on surface hydropattern that influence the availability of suitable foraging sites and indirectly, through impacts on salinity and primary and secondary productivity in the foraging area.

We have organized 3 recommendations relative to water management practices into two categories, direct and indirect. In addition, we present 2 recommendation to afford the spoonbills greater protection in other foraging areas and from direct human disturbance and 5 recommendations for other research and monitoring studies for future evaluations of the health of the system and success of restoration.

Direct Impacts of Water Management

RECOMMENDATION: Focus management on ecosystem restoration; proceed with proposals to raise water levels in the upper C-111 basin and increase discharges. Monitor spoonbill

reproductive success during the later part of their nesting season. Considerable attention has been focused on changing water management practices in the C-111 basin to bring additional water into northeast Florida Bay (Van Lent *et al.* 1993). These activities have raised questions regarding the potential impact of greater water releases on the spoonbill population. Our analyses showed that the hydropattern of most the ecotone is independent of discharges from the C-111 canal. Therefore, spoonbills were immune from direct effects of discharges while they were foraging in the ecotone during the first half of the nesting season (October to mid-January).

It is difficult to assess potential impacts of management modifications on spoonbills between mid-January and March when they tended to forage in the upper regions of the basin. In part difficulty arose because existing simulation models do not yet accurately predict hydropatterns for that area (Van Lent *et al.* 1993). Therefore, there is no way to determine precise surface water conditions in lower C-111 basin that will result from proposed modifications. Moreover, the spoonbills are apparently flexible in their choice of foraging locations, and are able to use alternative foraging areas when conditions in the lower C-111 basin are not optimal. Proposed water management, however, would likely affect freshwater hydropatterns over much of the southeast ecotone, potentially limiting foraging sites during a critical part of the nesting cycle.

The effect of higher ground water flows under new management scenarios on surface water depth and timing of natural recession for both of the lower regions of Taylor Slough and C-111 basins is another data set necessary to determine the impacts on foraging habitat availability for spoonbills. If future water management plans substantially raise surface water levels throughout Taylor Slough and lower C-111 basins, there may not be many foraging options available to the northeast birds during the later part of their nesting season. Given these limitations and to the extent that future freshwater increases do not significantly increase the food base for spoonbills in the ecotone our analysis must be largely speculative. Spoonbills generally do not forage in depths over about 20 cm (Powell 1987), and during our study, spoonbills moved into upper basin foraging areas when water levels dropped below average marsh surfaces, presumably in response to resulting concentrations of fish. If that surface flooding parameter continues to be the habitat selection criterion, under new management scenarios, spoonbills will likely be excluded from the freshwater marshes during the late nesting stage. We speculate that greater secondary productivity in the ecotone brought about by increased freshwater input would compensate for the delayed access to freshwater habitats in the lower C-111 basin. In addition, temporal variation in drying of marshes further east (east of U.S. Highway 1) could continue to provide alternate sites during times when lower C-111 and Taylor Slough basin sites are not accessible, as long as degradation of those areas does not continue.

Based on these findings we conclude that except during about mid-January to March, spoonbill reproduction cannot be used as a basis for evaluating direct effects of water management on the lower C-111 basin ecosystem. Similarly, while we can propose specific management recommendations to correct practices that are probably impacting the productivity of the ecotone marshes (see below), we

cannot make specific recommendations for water management based on direct effects to spoonbills that forage there. In any case, restoration should be focused on recreating a functional ecosystem rather than fulfilling the needs of a single species, at least until it has been demonstrated that restoration is endangering the population.

Because of the spoonbills' vulnerability to proposed changes during the later part of the nesting season, their reproductive success should be monitored at that time to insure they succeed in the new habitat conditions. A representative sample of nests (30-50) should be marked along a route established at each of 2 major northeast Florida Bay colonies (e.g. Tern, Porjoe, Park keys). A census of nest contents conducted in late December, another in mid-January, and then finally in early to mid-February in conjunction with a census of Bay-wide nesting numbers (see last recommendation) should be sufficient to evaluate their nesting success for the season.

As actual measurements of virtually all hydrological parameters of the historical, pre-drainage conditions of the C-111 basin are lacking, restoration must attempt to recreate conditions predicted by the best Natural System Models that can be developed. Based on our data, we conclude that ENP proposals to raise water levels in the upper C-111 basin (Van Lent *et al.* 1993) and increase discharges into the ecotone would likely improve conditions for spoonbills over the long run.

While we agree with ENP hydrologists and others that more water is needed in both the C-111 and Taylor Slough basins, we take exception to ENP's recommendation that during the dry season, water deliveries "should continue into Taylor Slough and Eastern Panhandle basins whenever upstream water is available" (Van Lent *et al.* 1993). Water should be delivered to the basin based on a model that recreates historic conditions. Discharges above those called for by the model should be prevented by storing excesses in water management areas to make up for missing natural storage capacity.

Potential Indirect Impacts of Water Management

We have no information on use of the southern ecotone as foraging habitat by spoonbills before its hydrology was disrupted by extensive draining and water management. Lack of such information prohibits a comparison of current and historic use of the region by spoonbills. Our understanding of spoonbill responses to various hydrologic conditions on their foraging grounds was further limited by the low level of interannual variability in climate and hydro patterns during the period of this study; there was relatively little rainfall and no major reversals of surface water. We do know that although spoonbills have consistently experienced high reproductive success during the past 5 years, the eastern nesting subpopulation has not increased, suggesting it has reached carrying capacity. We also know that this same nesting subpopulation was over 40% larger in the mid- to late 1970's compared to the past 5-year average and then crashed over a 5-year period which included 3 years of high rainfall during the nesting season. We know that as recently as the 1950's and early 1960's, spoonbill reproduction in the area was significantly less susceptible to disruption by inclement

weather than currently, an indication that the population was more robust at that time. This information suggests that the status of the population has deteriorated in recent decades.

We looked to other relevant data sets for the ecotone for evaluating indirect impacts of future water management on the spoonbill population and other wading bird species, in particular with regard to proposed management based on a Natural System Model. Wood Storks historically concentrated their foraging in the southern ecotone wetlands from November to January (J.C. Ogden unpubl. data). Foraging distribution combined with evidence from a shift in timing and the decline of Wood Stork nesting (which occurred in November and December) in the Taylor Slough basin indicates that degradation of the ecotone habitat has occurred. Our results from modeling salinity based on predictions of historic upper basin levels and their relationships to salinity indicate that the ecotone now experiences far higher salinities than prior to the lowering of the water table in the headwaters of the C-111 basin and adjacent Taylor Slough. Corroborating evidence of a lower salinity ecotone is derived from comparison of reported distributions of major plant communities in 1940's and 1960's with current distributions. The sawgrass prairie belt which extended into the lower portion of the ecotone in 1945 (Egler 1950) and later described as dominated by *Eleocharis* in 1967 (Tabb 1967), has been replaced by a sparsely vegetated, red mangrove-dominated community. Recent results from studies of prey base fishes in the ecotone indicate that fish populations, particularly small individuals which comprise the wading bird prey base, reach much higher densities and total biomass in thickly-vegetated areas as compared to lightly-vegetated or non-vegetated areas (Lorenz 1993a). Therefore, as suggested by Lorenz (1993a), loss of the herbaceous sawgrass marshes in the ecotone may have resulted in a decline of the prey base fishes. Other preliminary analysis from this study of prey base fishes in the ecotone also found higher fish production associated with higher water levels in the wet season (Lorenz 1993b). Reduced surface and ground water flows have resulted in lower wet season water levels (Van Lent *et al.* 1993).

Until modelers have better data on the indirect impacts of water management on ecotone productivity, they must work with the best available information. Based on the above evidence it is clear that changes have occurred in the ecotone and a major restoration effort is required to revitalize the area. Targets for that restoration should be focused on recreating historical conditions as they can best be predicted. Toward that end, we make the following recommendations.

RECOMMENDATION: Model for salinity; focus management model end points on the resultant downstream salinity regime. Because the ecotone's salinity regime is likely an important indicator of balance within the system, model end points should be focused more on the resultant downstream salinity patterns rather than upstream flow volumes. Consideration must be given not only to extending hydroperiod to lower maximum salinities to levels consistent with historical levels, but to eliminating the discharge induced drastic swings in salinity that now characterize the area. A step immediately necessary to proceed in that process is to survey Florida Bay and ecotone recorders into sea level datum and to develop a more complete salinity monitoring network.

RECOMMENDATION: Establish water management/conservation areas. We agree with ENP's priority to maintain optimum wet season water levels in the L-31N and L-31W canals based on the rainfall and the Natural System Model (NSM) and to allow canal stages to recede "naturally" into dry season (Van Lent *et al.* 1993). However, there are limits to water availability as a result of anthropogenic changes in the basin headwaters. Consequently, maintaining optimum water levels will be dependent on dedicating sufficient quantity of water with the appropriate temporal distribution. Unless ground water stages are maintained closer to historic levels, surface water will not be available to downstream ecotone marshes and Florida Bay (ENP 1993) to maintain historic salinities. Taylor Slough and C-111 basins cannot be allowed to become either a dumping area when there is excess water or a sacrificial area when water shortages occur. Water management procedures must include provisions to buffer against the impacts of anthropogenic needs such as flood relief when they threaten to override adherence to the water management plan for the area. To achieve that goal it will likely be necessary to establish water conservation areas that allow water recession rates to simulate "natural" conditions, as determined by a Natural System Model that includes management for historical salinity regimes in the estuary.

One area that must be reintegrated into the ecosystem is "The Frog Pond" (Van Lent *et al.* 1993). However, acquisition of the land to allow for adjacent canal (L-31W and C-111) stages to be raised, may not be enough to restore lost storage capacity. If modeling scenarios, which incorporate flooding of the Frog Pond to allow higher canal stages, still fall short of the storage capacity necessary to maintain desired recession rates and downstream salinities, consideration should be given to developing and installing some kind of water management "liner" in the Frog Pond. The ideal "liner" would allow for storage of "excess" water during the wet season; as ground water levels receded, water would be released from the "liner" to maintain ground water closer to historic levels. The Frog Pond has been permanently altered by rock plowing and will be difficult to restore it to natural conditions because of the invasion of exotic vegetation. An additional benefit to maintaining the Frog Pond with a long hydroperiod would be to reduce invasions by exotic vegetation as it allowed for proactive water management of the eastern ecotone and Florida Bay.

The impounded area between C-111 canal and U.S. Highway 1 is already functioning as a defacto water conservation area. Ideally, that site should be restored as part of the continuous ecotone. However, if sufficient alternative sites for water storage cannot be identified, serious consideration should be given to maintaining and enhancing this area's function as a water conservation area.

Other Habitat Management Recommendations

RECOMMENDATION: Protect and restore ecotone wetlands east of U.S. Highway 1. The wetlands east of U.S. Highway 1 contain important wading bird habitat. While this ecotone habitat is outside ENP, our research demonstrated that they provide important foraging habitat for Roseate Spoonbills that nest in the Park. Therefore, successful restoration of northeast Florida Bay depends on

protection and restoration of these wetlands.

Distribution and soil composition of the transverse glades upstream of the ecotone, hammock orientations and historic drainage patterns suggest that much greater surface flow occurred to the east than currently (J. Meeder pers. comm.). Culverting of U.S. Highway 1 and the proposed east-west spreader canal should be evaluated for their potential to increase freshwater surface flows to that region, but without sacrificing designated water needs of adjacent areas.

These wetlands comprise the Model Lands Basin Project which is a priority purchase for the SFWMD this year (B. Helfferich pers. comm.) and Dade County has recommended immediate acquisition under their Environmentally Endangered Lands program. This purchase should be completed.

RECOMMENDATION: Protect breeding colonies from human disturbance. Increasing recreational use of Florida Bay increases the likelihood of increased direct human interference at spoonbill colonies within ENP. During our study, we discovered two colonies that were impacted by human disturbance. In response to the increasing human activity, ENP Enforcement Division should be required to ensure that sufficient isolation is maintained between colonies and Park visitors. In the face of increasingly heavy human use of Florida Bay, it is important that all breeding colonies within the Park be patrolled with sufficient regularity to determine that they are not being disrupted. Studies have determined that a 100 m (Erwin 1989) to 125 m (Rodgers and Smith 1991) buffer zone is necessary to minimize disturbance to wading bird colonies and rookeries. In light of that information and our observations of some continued disturbance to the Porjoe colony from boating traffic, we recommend increasing the distance of posting from Porjoe colony to 100 m and insuring that signs are placed in front of each primary point of access to the island. The type of intrusion observed at Buchanan Key should be eliminated with blocks to close human-created passage ways.

Other Research and Monitoring Priorities

The poor level of understanding of even the most basic ecological processes in the ecotone is impeding efforts to restore the greater Everglades ecosystem to historic conditions. To overcome these deficiencies, we recommend an increased research focus in the ecotone habitats.

RECOMMENDATION: Develop a greater understanding of determinants of primary and secondary productivity. Priority should be given to developing a greater understanding of determinants of primary and secondary productivity, a goal that will require vastly improving the capacity to monitor basic physical parameters, such as water level fluctuations, rainfall, surface and ground water flows, evapotranspiration and conductivity. Field studies, as well as studies that will allow laboratory manipulation of parameters (e.g. salinity concentrations and fluctuations, primary productivity) on fish growth, reproduction and larval recruitment are necessary.

RECOMMENDATION: Complete the topographical survey of the ecotone and survey water level recorders to sea level. These surveys must be completed to allow the integration of data from the ecotone with those of freshwater marsh and Florida Bay. As well, the past, present and future influence of sea level rise on the ecotone cannot be evaluated without this information.

RECOMMENDATION: Model ecotone hydrology: analyze impact of large discharges and increased canal stages (under the natural system model) on ecotone hydropatterns. Our conclusion that discharges do not impact surface water levels over most of the ecotone are based on three years of hydrological data collected during a relatively dry period in south Florida. During that time C-111 canal stages were <3.9 ft (dry season stages averaged much lower, Van Lent *et al.* 1993) and discharge events <6000 acre-ft. The relationship between ecotone hydropatterns, C-111 canal stage and discharge should be evaluated under a greater range of conditions and with a more complete data network.

RECOMMENDATION: Investigate level of mercury contamination in the ecotone. Based on mercury concentrations in spoonbill nestlings in northeastern Florida Bay colonies, further investigation into occurrence of mercury in fish populations in the eastern ecotone should be conducted.

RECOMMENDATION: Monitor annual spoonbill population size (in addition to reproductive success in first recommendation). Although our analyses indicate that spoonbills are not directly impacted by canal discharges in the lower C-111 basin, the stability of their population will likely be influenced by the proposed changes. Along with lower C-111 basin, Taylor Slough provides important foraging habitat for the northeast Florida Bay nesting birds. Proposed structural and water management modifications to deliver more freshwater to the Bay will affect the ecological processes of both basins. Spoonbills are a Florida Species of Special Concern with greater than 90% of their nesting is concentrated in Florida Bay, about half of which depends on the southeastern ecotone for foraging. Monitoring spoonbill nesting distribution and abundance, therefore, is critical to assessing their status. At a minimum, this will require a single annual visit to the principal colonies (25 pairs or more), in early February. At that time, the spoonbill nestlings will be out of their nests but will probably still remain in the colonies; the threat of disturbance is avoided, but signs of nesting activity will remain clearly visible. The relatively low costs required to continue monitoring the size of the population make this data set a cost-effective measure of population status.

LITERATURE CITED

- Allen, R.P. 1942. The Roseate Spoonbill. National Audubon Society Research Report No. 2. Dover Publications Inc., New York. 142 pp.
- Allen, D.M., J.H. Hudson and T.J. Costello. 1980. Postlarval shrimp (*Penaeus*) in the Florida Keys: species, size and seasonal abundance. Bull. Mar. Sci. 30:21-33.
- _____. 1963. The present status of the Roseate Spoonbill, a summary of events 1943-1963. Unpubl. rept., National Audubon Society Research Department, Tavernier, Florida.
- Bancroft, G.T., S.D. Jewell and A.M. Strong. 1990. Foraging and nesting ecology of herons in the lower Everglades relative to water conditions. Final report to the South Florida Water Management District, West Palm Beach, Florida. 167 pp.
- Bancroft, G.T., A.M. Strong, R.J. Sawicki, W. Hoffman, S.D. Jewell. 1994. Relationships among wading bird foraging patterns, colony locations, and hydrology in the Everglades. *in* Everglades: the ecosystem and its restoration. S.M. Davis and J.C. Ogden (eds.), St. Lucie Press, Delray Beach, Florida.
- Bjork, R. and G. Powell. in press. Roseate Spoonbill. *in* Rare and endangered biota of Florida, Birds (Rodgers, J.A., ed.). Univ. Press, Gainesville, Florida.
- Blaha, J.P. 1984. Fluctuations of monthly sea level as related to intensity of the Gulf Stream from Key West to Norfolk. J. Geophys. Res. 89(C5):8033-8042.
- Egler, F. 1950. Southeast saline Everglades vegetation, Florida, and its management. American Museum of Nat. History. New York. 265 pp.
- Erwin, R.M. 1989. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. Colonial Waterbirds 12(1):104-108.
- Everglades National Park. 1978. Roseate Spoonbill biology. Progress Report, June 1978. Homestead, Florida.
- _____. 1979. Roseate Spoonbill biology. Annual Report, FY79. Homestead, Florida.
- _____. 1993. Preliminary recommendations for improved water management and increased water deliveries to Everglades National Park. Unpubl. rpt. Homestead, Florida.

- Frederick, P.C. 1986. Self-tripping trap for use with colonial nesting birds. *North Amer. Bird Bander* 11:94-95.
- _____ and M.W. Collopy. 1988. Reproductive ecology of wading birds in relation to water conditions in the Florida Everglades. Florida Coop. Fish and Wildl. Res. Unit, Sch. For. Res. and Conserv., Univ. of Florida. Tech. Rept. No. 30., Gainesville, Florida. 259 pp.
- _____ and S.M. McGehee. 1992. Wading bird use of wetlands receiving wastewater effluent in Florida. Report to the Environmental Protection Agency, Washington, D.C.
- _____ and W.L. Loftus. in press. Responses of marsh fishes and breeding wading birds to low temperatures: a possible behavioral link between predator and prey. *Estuaries*.
- _____ and M.G. Spalding. 1994. Factors affecting reproductive success by wading birds (Ciconiiformes) in the Everglades ecosystem. *in* Everglades: the ecosystem and its restoration. S.M. Davis and J.C. Ogden (eds.), St. Lucie Press, Delray Beach, Florida.
- Fleming, T.L. and B.C. Scheuch. 1990. Epoxies and gluing technique applicable to Marbled Murrelet and other seabird telemetry research. Unpubl. rept. for Titan Corporation, Lynnwood, Washington. 14 pp.
- Ford, G. 1987. CAMRIS Computer Aided Mapping and Resource Inventory System. Portland, Oregon.
- Henny, C.J. 1972. An analysis of the population dynamics of selected avian species with special reference to changes during the modern pesticide era. U.S. Fish Wildl. Serv. Wildl. Res. Rept. 1
- Hensler, G.L. 1985. Estimation and comparison of functions of daily nest survival probabilities using Mayfield method. *in* Statistics in ornithology, B.G.T. Morgan and P.M. North, (eds.). Springer-Verlag, New York. pp. 289-301.
- _____ and J.D. Nichols. 1981. The Mayfield method of estimating nesting success: A model, estimators and simulation results. *Wilson Bulletin* 93:42-53.
- Hoffman, W, T. Lane and G.T. Bancroft. 1992. Aerial surveys of wading birds in the Everglades WCAs: an analysis of sampling frequency and intensity in systematic reconnaissance flight survey design. National Audubon Society Report. Tavernier, Florida. 65 pp.
- Holmquist, J.G., G.V.N. Powell and S.M. Sogard. 1989. Sediment, water level and water temperature

- characteristics of Florida Bay's grass-covered mud banks. *Bull. Mar. Sci.* 44:348-364.
- Johnson R.A. and R.J. Fennema. 1989. Conflicts over flood control and wetland preservation in the Taylor Slough and eastern panhandle basins of Everglades National Park. *Wetlands: Concerns and Successes*, American Water Resources Association: 451-462.
- Kahl, M.P., Jr. 1964. Food ecology of the Wood Stork (*Mycteria americana*) in Florida. *Ecol. Monogr.* 34:97-117.
- Kushlan, J.A. 1976. Wading bird predation in a seasonally fluctuating pond. *Auk* 93:464-476.
- Kushlan, J.A., J.C. Ogden and A.L. Higer. 1975. Relation of water level and fish availability to Wood Stork reproduction in the southern Everglades, Florida. *USGS Open File Report* 75-434.
- Lidz, B.H. and E.A. Shinn. 1991. Paleoshorelines, reefs, and a rising sea: south Florida, U.S.A. *J. Coastal Res.* 7(1):203-229.
- Lorenz, J.J. 1993a. The effect of management induced changes in habitat type of the C-111 and Taylor Slough basins since 1940: the effects on prey base fishes and Documenting the influence of changes in hydrology on fish populations in the mangrove zone of C-111 and Taylor Slough basins: a biological monitor of water management alterations. Proposal to the South Florida Water Management District, West Palm Beach, Florida. 22 pp.
- _____. 1993b. Influence of hydrology on fish populations in the mangrove dominated zones of the C-111 and Taylor Slough basins and Biscayne Bay. Progress report to Everglades National Park, Homestead, Florida. 43 pp.
- _____ and G.V.N. Powell. 1992. Influence of hydrology on fish populations in the mangrove dominated zones of the C-111 and Taylor Slough basins and Biscayne Bay. Second Annual progress report to Everglades National Park, Homestead, Florida.
- Mazzotti, F.J. and L.A. Brandt. 1989. Evaluating the effects of ground water levels on the reproductive success of the American crocodile in Everglades National Park (RWO 50). Final Report to the U.S. Army Corps of Engineers and the South Florida Water Management District, West Palm Beach, Florida. 120 pp.
- Mayfield, H.F. 1961. Nesting success calculated from exposure. *Wilson Bull.* 73:255-261.
- _____. 1975. Suggestions for calculating nest success. *Wilson Bull.* 67:84-99.

- Ogden, J.C. 1978. Roseate Spoonbill. Pp. 52-54 *in* Rare and endangered biota of Florida, vol. II: Birds (Kale, H.W., II, ed.). Univ. Presses. Gainesville, Florida.
- _____, H.W. Kale II, and S.A. Nesbitt. 1980. The influence of annual variation in rainfall and water levels on nesting by Florida populations of wading birds. *Trans. Linn. Soc., New York* 9:115-126.
- _____. 1994. A comparison of wading bird nesting colony dynamics, 1931-1946 and 1974-1989, as an indication of changes in ecosystem conditions in the southern Everglades, Florida. *in* Everglades: the ecosystem and its restoration. S.M. Davis and J.C. Ogden (eds.), St. Lucie Press, Delray Beach, Florida.
- Olmsted, I., H. Dunevitz and W.J. Platt. in press. Effects of freezes on tropical trees in Everglades National Park, Florida, USA. *Tropical Ecology*.
- Powell, G.V.N. 1987. Habitat use by wading birds in a subtropical estuary: implications of hydrography. *Auk* 104:740-749.
- _____, R.D. Bjork, J.C. Ogden, R.T. Paul, A.H. Powell, W.B. Robertson Jr. 1989. Population trends in some Florida Bay wading birds. *Wilson Bull.* 101:436-457.
- _____ and R.D. Bjork. 1990. Studies of wading birds in Florida Bay: a biological assessment of the ecosystem. Comprehensive Report 1987-1990 submitted to the South Florida Research Center, Everglades National Park, Homestead, Florida.
- Rodgers, J.A. and H.T. Smith. 1991. Minimum buffer zone requirement to protect nesting bird colonies from human disturbance. *Proc. Coastal Nongame Workshop. U.S. Fish and Wildl. Ser. and Fl. Game Freshwater Fish Comm., Gainesville, FL.* pp. 55-56.
- Schomer, N.S. and R.D. Drew. 1982. An ecological characterization of the Lower Everglades, Florida Bay and the Florida Keys. U.S. Fish Wildl. Serv., Off. Biol. Serv. FWS/OBS-82/58.
- Sculley, S.P. 1986. Florida Bay salinity concentration and ground water stage correlation and regression. Unpubl. rept., South Florida Water Management District, West Palm Beach, Florida.
- Spalding, M.G. and D.J. Forrester. 1991. Effects of parasitism and disease on the nesting success of colonial wading birds (Ciconiiformes) in southern Florida. Draft Rpt. to Fl. Game and Freshwater Fish Commission, submitted as Final Rpt. No. NG88-008. 128 pp.

- Tabb, D.C. 1967. Predictions of estuarine salinities in Everglades National Park, Florida by the use of ground water records. Ph.D. Dissertation, Univ. of Miami, Florida.
- Van Lent, T.J.V., R. Johnson, and R. Fennema. 1993. Draft: Water management in Taylor Slough and effects on Florida Bay, January 1993. South Florida Research Center Rept., Everglades National Park, Homestead, Florida.
- Walters, C., L. Gunderson and C.S. Holling. 1992. Experimental policies for water management in the Everglades. *Ecological Applications* 2(2):189-202.
- White, D.A. 1983. Oceanographic monitoring study 1980-1983. Report of the South Florida Research Center, Everglades National Park, Homestead, Florida. 144 pp.
- White, D.H., C.A. Mitchell and E. Cromartie. 1982. Nesting ecology of Roseate Spoonbills at Nueces Bay, Texas. *Auk*. 99:275-284.
- Wilkinson, L. 1990. SYSTAT: The system for statistics, Version 5.0. SYSTAT, Inc., Evanston, Illinois.
- Wood, D.A. 1992. Official lists of endangered and potentially endangered fauna and flora in Florida. *Fl.Game Freshwater Fish Comm.*, Tallahassee, Florida.

Table 1. Description of independent variables used in multiple variable linear regression.

1	Rate of change (cm/day) in freshwater marsh water level	Difference in mean water level in late December (27-31 Dec) and early March (1-5 Mar) divided by the number of days in the period (the time when spoonbills would likely have foraged in freshwater marshes). Data are from recorder G1251 ¹ . This variable represents the extent of drydown; the higher the rate, the less the water recession.
2	Freshwater marsh water level (cm) in January	Mean monthly water level for January at recorder G1251 ¹ .
3	Rate of change (cm/day) in marine water level	Difference in mean monthly water level in late October (27-31 Oct) and early January (1-5 Jan) divided by the number of days in period (the time when spoonbills would likely have foraged in coastal marshes). Data are from the Key West recorder ² . This variable represents the extent of drydown; the higher the rate, the less the water recession.
4	Marine water level (cm) in December	Mean monthly water level for December at recorder KW ²
5	Total rainfall	Total maximum daily rainfall at the S-18C rainfall recorder ³ during the estimated nest period from hatching to 4 weeks old.
6	Ambient temperature	Number of days with minimum daily temperature $\leq 11^{\circ}\text{C}$ (52°F) during the estimated nest period from hatching to 4 weeks old. 11°C is the temperature at which small fishes (primary prey species of spoonbills) exhibited reduced activity in laboratory experiments (Fredrick and Loftus in press). Temperature data were obtained for the Flamingo Ranger Station ⁴ .
7	Canal discharge	Flow (acre-ft) through S-197 ³ subtracted from flow (acre-ft) through S-18C ³ during the estimated nest period from hatching to 4 weeks old.
8	Nesting Initiation	Estimated average date of nesting initiation at Tern Key based on nest data compiled from different sources (see Table 8 for sources).

¹ ENP, Homestead, FL

² U.S. Dept. of Commerce, NOAA, Rockville, MD

³ SFWMD, West Palm Beach, FL

⁴ NOAA Climatological Reports, Environmental Data and Information Service, Ashville NC

Table 2. Correlation coefficients of correlations between hydrographs from recorders along each of the Highway Creek and Joe Bay transects (in a roughly north-south alignment). Correlations were made using daily change in water level at recorders. Each pair of hydrographs was correlated for change in water level on the same day and with lags of 1, 2, and 3 days both from north to south and south to north. For example, in the Highway Creek transect in 1990-91, the correlation coefficient for a 1-day lag south to north between LS-UH was $r=0.60$, which was the change in water level of LS on day 1 and UH on day 2. Two dry seasons were analyzed: October-March, 1990-91 and 1991-92. Highlighted numbers ($r \geq 0.05$) are discussed in Results/Hydrology section. See Figure 5 for locations of recorders. ID means insufficient data.

HIGHWAY CREEK (eastern transect)

Oct 1990-Mar 1991

	CT3-EPSW	CT3-UH	CT3-LH	CT3-LS	EPSW-UH	EPSW-LH	EPSW-LS	UH-LH	UH-LS	LH-LS
Same day	0.61	0.48	0.49	0.37	0.57	0.49	0.30	0.83	0.58	0.74
North to South										
1-day lag	0.57	0.28	0.26	0.12	0.18	0.13	0.05	0.41	0.16	0.19
2-day lag	0.45	0.08	0.01	-0.06	-0.03	-0.08	0.14	0.10	-0.06	0.02
3-day lag	0.30	0.05	0.03	-0.14	-0.05	-0.13	0.22	-0.08	-0.25	-0.14
	LS-LH	LS-UH	LS-EPSW	LS-CT3	LH-UH	LH-EPSW	LH-CT3	UH-EPSW	UH-CT3	EPSW-CT3
South to North										
1-day lag	0.72	0.60	0.26	0.23	0.51	0.28	0.16	0.29	0.14	0.10
2-day lag	0.34	0.33	0.19	0.08	0.25	0.20	0.02	0.21	-0.01	-0.20
3-day lag	0.16	0.20	0.19	0.03	0.16	0.21	0.09	0.15	-0.02	-0.23

Oct 1991-Mar 1992

	CT3-EPSW	CT3-UH	CT3-LH	CT3-LS	EPSW-UH	EPSW-LH	EPSW-LS	UH-LH	UH-LS	LH-LS
Same day	0.40	0.24	0.20	-0.13	0.29	0.25	-0.13	0.83	0.47	0.66
North to South										
1-day lag	0.09	0.09	0.07	-0.19	0.14	0.08	-0.27	0.31	-0.06	0.07
2-day lag	0.06	0.03	0.09	-0.13	-0.03	0.05	-0.18	0.01	-0.26	-0.21
3-day lag	-0.13	0.01	0.10	-0.06	-0.10	0.13	-0.10	0.08	-0.16	-0.12
	LS-LH	LS-UH	LS-EPSW	LS-CT3	LH-UH	LH-EPSW	LH-CT3	UH-EPSW	UH-CT3	EPSW-CT3
South to North										
1-day lag	0.60	0.55	0.01	0.01	0.54	0.11	0.16	0.14	0.17	0.39
2-day lag	0.23	0.24	0.06	0.26	0.11	0.04	0.08	0.09	0.11	-0.04
3-day lag	0.16	0.13	0.03	0.25	0.02	0.04	0.10	0.01	0.06	-0.27

Table 2 (continued)

JOE BAY (western transect)										
Oct 1990-Mar 1991										
	CT50-EPSW	CT50-UJ	CT50-LJ	CT50-JB	EPSW-UJ	EPSW-LJ	EPSW-JB	UJ-LJ	UJ-JB	LJ-JB
Same day	0.70	0.49	ID	0.37	0.70	ID	0.42	ID	0.53	ID
North to South										
1-day lag	0.61	0.50	ID	0.28	0.47	ID	0.17	ID	0.08	ID
2-day lag	0.34	0.24	ID	-0.01	0.15	ID	-0.03	ID	-0.12	ID
3-day lag	0.20	0.14	ID	-0.09	0.05	ID	-0.09	ID	-0.13	ID
	JB-LJ	JB-UJ	JB-EPSW	JB-CT50	LJ-UJ	LJ-EPSW	LJ-CT50	UJ-EPSW	UJ-CT50	EPSW-CT50
South to North										
1-day lag	0.39	0.59	0.28	0.12	ID	ID	ID	0.24	-0.01	0.06
2-day lag	0.35	0.37	0.15	0.04	ID	ID	ID	0.10	-0.05	-0.17
3-day lag	0.27	0.17	0.06	0.02	ID	ID	ID	0.01	-0.07	-0.19
Oct 1991-Mar 1992										
	CT50-EPSW	CT50-UJ	CT50-LJ	CT50-JB	EPSW-UJ	EPSW-LJ	EPSW-JB	UJ-LJ	UJ-JB	LJ-JB
Same day	0.47	0.29	0.21	0.24	0.61	0.35	0.30	0.55	0.45	0.87
North to South										
1-day lag	0.13	0.30	0.23	0.14	0.45	0.20	0.12	0.16	0.06	0.29
2-day lag	0.07	0.17	0.06	-0.05	0.18	-0.01	-0.08	-0.18	-0.21	-0.15
3-day lag	-0.15	0.12	-0.03	-0.08	-0.06	-0.09	-0.14	-0.22	-0.23	-0.20
	JB-LJ	JB-UJ	JB-EPSW	JB-CT50	LJ-UJ	LJ-EPSW	LJ-CT50	UJ-EPSW	UJ-CT50	EPSW-CT50
South to North										
1-day lag	0.76	0.51	0.02	0.11	0.54	0.20	0.11	0.20	0.12	0.29
2-day lag	0.24	0.30	-0.03	0.06	0.26	0.12	0.05	-0.05	-0.08	-0.02
3-day lag	-0.05	0.06	0.02	0.07	-0.02	0.05	0.04	0.09	-0.08	-0.25

Table 3. Banding statistics for Roseate Spoonbills radio-tagged during 2 nesting seasons.

Colony	FWS#	Radio Frequency	Date Banded	Bird Mass (g)
1990-91				
	Tern Key			
	867-16039	918.6	12 Dec 90	1553
	867-16041	892.1	17 Dec 90	1799
	867-16044	888.2	20 Dec 90	1629
	867-16042	894.0	18 Dec 90	1395
	867-16045	899.5	20 Dec 90	1716
	867-16043	890.1	18 Dec 90	1595
	867-16040	908.5	14 Dec 90	1621
	Porjoe Key			
	867-16046	896.1	27 Dec 90	1773
	867-16054	886.1	3 Jan 91	1346
	867-16059	874.3	8 Jan 91	1428
	867-16060	826.2	16 Jan 91	1520
	667-94877	870.2	18 Jan 91	1242
	667-94882	852.2	24 Jan 91	1257
1991-92				
	Tern Key			
	667-94889	918.5	21 Dec 91	1790
	667-94893	927.9	27 Dec 91	1483
	667-94895	962.0	30 Dec 91	1428
	667-94896	982.0	31 Dec 91	1281
	667-94891	977.9	26 Dec 91	1454
	667-94890	874.2	21 Dec 91	1377
	667-94898	935.7	7 Jan 92	1350
	4007-0020	939.8	7 Jan 92	ND
	667-94894	947.7	30 Dec 91	1479
	667-94892	970.0	26 Dec 91	1408
	Porjoe Key			
	4007-00027	950.9	12 Jan 92	1705
	4007-00028	965.9	18 Jan 92	1665
	4007-00021	943.8	8 Jan 92	1449
	4007-00023	954.0	8 Jan 92	1227
	4007-00097	963.9	28 Jan 92	1242

Table 4. Number of nesting pairs of Roseate Spoonbills in Florida Bay, 1987-88 through 1991-92. Totals do not include small numbers of spring nests which are believed to be second nesting attempts. Colonies are arranged by relative location in Florida Bay for regional analyses. Nesting numbers/colony from 1935-1987 are in Powell *et al.* 1989. ND = no data.

Key	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992
Central Region					
East Bob Allen	9	15	34	35	24
Bottle	0	6	19	30	40
East Buchanan	19	1	8	7	0
West Buchanan	0	6	8	4	9
Middle Butternut	14	10	12	18	17
East Butternut	8	10	6	11	4
Cowpens	14	14	9	8	8
Crab	0	0	0**	0	0
Crane	12	21	17	13	13
East	0	0	0	0	0
Jimmie Channel	28	13	18	19	47
Manatee	0	0	0	0	0
Pigeon	12	0	3	8	5
Stake	0	0	8	19	18
Twin	ND	ND	5	8	8
West	9	8	1*	8	6
Northeast Region					
Tern***	110	153	113	113	172
North Park	9	50	36	30	36
South Park	10	39	17	25	25
Pass	2	0	0	0	ND
Porjoe	75	25	28	60	66
South Nest	21	43	39	39	59
Northwest Region					
Big Oyster	0	4	9	8	45
Frank	4	13	22	23	46
Sandy	151	223	163	221	232
Total colonies	17	18	21	21	20
Total nests	507	654	575	707	880

* colony shift in location on the island was not detected until 1990-91

** aerial survey of island only

*** 1992-93 count at Tern Key was 102 nests, less than counts from the last 5 seasons.

Table 5. Productivity of Roseate Spoonbills at three colonies in Florida Bay for five consecutive nesting seasons. Note, because of relatively small nesting numbers, the Porjoe colony was not monitored in 1989-90 and 1990-91.

Colony Year	Mean clutch size $\pm$ s.d.(N)*	Mean young to 14 d per successful nest $\pm$ s.d. (N)	Mean young to 14 d per nest attempt $\pm$ s.d. (N)	Mean young to 21 d per successful nest $\pm$ s.d. (N)	Mean young to 21 d per nest attempt $\pm$ s.d. (N)
Tern					
1987-88	3.0 $\pm$ 0.0 (31)	2.3 $\pm$ 0.8 (50)	2.0 $\pm$ 1.1 (57)	1.9 $\pm$ 1.1 (39)	1.3 $\pm$ 1.1 (57)
1988-89	3.0 $\pm$ 0.6 (44)	2.7 $\pm$ 0.6 (53)	2.2 $\pm$ 1.2 (64)	2.4 $\pm$ 0.7 (45)	1.9 $\pm$ 1.2 (59)
1989-90	3.3 $\pm$ 0.7 (59)	2.7 $\pm$ 0.6 (51)	2.4 $\pm$ 1.1 (58)	2.6 $\pm$ 0.7 (39)	2.2 $\pm$ 1.2 (46)
1990-91	3.5 $\pm$ 0.7 (19)	3.0 $\pm$ 0.9 (35)	2.3 $\pm$ 1.5 (45)	2.8 $\pm$ 1.0 (18)	1.8 $\pm$ 1.6 (28)
1991-92	3.7 $\pm$ 0.6 (43)	2.7 $\pm$ 0.7 (47)	2.2 $\pm$ 1.3 (58)	2.4 $\pm$ 0.8 (30)	1.5 $\pm$ 1.3 (49)
Porjoe					
1987-88	2.8 $\pm$ 0.4 (10)	2.1 $\pm$ 0.7 (21)	1.4 $\pm$ 1.1 (30)	1.8 $\pm$ 0.6 (19)	1.1 $\pm$ 1.0 (30)
1988-89	3.0 $\pm$ 0.4 (13)	2.8 $\pm$ 0.6 (12)	2.1 $\pm$ 1.3 (16)	2.6 $\pm$ 0.8 (10)	1.7 $\pm$ 1.4 (15)
1991-92	3.2 $\pm$ 0.6 (31)	2.5 $\pm$ 0.9 (18)	1.6 $\pm$ 1.4 (29)	2.1 $\pm$ 1.0 (11)	0.8 $\pm$ 1.2 (29)
Sandy					
1987-88	3.0 $\pm$ 0.7 (22)	2.8 $\pm$ 0.7 (51)	2.6 $\pm$ 0.9 (54)	**	**
1988-89	2.8 $\pm$ 0.6 (31)	2.7 $\pm$ 0.7 (27)	2.3 $\pm$ 1.1 (31)	2.7 $\pm$ 0.6 (10)	1.9 $\pm$ 1.4 (14)
1989-90	3.5 $\pm$ 0.6 (17)	2.7 $\pm$ 0.6 (23)	2.6 $\pm$ 0.8 (24)	2.8 $\pm$ 0.7 (8)	2.4 $\pm$ 1.1 (9)
1990-91	3.2 $\pm$ 0.6 (34)	2.5 $\pm$ 0.8 (26)	2.4 $\pm$ 0.9 (27)	2.5 $\pm$ 0.5 (11)	2.1 $\pm$ 1.0 (13)
1991-92	3.3 $\pm$ 0.8 (13)	2.6 $\pm$ 0.8 (28)	2.5 $\pm$ 1.0 (29)	2.4 $\pm$ 0.7 (22)	2.0 $\pm$ 1.1 (26)

* Because of sensitivity of Roseate Spoonbills to disturbance during the early stages of nesting, we did not begin monitoring nests until 1-2 weeks after nest initiations. Mean clutch size was calculated from clutches in nests observed for a minimum of 2 previous nest surveys ($\approx$ 10 days) before hatching.

** High density of nests and mobility of young birds made it difficult to follow the success of individual nests. In 1987-88, birds older than 14 days grouped together in branches. No mortality in nests or the nesting area was recorded between the 14- and 21-day nesting period, and counts of these branchlings indicated continued high success.

Table 6. Summary of causes of mortality of nestling Roseate Spoonbills found dead in their nests. Data were derived from necropsies performed by Marilyn Spalding, DVM.

Cause of Mortality	Number of necropsies					All years	
	1987-88	1988-89	1989-90	1990-91	1991-92	# of necropsies	%
Disease	6	4	12	0	0	22	20
Parasites	2	1	0	4	0	7	6
Predation	15	4	6	0	13	38	35
Malnutrition	5	6	7	1	4	23	21
Other*	2	3	2	0	3	10	9
Unknown	0	0	6	1	3	10	9
Total	30	18	33	6	23	110	100

*nestlings with combination of causes of mortality including malnutrition, disease and parasitism.

Table 7. Mercury concentrations (ppm, wet weight) in liver tissues of nestling Roseate Spoonbills collected in Florida Bay colonies (from Spalding and Forrester 1991).

Northeastern Florida Bay			Northwestern Florida Bay		
ID#	Size*	ppm Hg	ID#	Size*	ppm Hg
90106	I	0.34	90029	III	0.16
89020	III	0.74	89031	IV	0.26
90019	III	0.31	90084	IV	0.35
90035	IV	0.39	89027	V	0.34
90031	V	0.57			
90032	V	5.38			
90033	V	1.88			
90034	V	0.63			
90037	V	0.51			
90153	VI	0.84			
Mean		0.73	Mean		0.27

* Size determination was made by subtracting hatchling bill length from adult bill length and dividing the result into 5 equal categories with I= newly hatched to V=fledging size.

Table 8. Timing of nesting and productivity (young 3-5 weeks old/nest attempt) of Roseate Spoonbills estimated from field notes, unpublished reports and this study during the period 1974-75 through 1991-92.

Year	Nest Initiation	Productivity	Source ¹
1974-75	20 Nov 74	1.4	3
1977-78	15 Nov 77	0	4
1978-79	15 Dec 78	0.6	5
1982-83	4 Dec 82	0	6
1983-84	1 Dec 83	0.5	7
1986-87	18 Nov 86	0	8
1987-88	27 Dec 87	1.1	9
1988-89	21 Nov 88	1.9	9
1989-90	7 Dec 89	2.2	9
1990-91	15 Nov 90	1.8	9
1991-92	23 Nov 91	1.5	9

¹Source

1. W.B. Robertson and J.C. Ogden, field notes; WOS²; D.H. Castlebury, BOC³
2. W.B. Robertson and J.C. Ogden, field notes
3. W.B. Robertson, J.C. Ogden, and J.A. Kushlan, field notes
4. ENP Roseate Spoonbill Biology Progress Report, June 1978
5. ENP Roseate Spoonbill Biology Annual Report, FY 79
6. B. Patty, field notes
7. G. Powell, field notes
8. R. Bjork, field notes
9. this report

² Wildlife Observation Card, ENP

³ Bird Observation Card, ENP

Table 9. Hydrologic/climatic data used in correlation and in multiple variable regression (top). Refer to Table 1 for description of variables. Table 8 lists spoonbill nesting initiation and productivity estimates. Pearson correlation matrix of hydrologic/climatic variables (bottom).

Year	Variables						
	Freshwater marsh rate of water level change (cm/day)	Freshwater marsh water level in January (cm)	Marine rate of change in water level (cm/day)	Marine water level in December (cm)	Total rainfall (cm)	# of days w/ minimum temp $\leq 11^{\circ}\text{C}$	Canal discharge (acre-ft)
1974-75	-0.63	-16.5	-1.22	155.8	4.7	2	0
1977-78	0.01	7.1	-0.02	161.1	17.3	12	0
1978-79	-0.31	2.6	-1.10	162.0	7.5	15	0
1982-83	0.17	13.1	-1.17	167.4	21.8	9	3822
1983-84	-0.25	7.0	-0.95	158.6	5.0	16	0
1986-87	-0.15	4.3	-0.67	168.7	15.0	3	13775
1987-88	-0.32	1.7	-0.55	167.9	4.4	9	5035
1988-89	-0.36	-13.2	-0.91	161.5	1.2	5	3363
1989-90	-0.26	-27.3	-1.61	146.8	0.5	3	2060
1990-91	-0.11	6.5	-0.62	159.3	1.1	4	2407
1991-92	-0.03	-8.0	-1.18	162.5	4.3	4	2629

PEARSON CORRELATION MATRIX

	Canal discharge	Freshwater rate of change in water level	Freshwater marsh water level in January	Nesting Initiation	Marine water level in December	Marine rate of change in water level	Ambient Temperature	Total Rainfall
Canal discharge	1.000							
Freshwater rate of change	0.189	1.000						
Freshwater level in Jan	0.162	0.585	1.000					
Nesting Initiation	-0.094	-0.149	-0.002	1.000				
Marine water level in Dec	0.547	0.380	0.722	0.091	1.000			
Marine rate of change	0.155	0.259	0.602	-0.286	0.499	1.000		
Temperature	-0.411	0.181	0.580	0.417	0.204	0.282	1.000	
Total Rainfall	0.288	-0.627	0.637	-0.109	0.562	0.342	0.280	1.00

Table 10. Data used to test the influence of rainfall and temperature on spoonbill productivity in the 1950's and 1960's and predicted spoonbill productivity for those years using the multiple linear regression model derived from 1970's-1990's data. See Table 1 for method of calculation of total rainfall (from NOAA Tavernier station) and ambient temperature parameters.

Nesting Season	Productivity # young/nest ¹	Rainfall (cm)	Temperature # days <11°C	Predicted Productivity # young/nest ²
1957-58	3.0	24.7	5	0.0
1958-59	2.6	3.0	6	1.5
1959-60	2.5	3.6	0	1.8
1960-61	2.0	0.6	4	1.8
1961-62	2.0	7.2	9	0.9
1962-63	2.0	2.2	6	1.6

¹Spoonbill productivity data were estimated from ENP and National Audubon Society field notes and unpublished reports.

²Predicted values are significantly lower than actual, estimated values of spoonbill productivity (Wilcoxon signed-rank test $P < 0.05$, Wilkinson 1990).

Table 11. Salinities (ppt) recorded at 100 m intervals along the western N-S transect between the LJ and UJ water level recorders and along the eastern transect between the LH and UH water level recorders. ND = no data. NSW = no surface water.

	1991			1992					
Western Stake #	13 Sep	14 Nov	13 Dec	23 Jan	19 Feb	25 Mar	27 Apr	10 Jun	14 Jul
1	1.5	0	2.0	11.5	17.0	26.5	31.0	29.0	0
2	1.5	0	2.0	11.5	16.0	26.5	29.0	27.0	0
3	1.0	0	1.5	9.0	13.5	26.0	28.5	27.0	0
4	1.0	0	2.0	7.0	12.5	25.0	30.0	25.0	0
5	1.0	0	1.5	7.5	12.0	24.0	30.0	24.0	ND
6	0.5	0	2.0	6.5	11.0	24.0	27.0	21.0	ND
7	0.5	0	2.0	5.5	11.0	23.0	27.0	21.0	0
8	1.0	0	1.5	5.0	11.5	23.0	27.0	20.0	0
9	0.5	0	2.0	4.0	12.0	22.0	28.0	20.0	0
10	ND	0	2.0	5.0	10.5	20.0	27.0	19.0	0
11	ND	0	2.0	4.0	9.5	19.0	25.0	18.0	0
12	0	0	2.0	3.0	10.0	17.0	24.0	18.0	ND
13	1.0	0	2.0	3.0	10.0	20.5	24.0	18.0	ND
14	0.5	0	1.5	3.0	10.0	16.5	14.5	18.0	0
15	0.5	0	2.0	3.0	10.0	12.0	ND	16.0	0
16	ND	0	ND	ND	10.0	ND	ND	16.0	0
17	0.5	0	2.0	2.0	9.5	ND	ND	16.0	0
18	0.5	0	2.0	1.5	6.0	11.0	18.0	16.0	0
19	0.5	0	1.0	1.5	5.0	9.0	ND	15.0	0
20	0.5	0	1.5	ND	5.0	7.5	14.0	15.0	0
21	0.5	0	1.0	1.5	5.0	8.5	15.0	14.0	0
22	0.5	0	1.0	1.5	5.0	8.0	ND	13.0	0
Eastern Stake #	26 Jul	7 Sept	30 Oct	8 Jan	14 Feb	16 Mar	23 Apr	22 May	4 Jul
1	2.5	0	3.0	20.0	15.5	26.0	32.5	ND	ND
2	1.0	0	0.5	8.5	ND	ND	27.0	56.0	0
3	1.0	0.5	0	7.0	8.0	26.5	29.0	45.0	0
4	1.0	ND	0.5	7.0	11.5	27.5	23.0	44.0	0
5	0	1.0	ND	7.0	9.0	20.0	17.0	42.0	0
6	0	1.0	0	4.0	5.0	19.0	14.0	42.0	0
7	0	1.5	0.5	3.5	5.0	14.0	25.0	42.0	0
8	0	1.5	0	3.0	12.0	26.0	NSW	41.0	0
9	0	1.0	0	3.0	NSW	NSW	NSW	44.0	0
10	0	1.0	0	2.5	NSW	NSW	NSW	55.0	0
11	0	1.0	0.5	2.0	NSW	NSW	NSW	45.5	0
12	0	1.0	0.5	2.0	NSW	NSW	NSW	ND	ND
13	0	1.0	0	1.5	NSW	NSW	NSW	36.5	0
14	0	ND	0	1.5	NSW	NSW	NSW	ND	0
15	0	0.5	0	1.5	13.0	NSW	NSW	34.0	0
16	0	1.0	0	1.5	NSW	NSW	NSW	37.0	0
17	0	ND	0	1.5	NSW	NSW	NSW	27.0	0

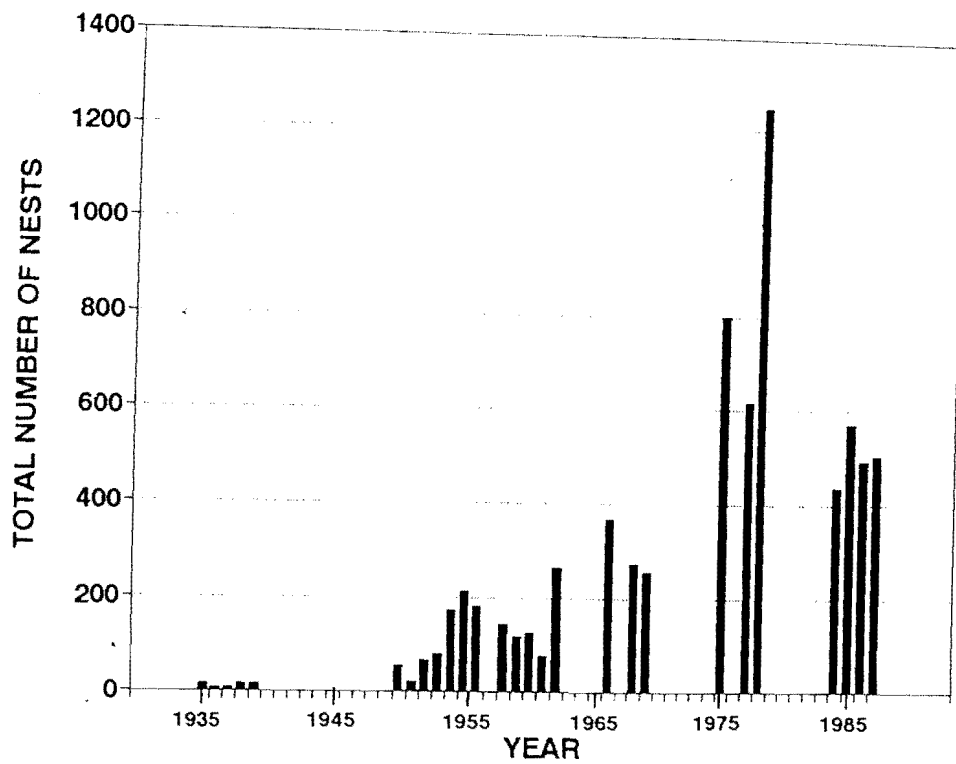


Figure 1. Number of Roseate Spoonbills nests in Florida Bay from 1935-36 through 1987-88.

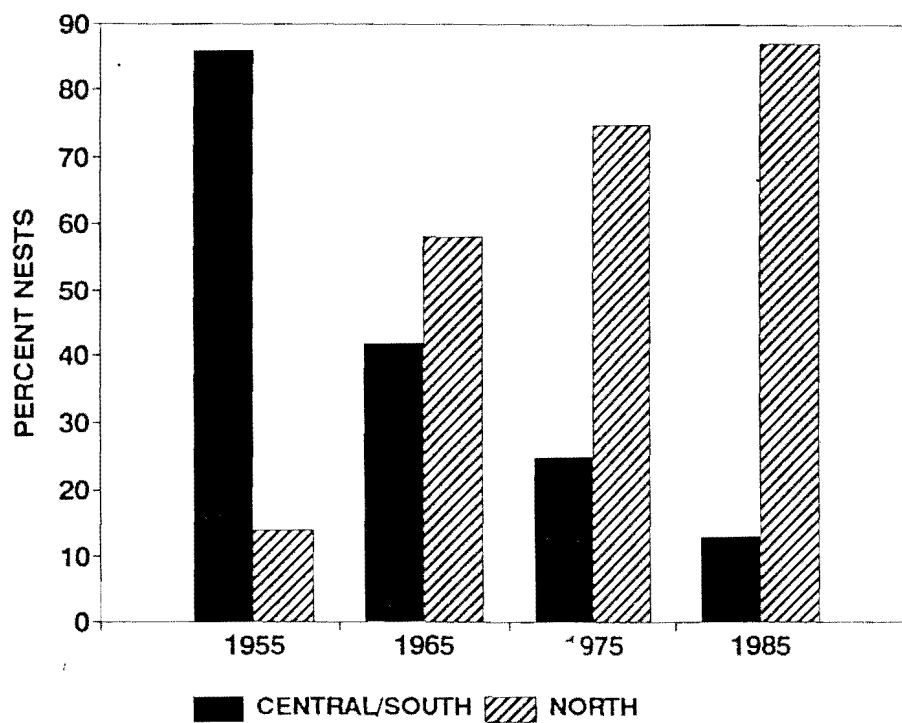


Figure 2. Regional distribution of Roseate Spoonbill nesting colonies in Florida Bay at 4 periods of time.

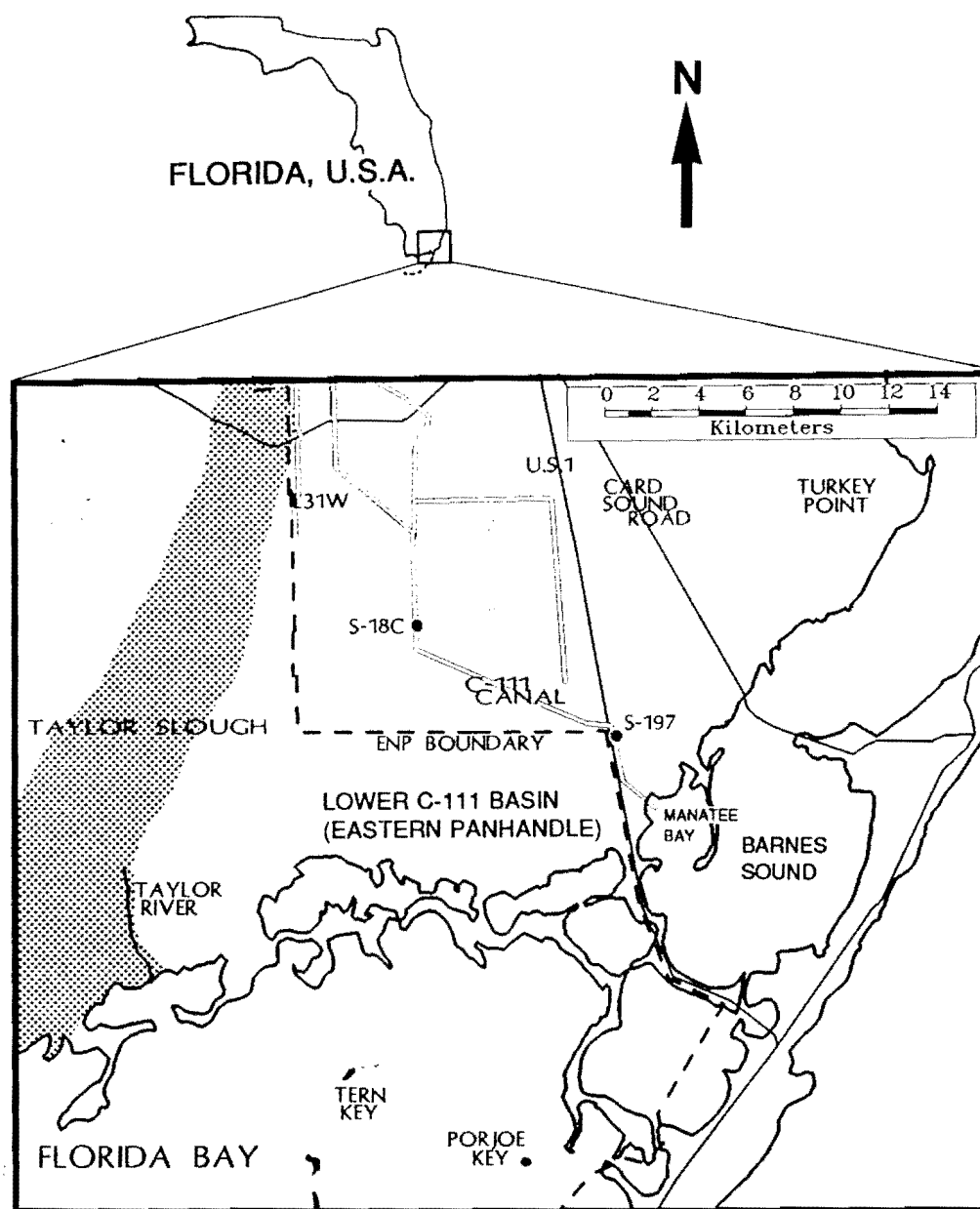


Figure 3. Overview of our primary study area, and the southern portion of the C-111 canal system, southeastern Florida.

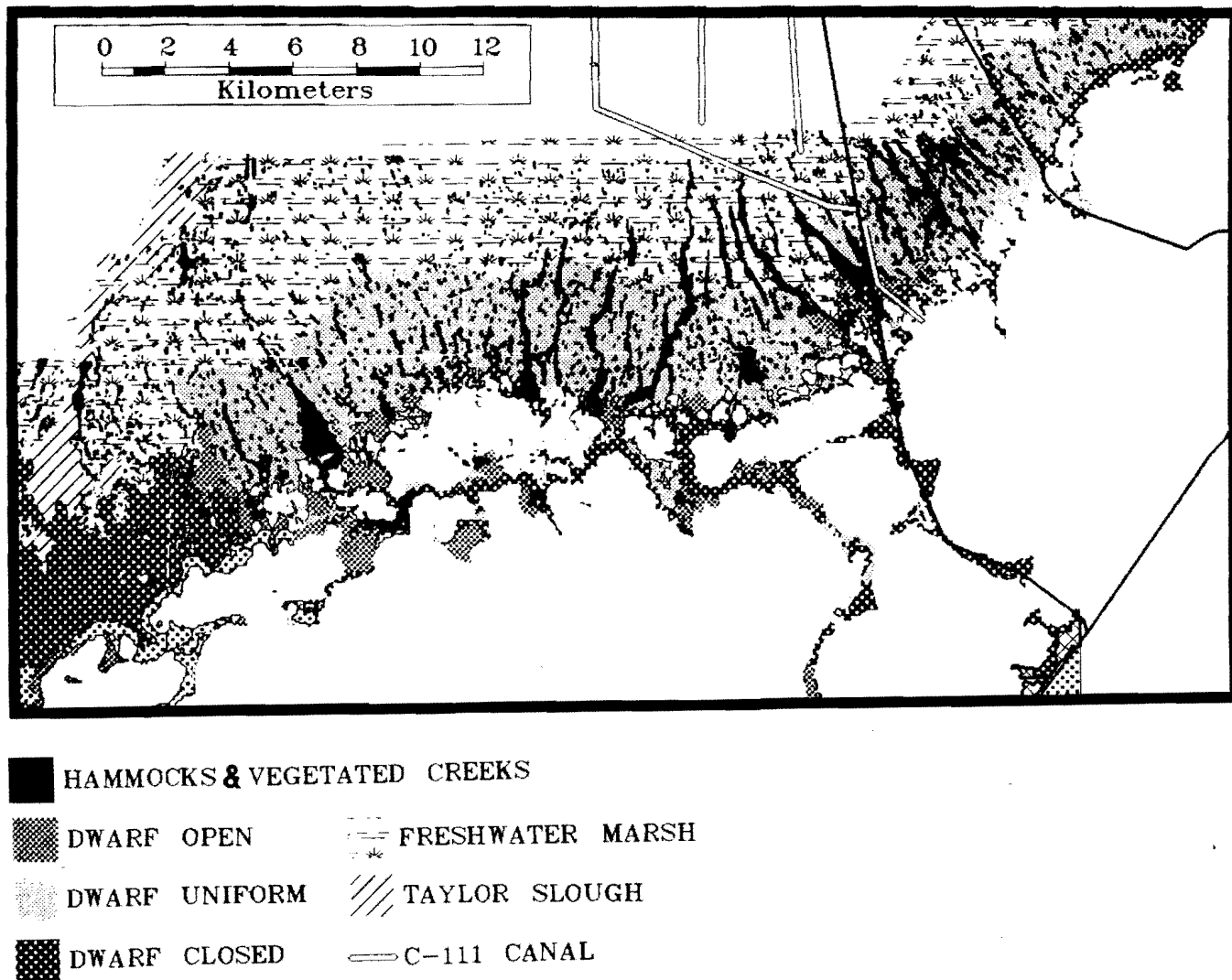


Figure 4. Map of distribution of dominant habitat categories in our primary study area of southeastern Florida. Refer to Appendix A for description of vegetation categories.

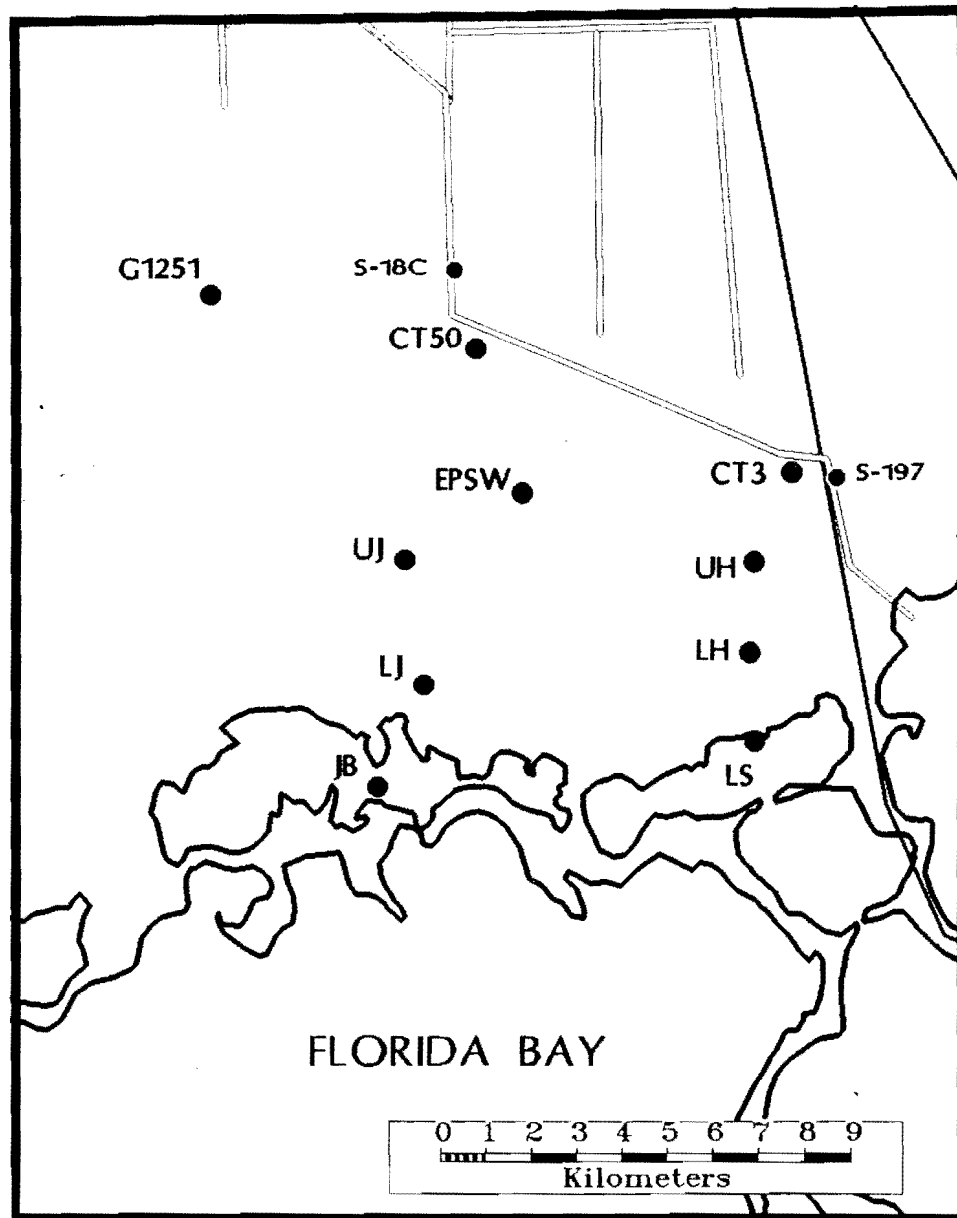


Figure 5. Locations of surface water recorders used in analyses of hydropatterns in the lower C-111 basin. Data from recorders G1251, CT50, CT3, EPSW, JB and LS was provided by Everglades National Park. Information on canal discharge through S-18C (minus discharge through S-197) was provided by the South Florida Water Management District.

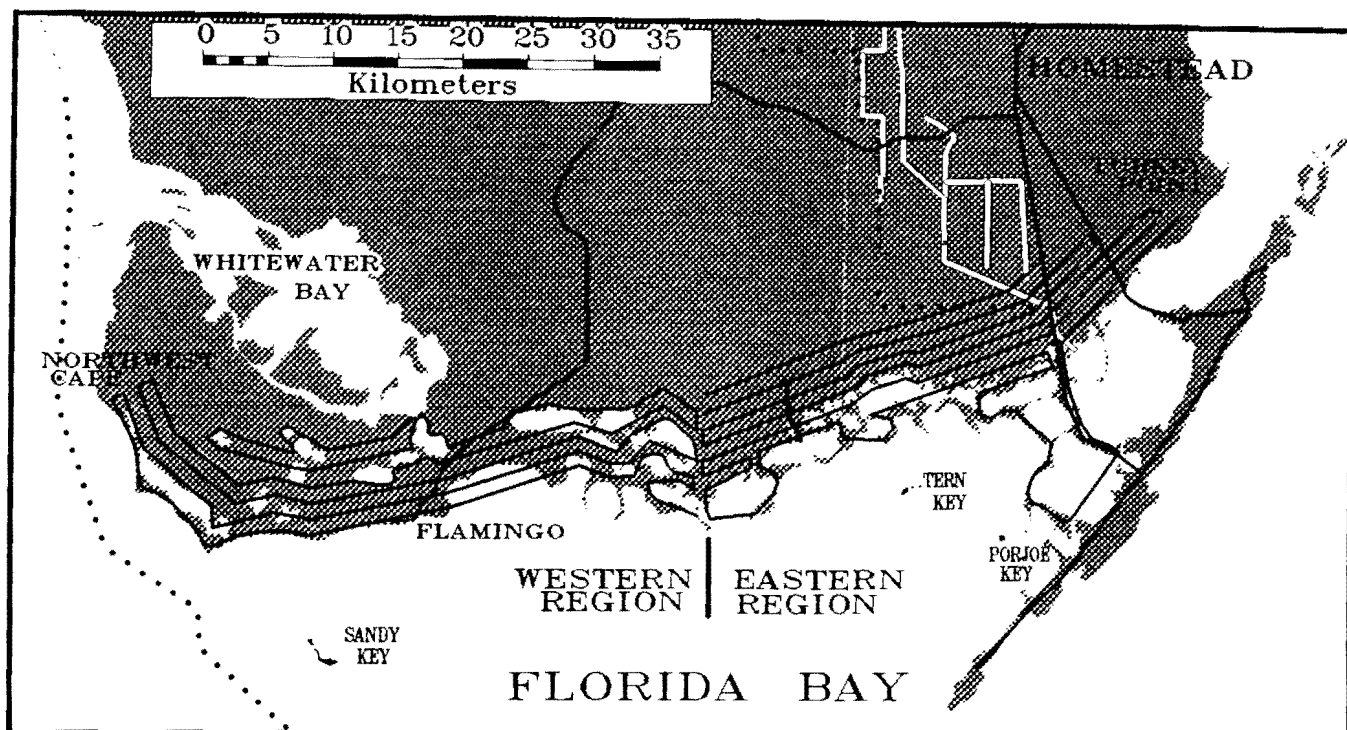


Figure 6. Transect pattern of wading bird/White Pelican aerial surveys conducted over the southern end of peninsular Florida. Bird abundance and density data were summarized separately for the eastern and western region.

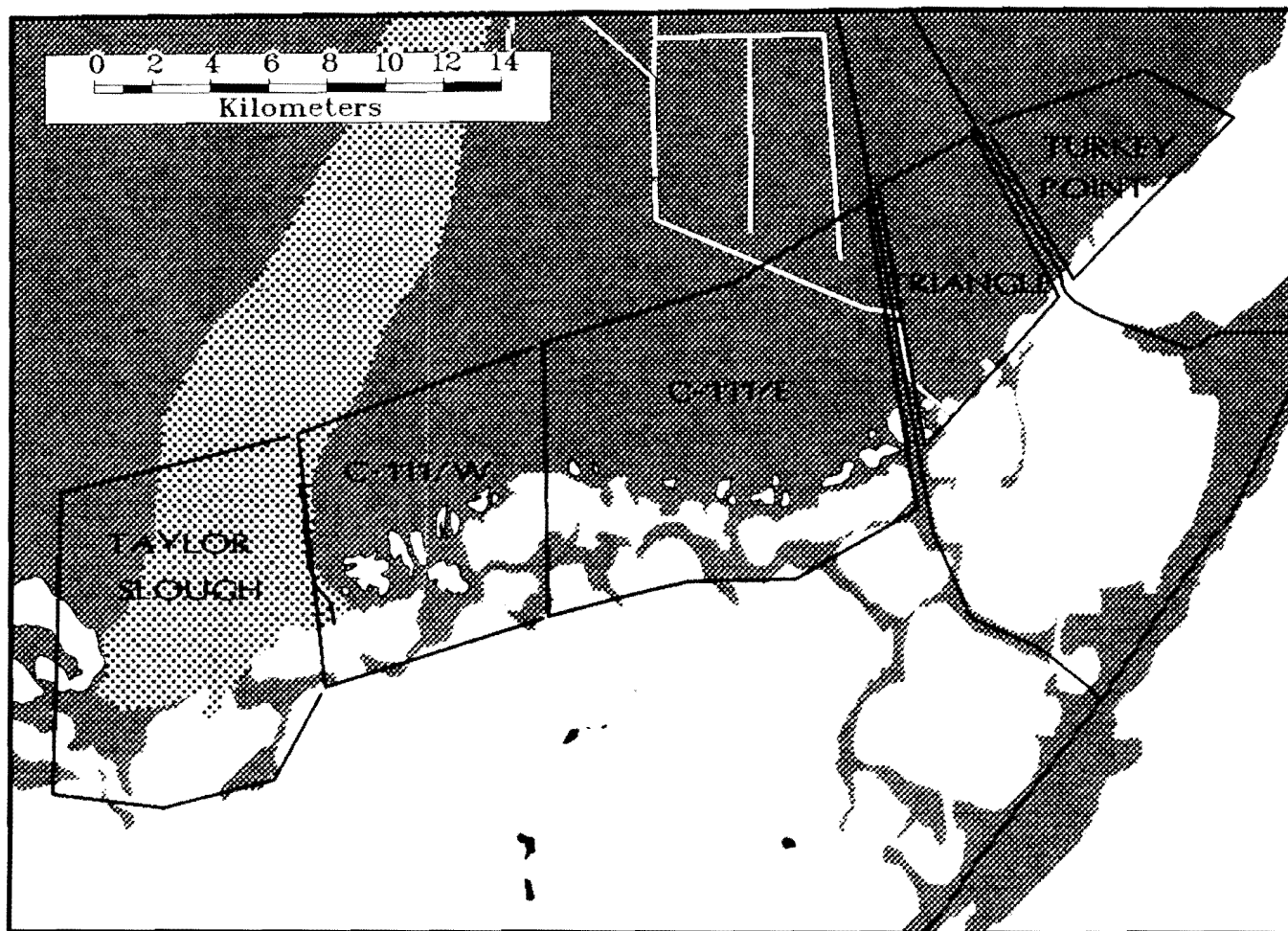


Figure 7. Boundaries of zones used in summaries of bird abundance (based on aerial survey data) in the eastern region. The C-111 Zone includes both C-111/E and C-111/W zones.

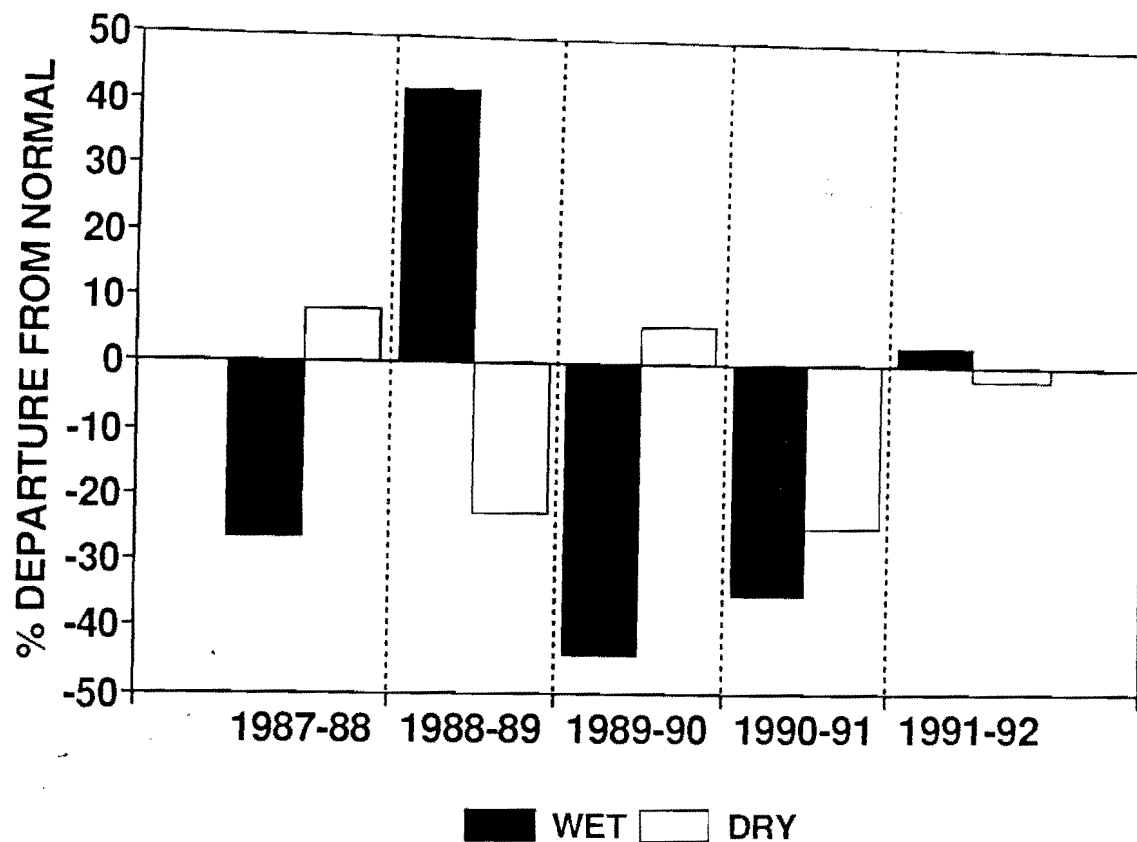


Figure 8. Precipitation data from the NOAA Tavernier station (% departure from normal) for the wet (May-October) and dry (November-April) seasons for the 5 years of our study.

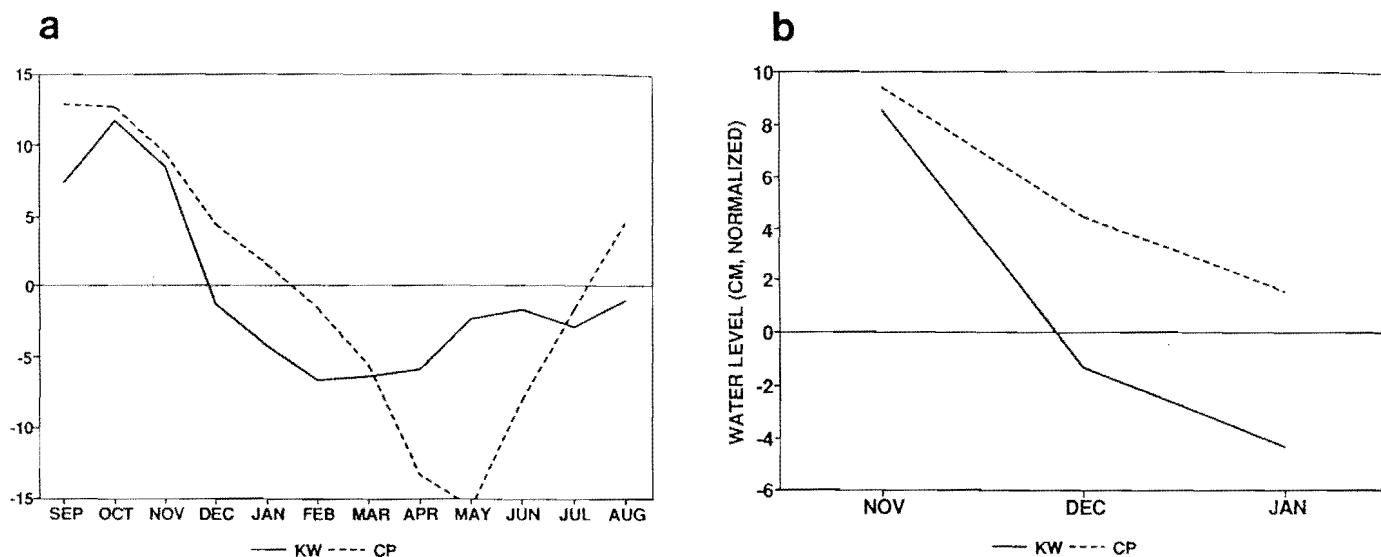


Figure 9. Hydrographs of mean monthly water level for the annual cycle (9a) and from November through January (9b) and at the marine recorder, Key West (KW) and the freshwater marsh recorder, Craighead Pond (CP). Monthly means are from period 1979 through 1988.

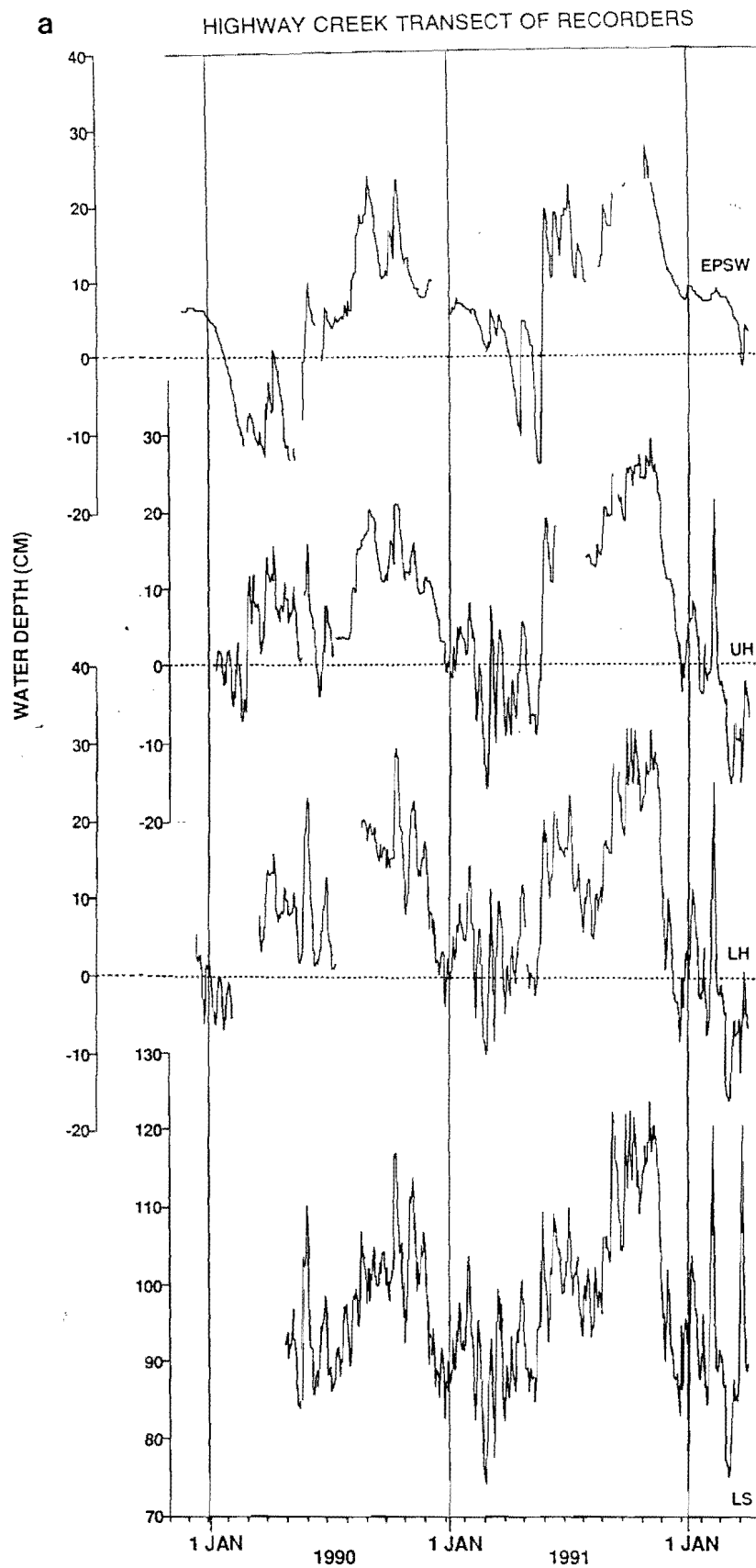


Figure 10. Surface water hydrographs from continuous water level recorders in the ecotone of lower C-111 basin. Dotted line at 0 for each hydrograph indicates approximate marsh surface.

b

JOE BAY TRANSECT OF RECORDERS

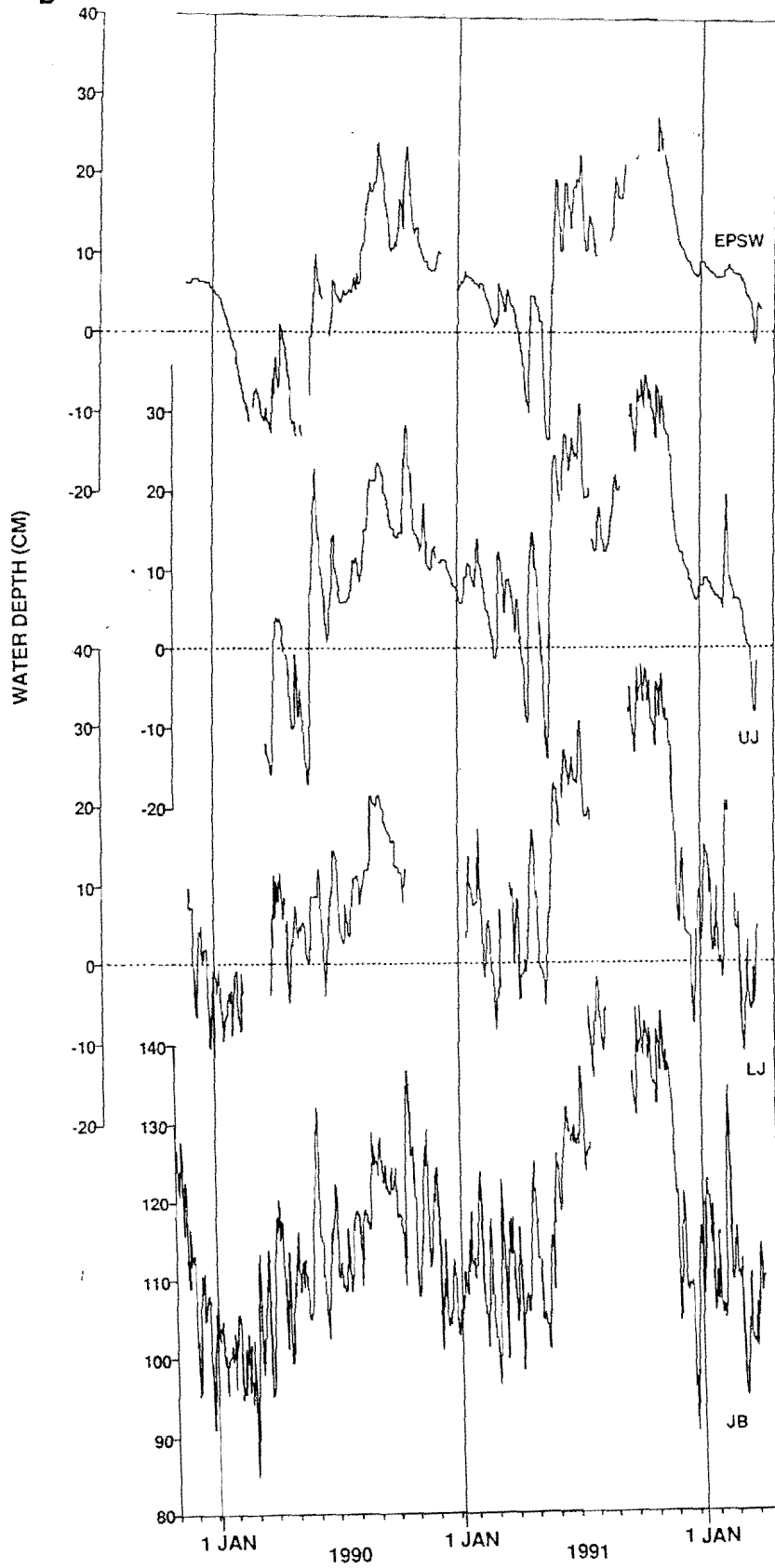
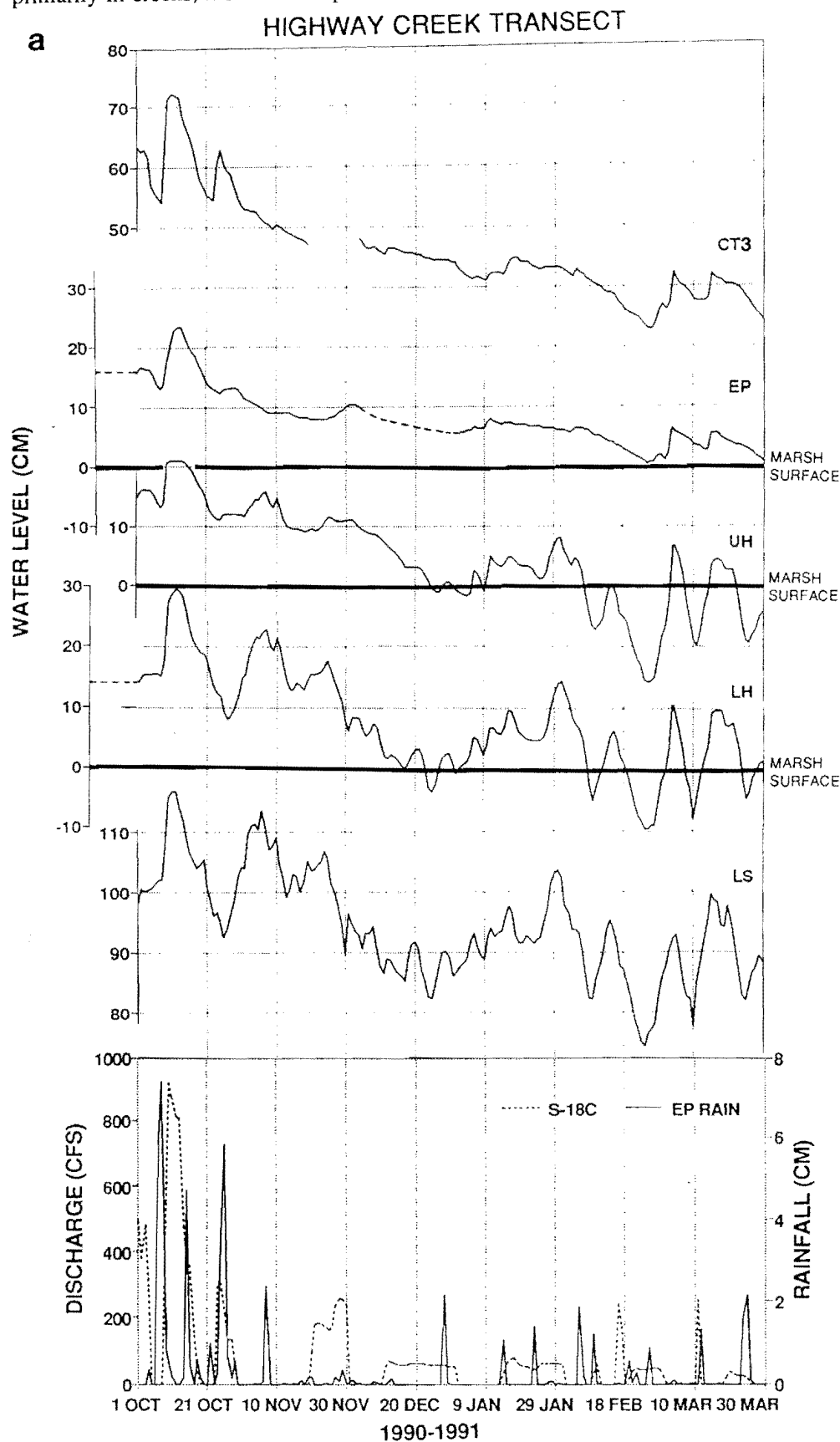
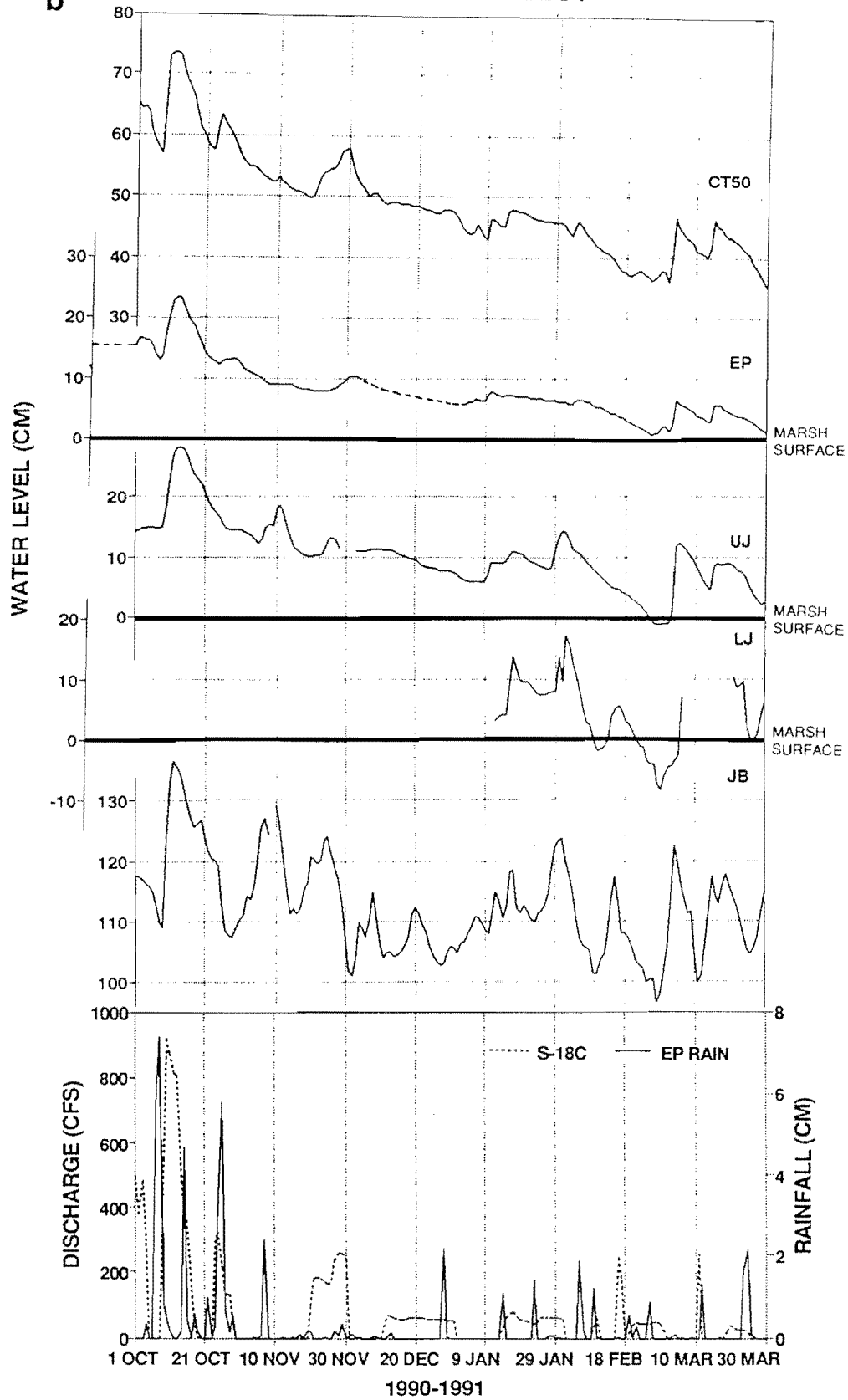


Figure 11. Hydrographs from recorders along 2 north-south transects in C-111 basin, canal discharge (S-18C minus S-197) and rainfall (EPR) for 2 dry seasons (from October through March). For 1990-91: Highway Creek (eastern transect, 11a) and Joe Bay (western transect, 11b), for 1991-92: Highway Creek transect (11c) and Joe Bay transect (11d). Heavy horizontal line across hydrographs indicates approximate marsh surface, so that when water level reaches 0, water is primarily in creeks, moats and depressions.

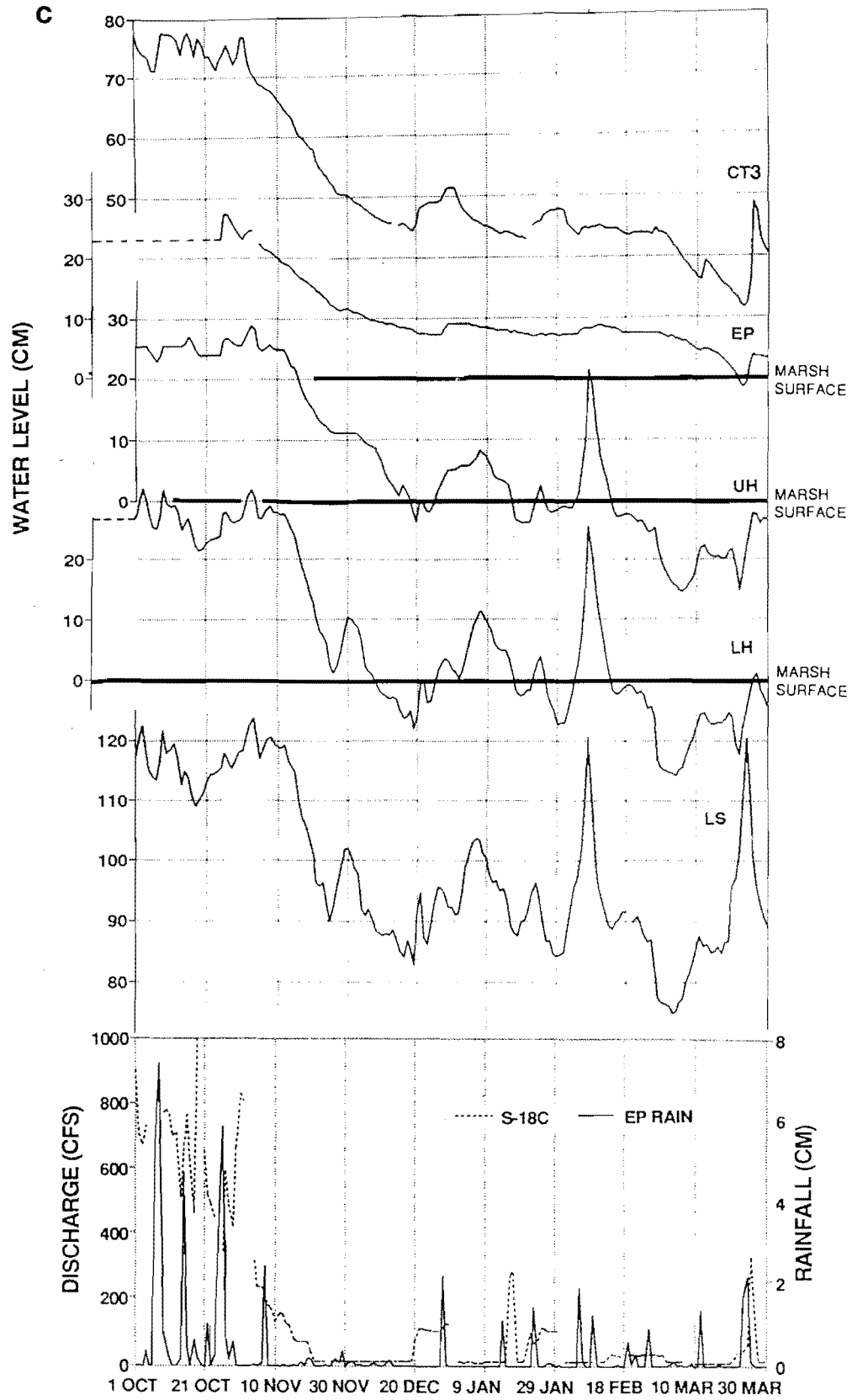


b

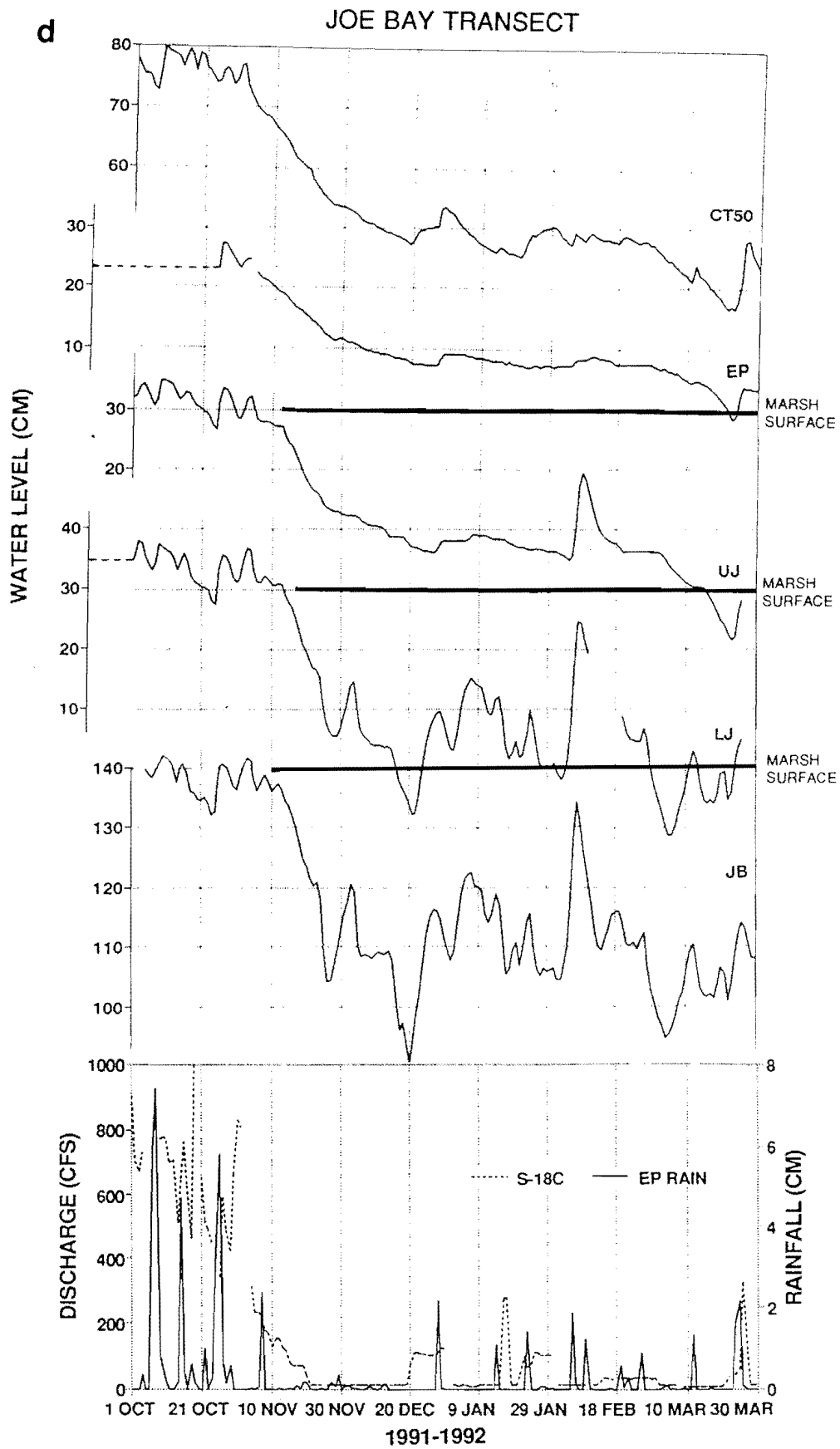
JOE BAY TRANSECT



HIGHWAY CREEK TRANSECT



1991-1992



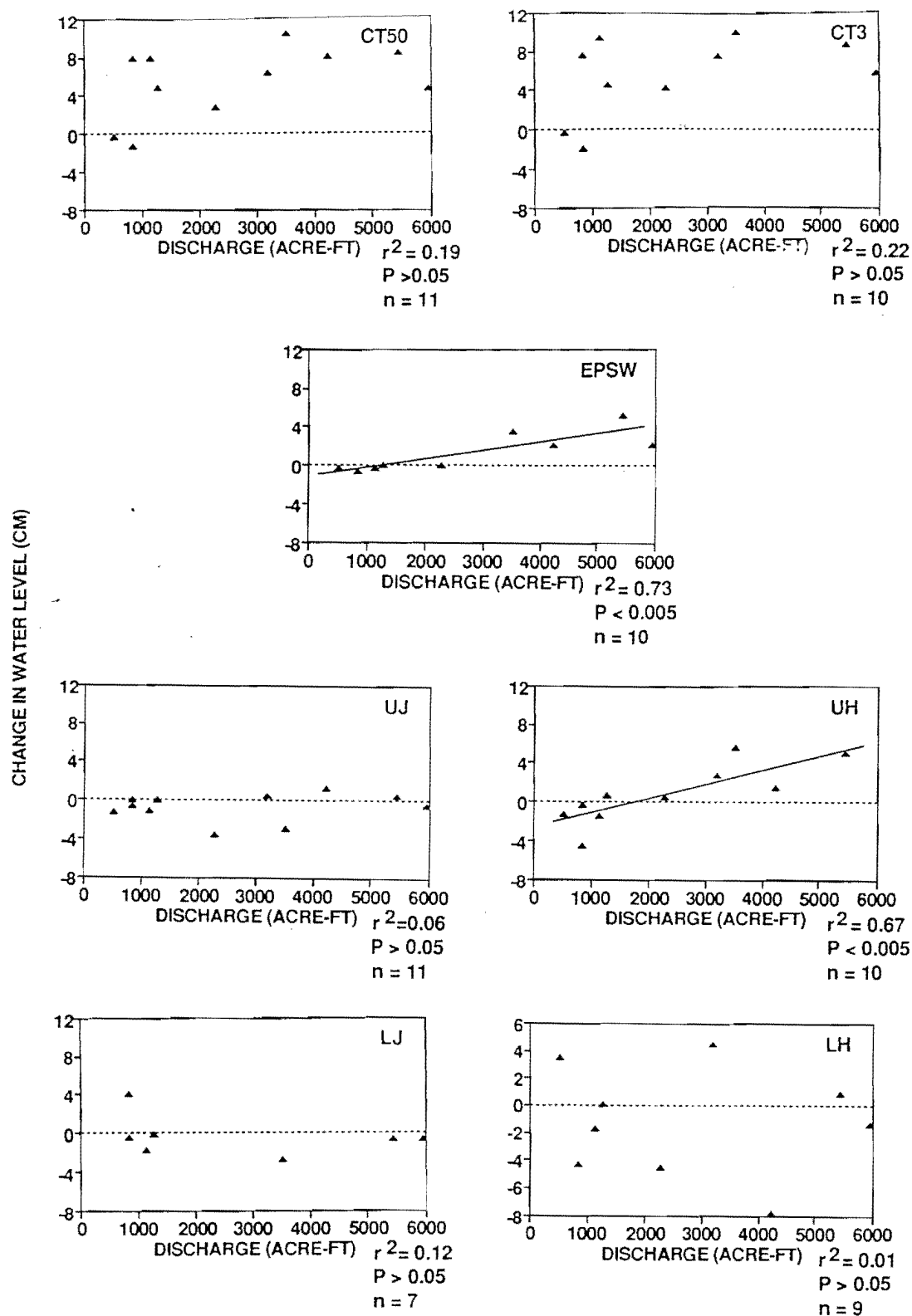


Figure 12. Effect of canal discharge events on change in water level (when there was no rainfall recorded at EPR and S-18C). There were significant positive correlations at upland marsh (EPSW) and upper recorder (UH). Although, there was no linear correlation at canal recorders (CT50 and CT3), it appears there was a strong effect. There was no correlation at the upper recorder (UJ) or the lower recorders (LJ and LH).

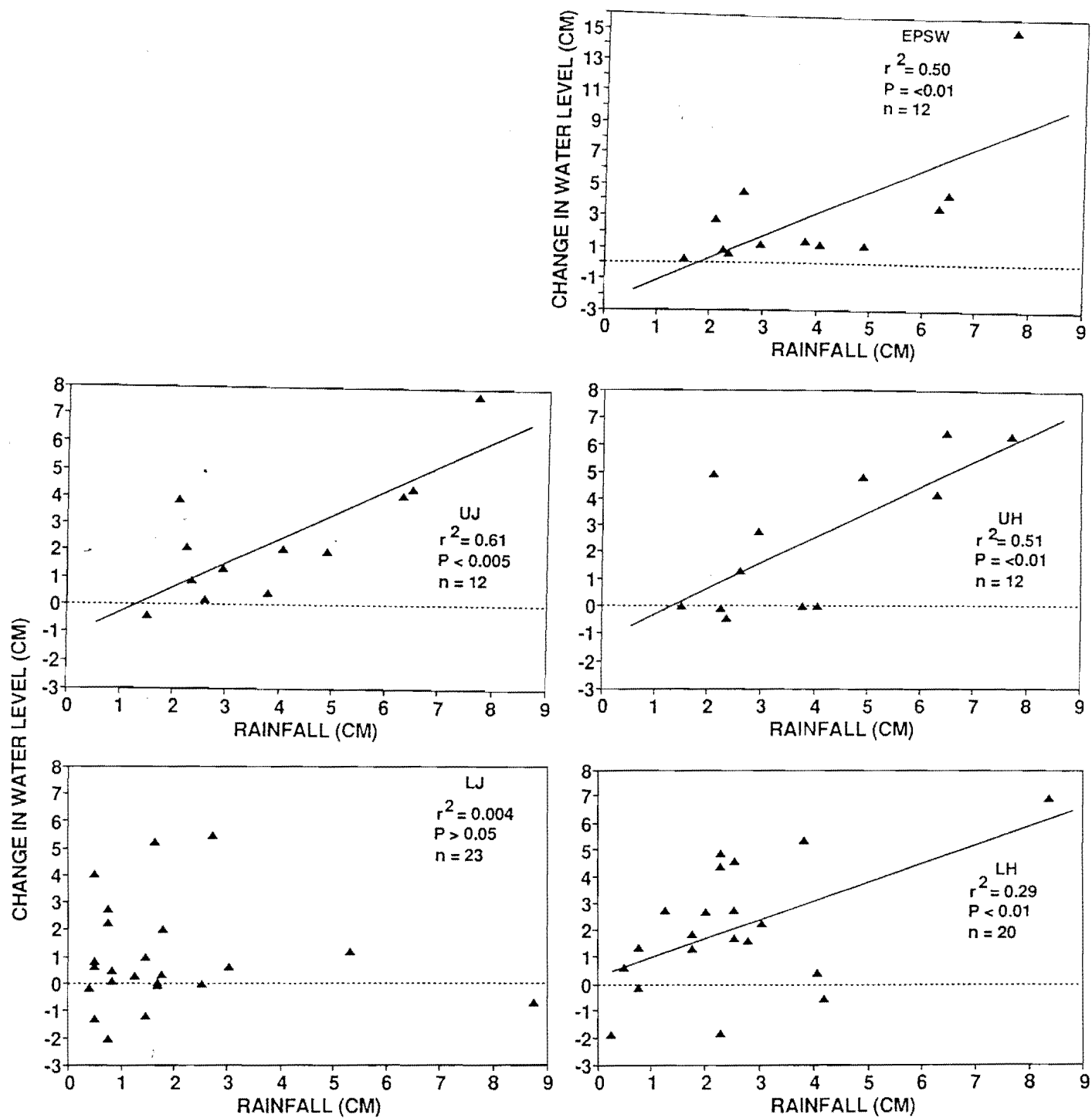


Figure 13. Effect of rainfall on change in water level at freshwater marsh (EPSW) and ecotone (UJ and UH, LJ and LH) recorders (when there was no canal discharge). There was a significant linear correlation at sites except LJ.

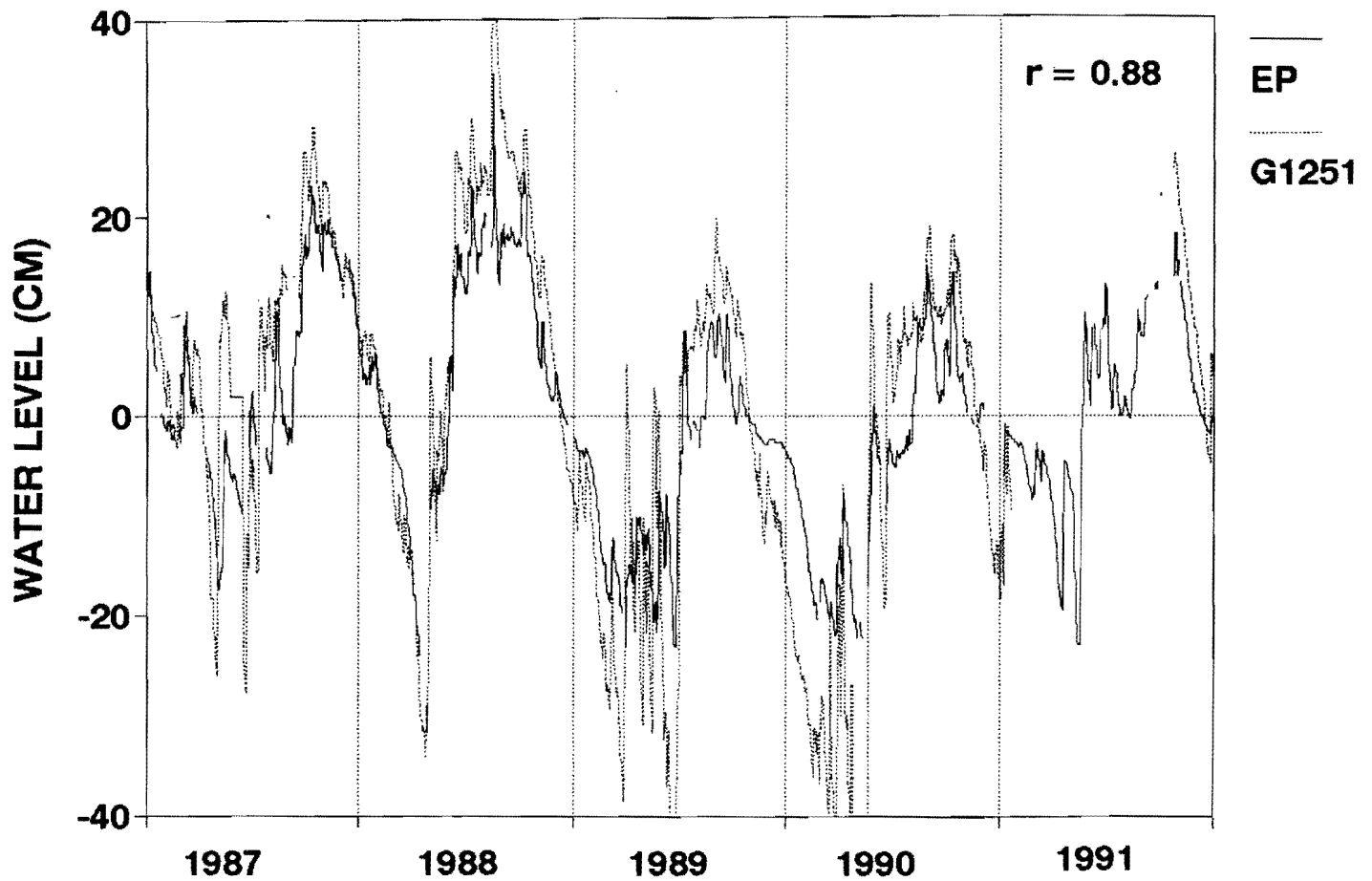
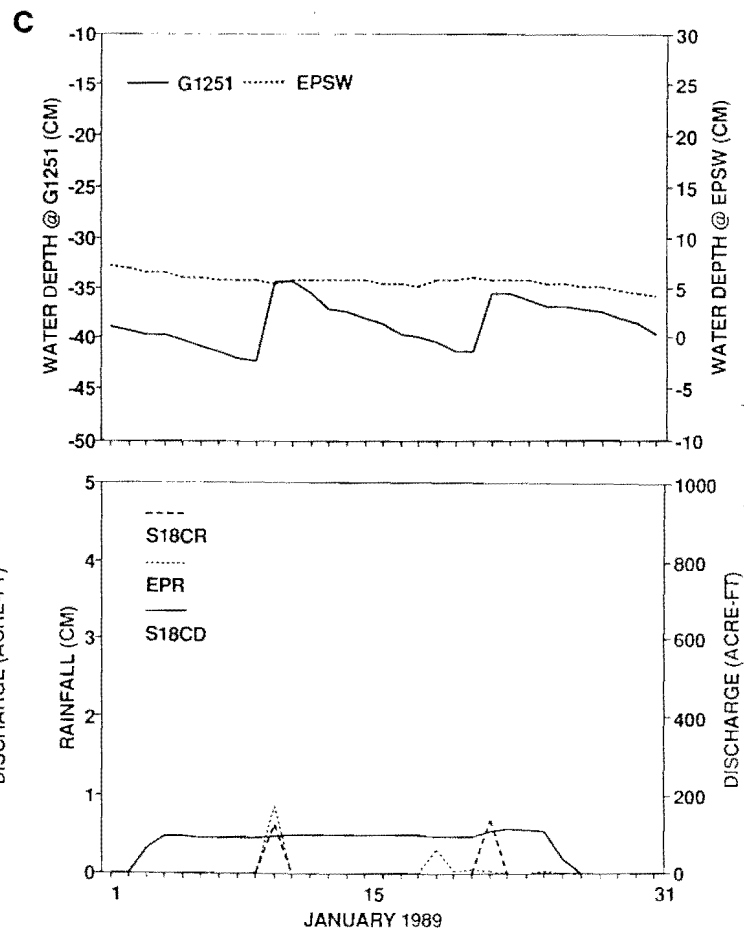
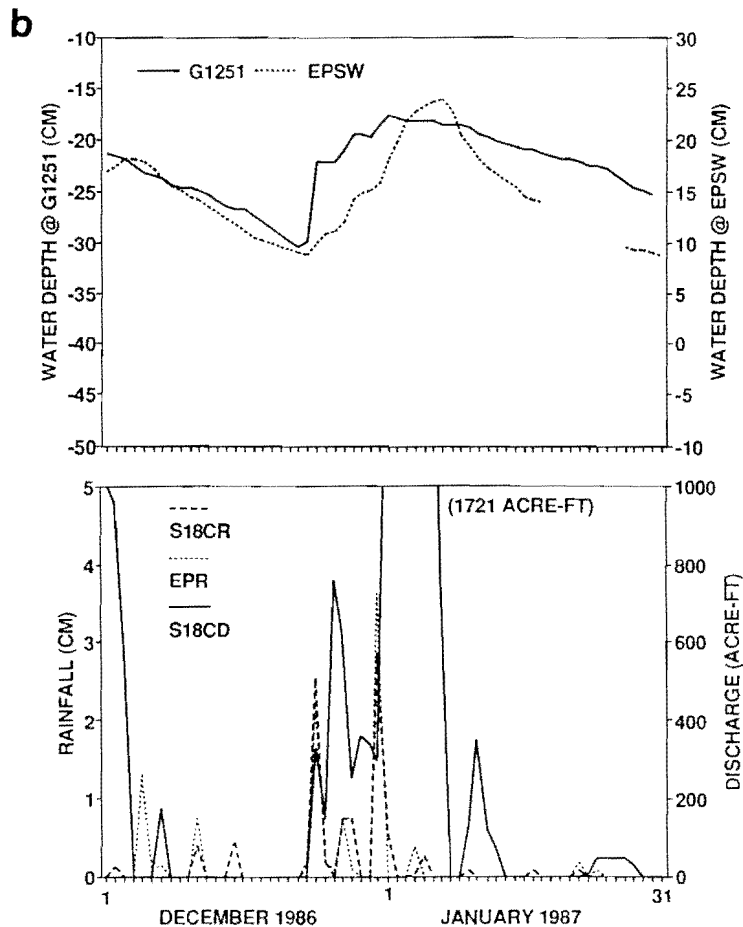
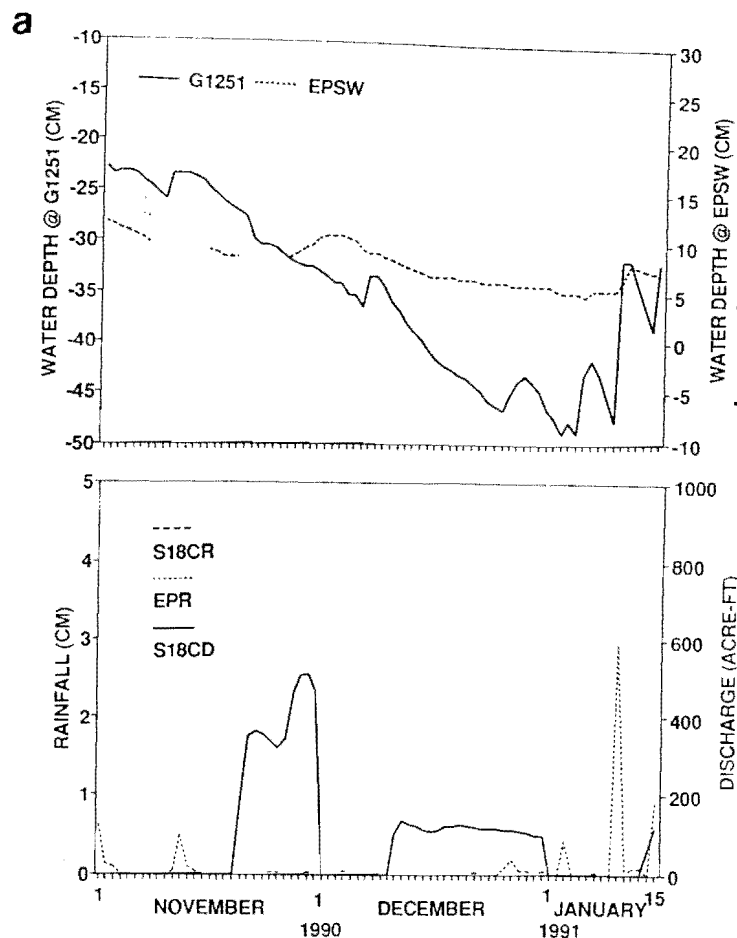
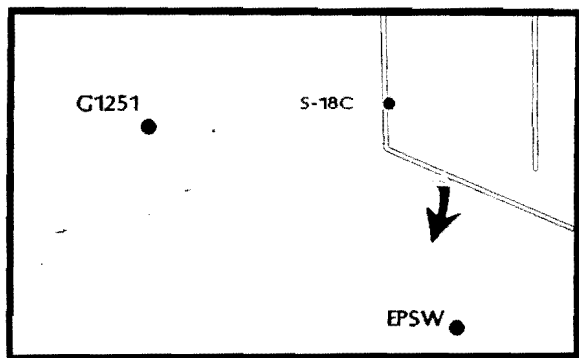


Figure 14. Hydrographs from freshwater marsh water level recorders, G1251 and EPSW. There was a high correlation between the 2 hydrographs ($r=0.88$).

Figure 15. Hydrographs from water level recorders G1251 and EPSW for 3 different rainfall and canal discharge events. G1251 displays greater response to rainfall (because water level is below ground) and EPSW displays greater response to discharge (because of its relative location to source of discharge).



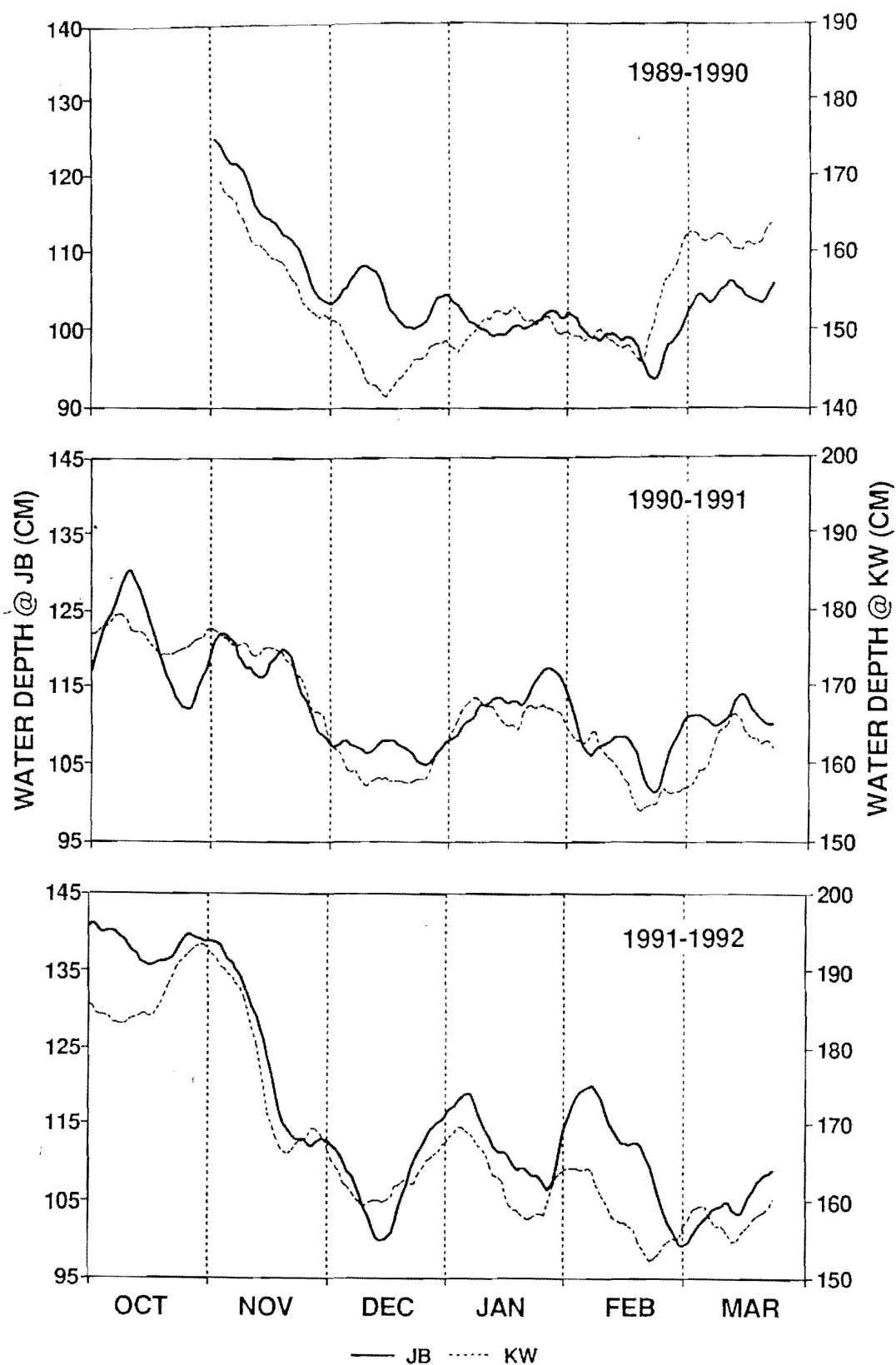


Figure 16. Comparison of hydrographs of mean daily water level at the marine station, Key West (KW), and the Florida Bay station, Joe Bay (JB). To smooth out the effects of daily tidal fluctuation 10-day running averages of mean daily water level were calculated.

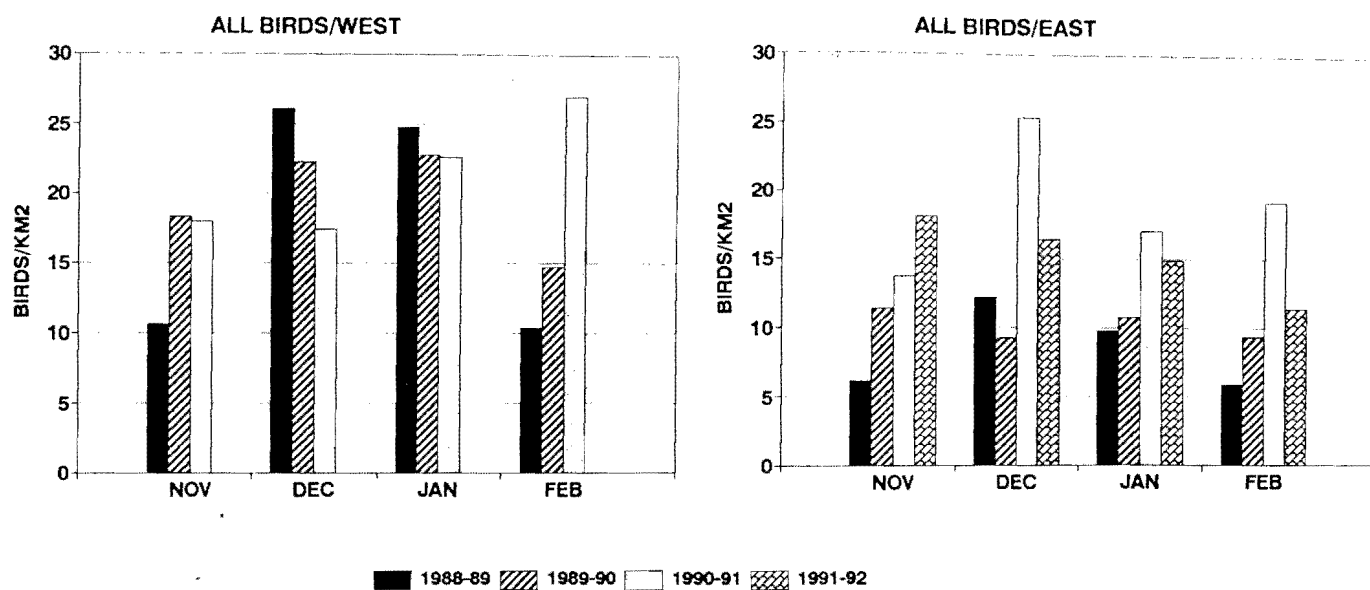


Figure 17. Mean density of foraging wading birds (see METHODS for list of species) by region, month and year. The west region was not surveyed in 1991-92.

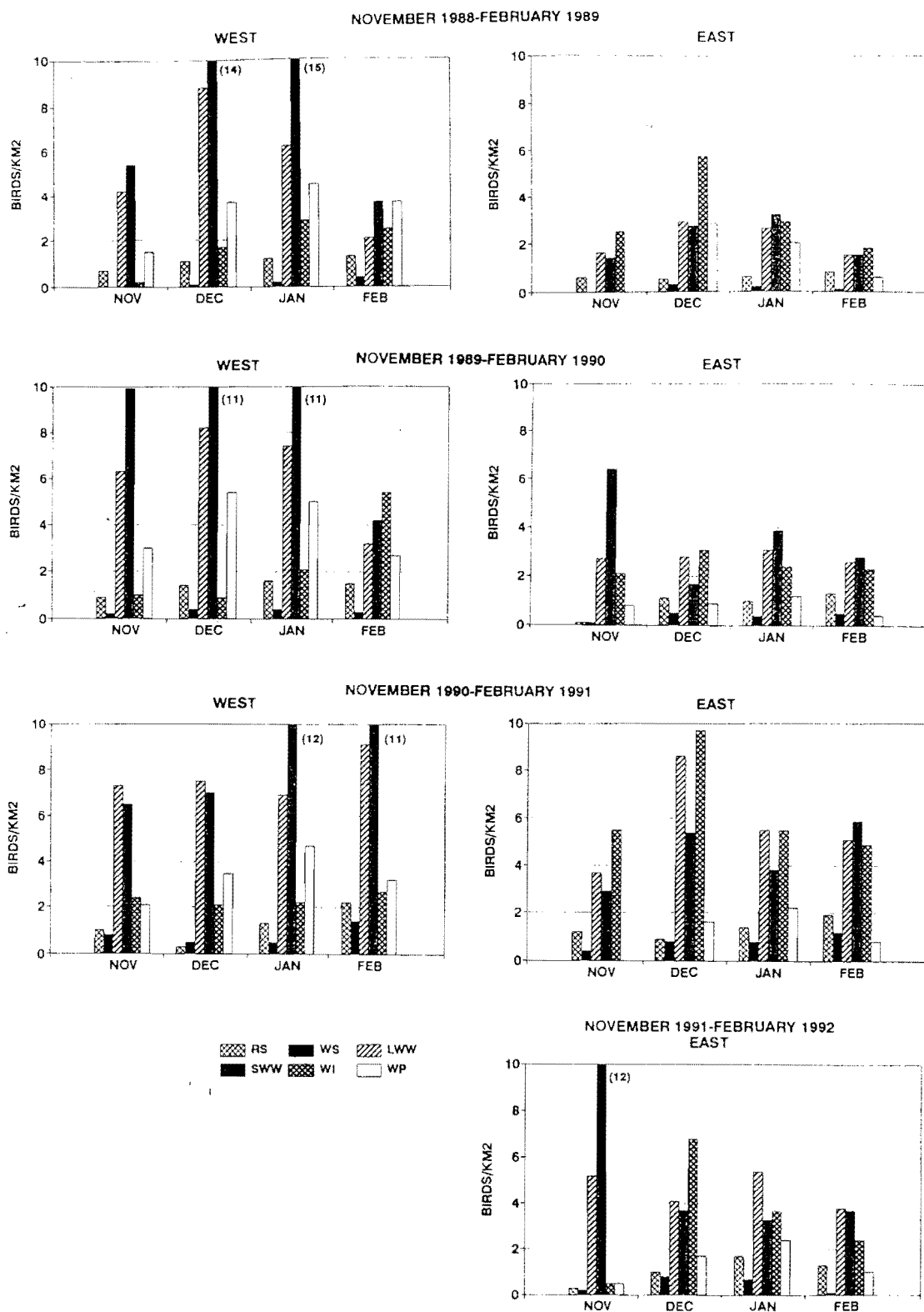


Figure 18. Mean density of foraging wading birds by species, region, month and year.

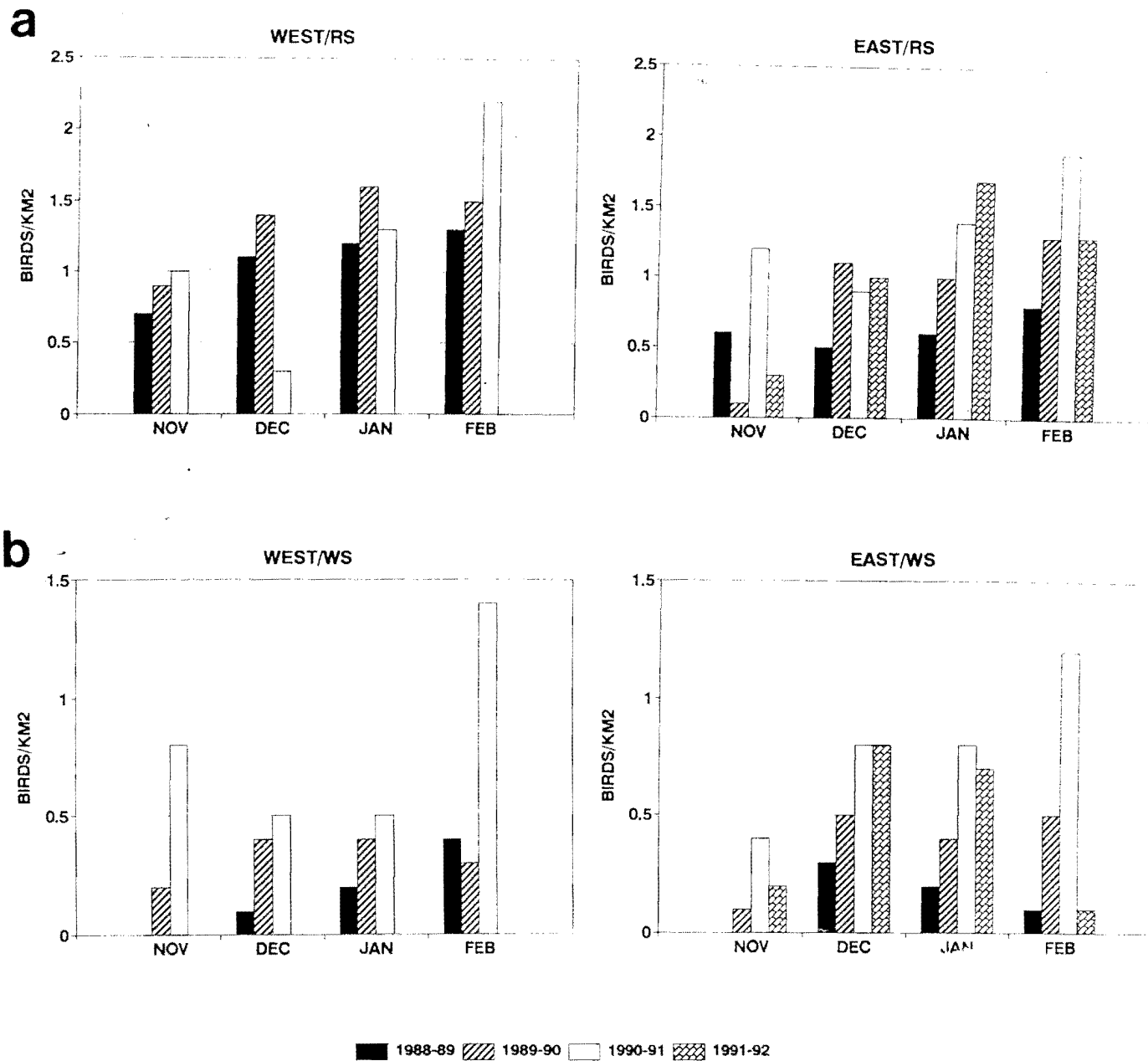


Figure 19. Mean density of Roseate Spoonbills (19a) and Wood Storks (19b) and by region, month and year.

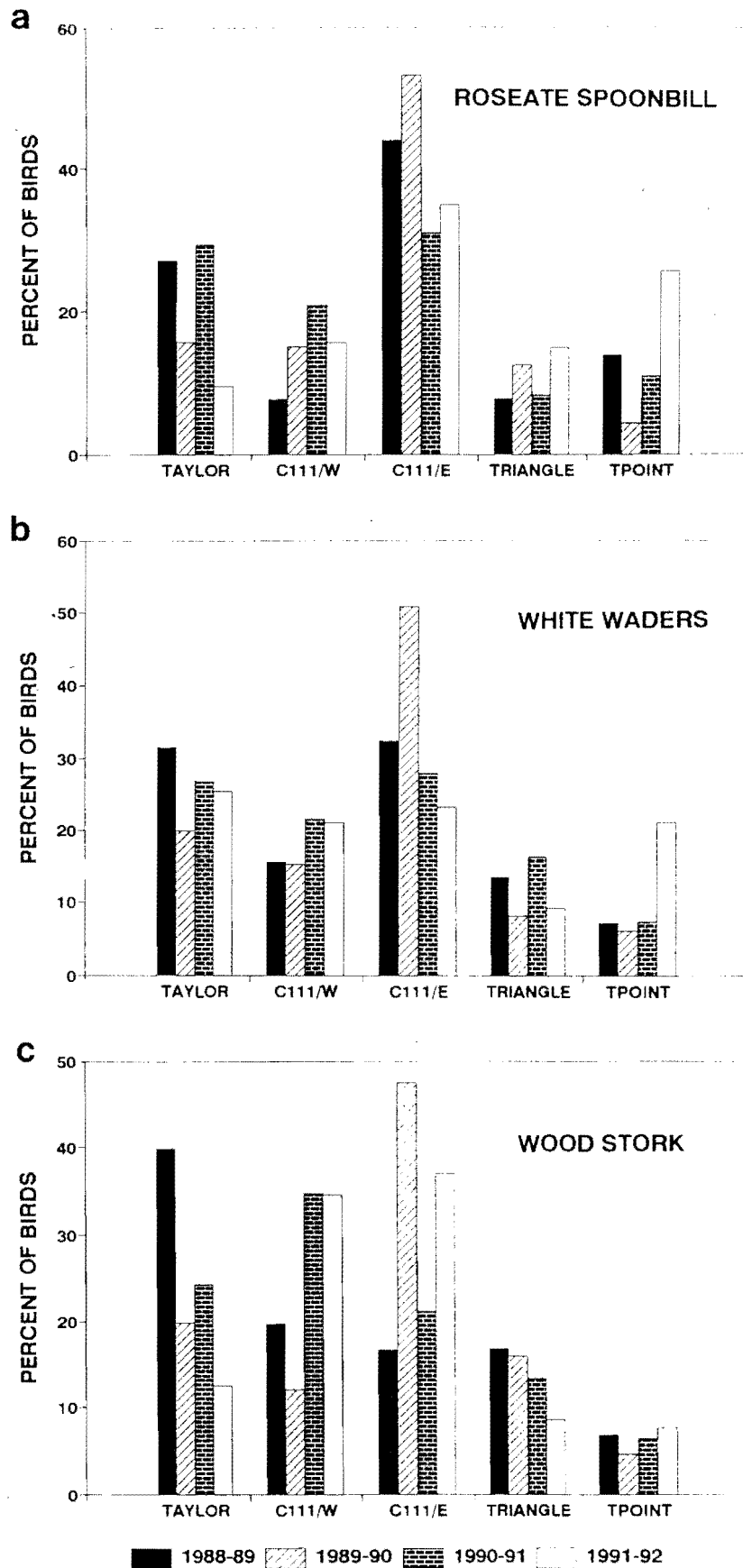


Figure 20. Distribution of Roseate Spoonbills (20a), other wading birds (excluding spoonbills and Wood Storks, 20b) and Wood Storks (20c) by zone in the eastern ecotone. Refer to Figure 7 for delineation of zones.

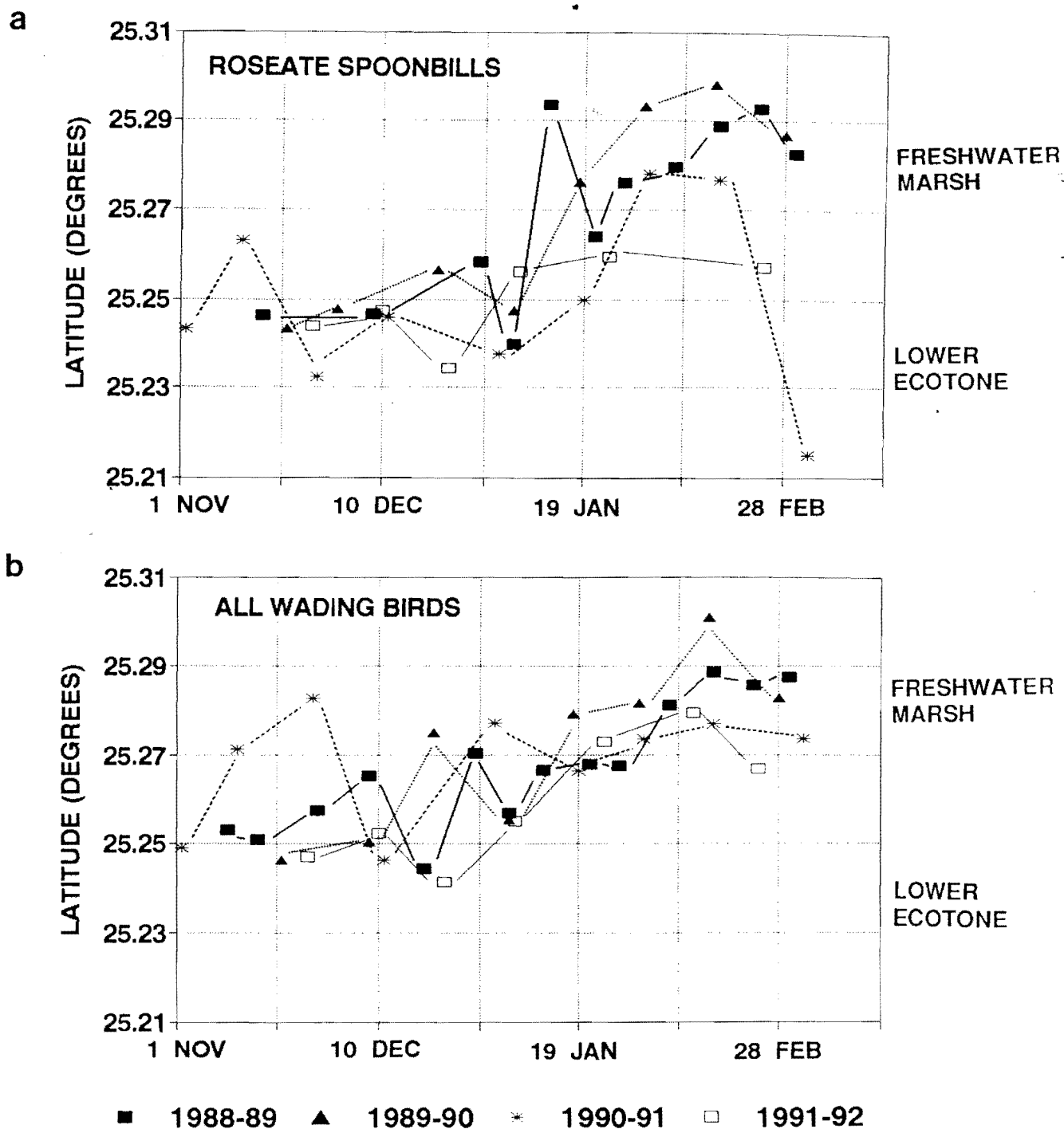


Figure 21. Mean latitude of Roseate Spoonbills (21a) and all other wading birds (21b) in the C-111 basin by survey and year.

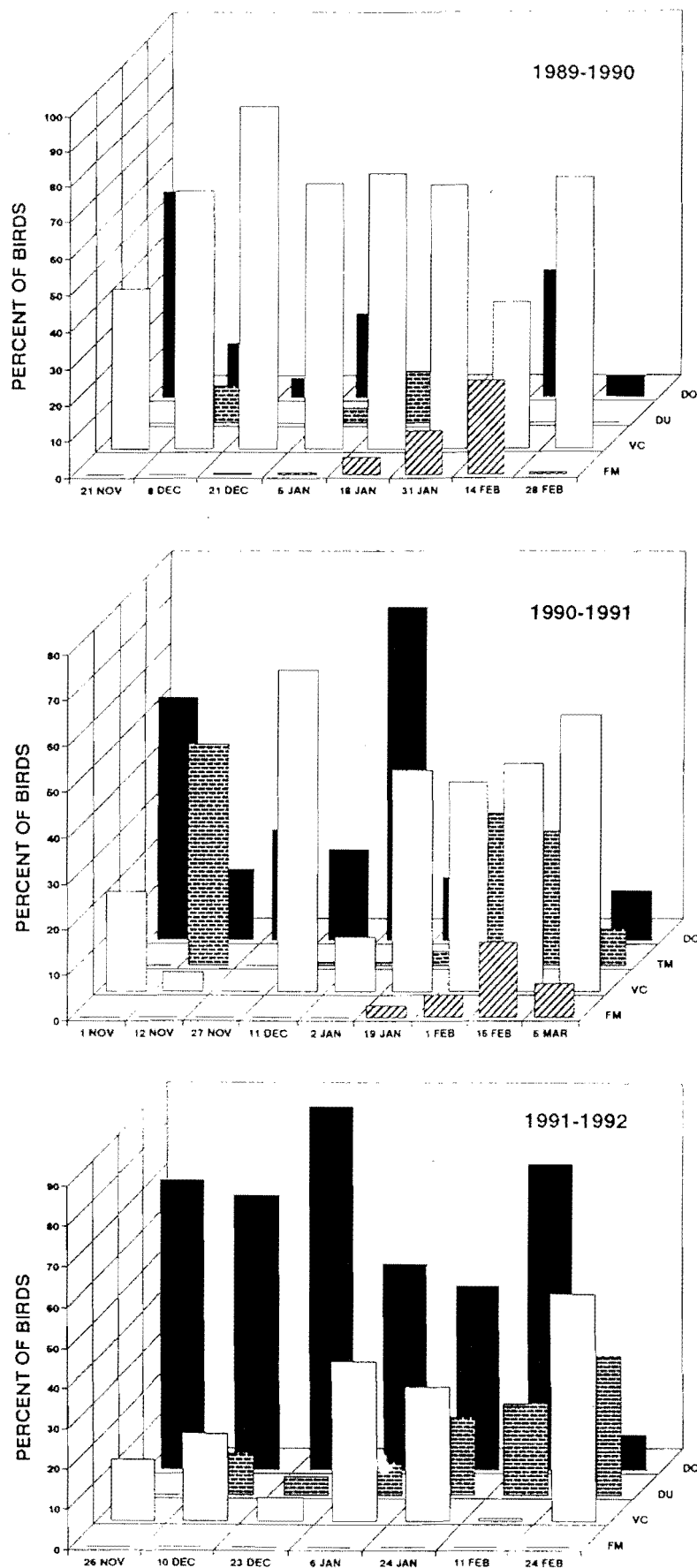


Figure 22. Distribution of Roseate Spoonbills in primary habitat categories (Dwarf Open, DO; Dwarf Uniform, DU; Vegetated Creeks, VC; Freshwater Marsh, FM and Transitional Marsh, TM) per survey during 3 nesting seasons. Refer to Appendix A for description of habitat categories.

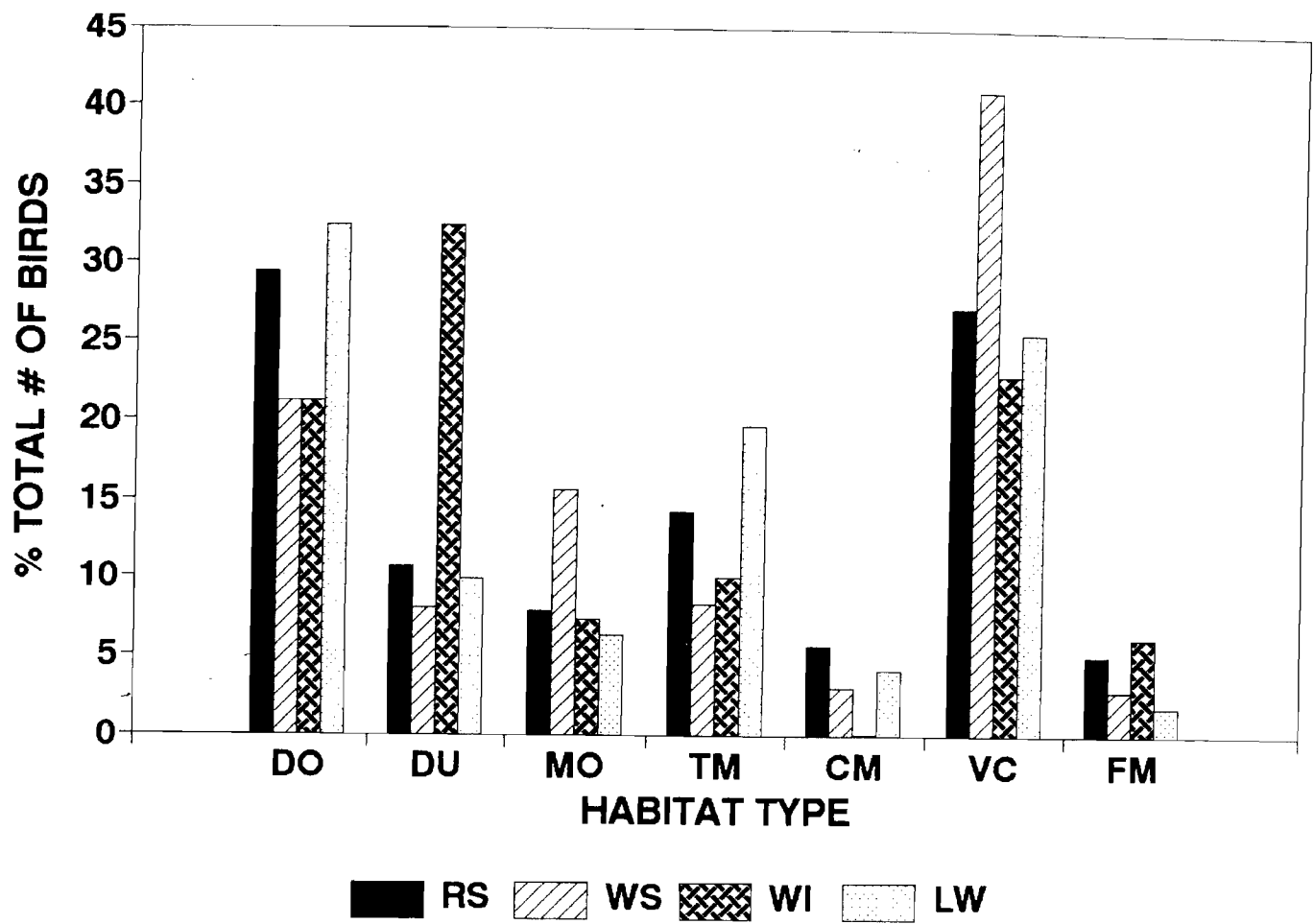
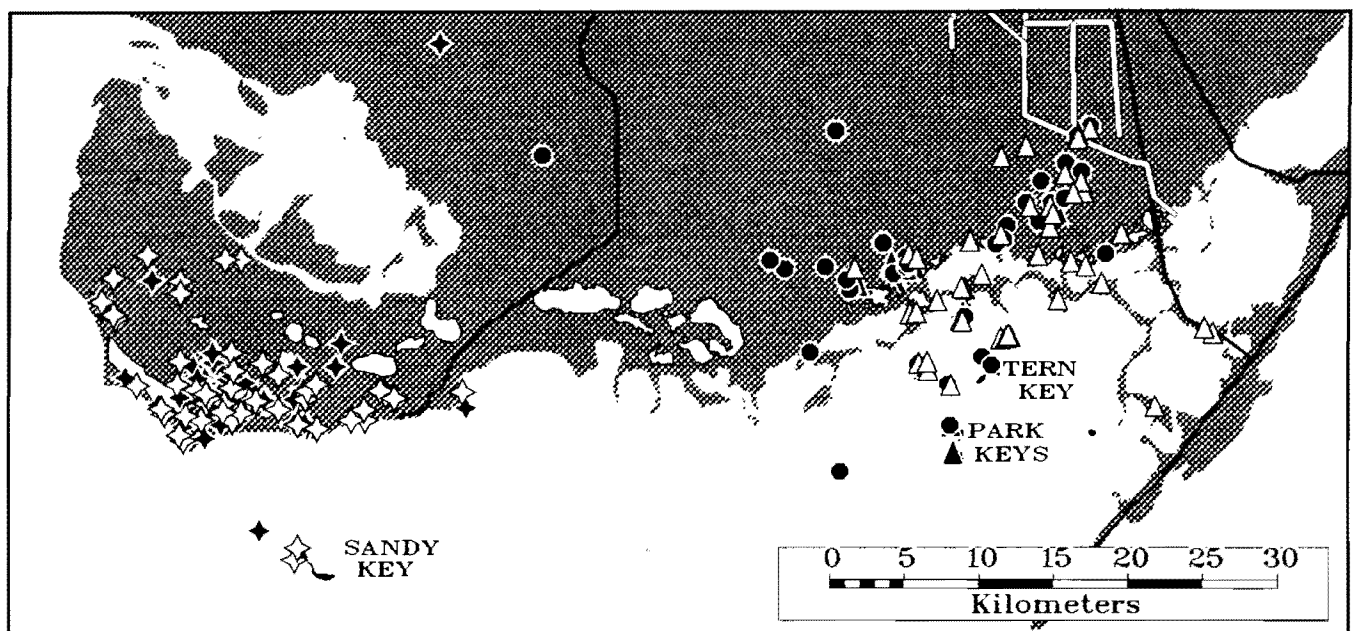


Figure 23. Distribution of wading birds (Roseate Spoonbills, RS; Wood Storks, WS; White Ibis, WI and Great Egrets/Great White Herons, combined, LW) in primary habitat categories in 1990-91

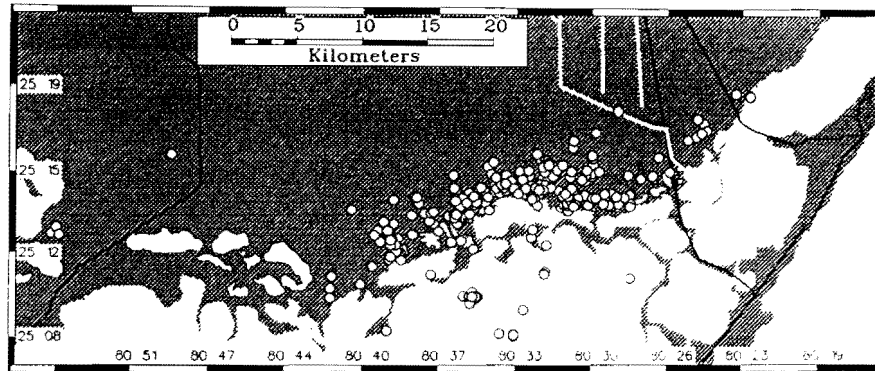


	1988-89 n	1989-90 n
TERN KEY	▲ 9	△ 50
SANDY KEY	◆ 45	◇ 50
PARK KEYS	● 38	

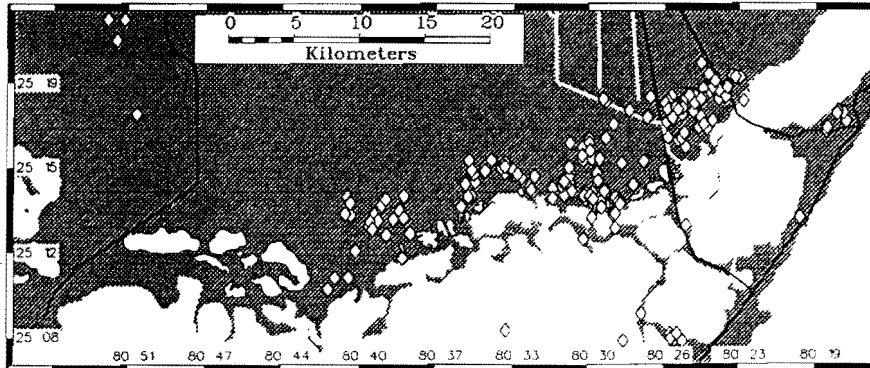
Figure 24. Locations of Roseate Spoonbills tracked by foraging flights from 3 colonies to foraging sites during 2 nesting seasons. Park Keys refers to birds from North and South Park keys colonies.

1990-91

TERN KEY $n = 438$

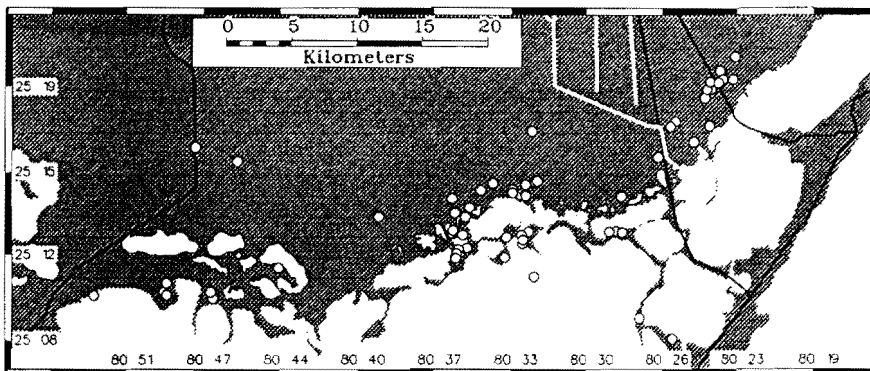


PORJOE KEY $n = 264$



1991-92

TERN KEY $n = 81$



PORJOE KEY $n = 45$

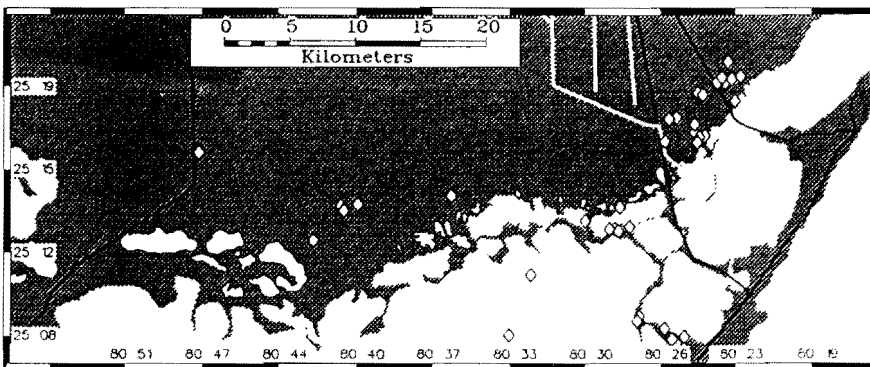


Figure 25. Foraging locations of radio-tagged Roseate Spoonbills nesting at Tern and Porjoe keys during 2 nesting seasons. In both years, Porjoe Key birds used wetlands east of U.S. Highway 1 to a much greater extent than Tern Key birds.

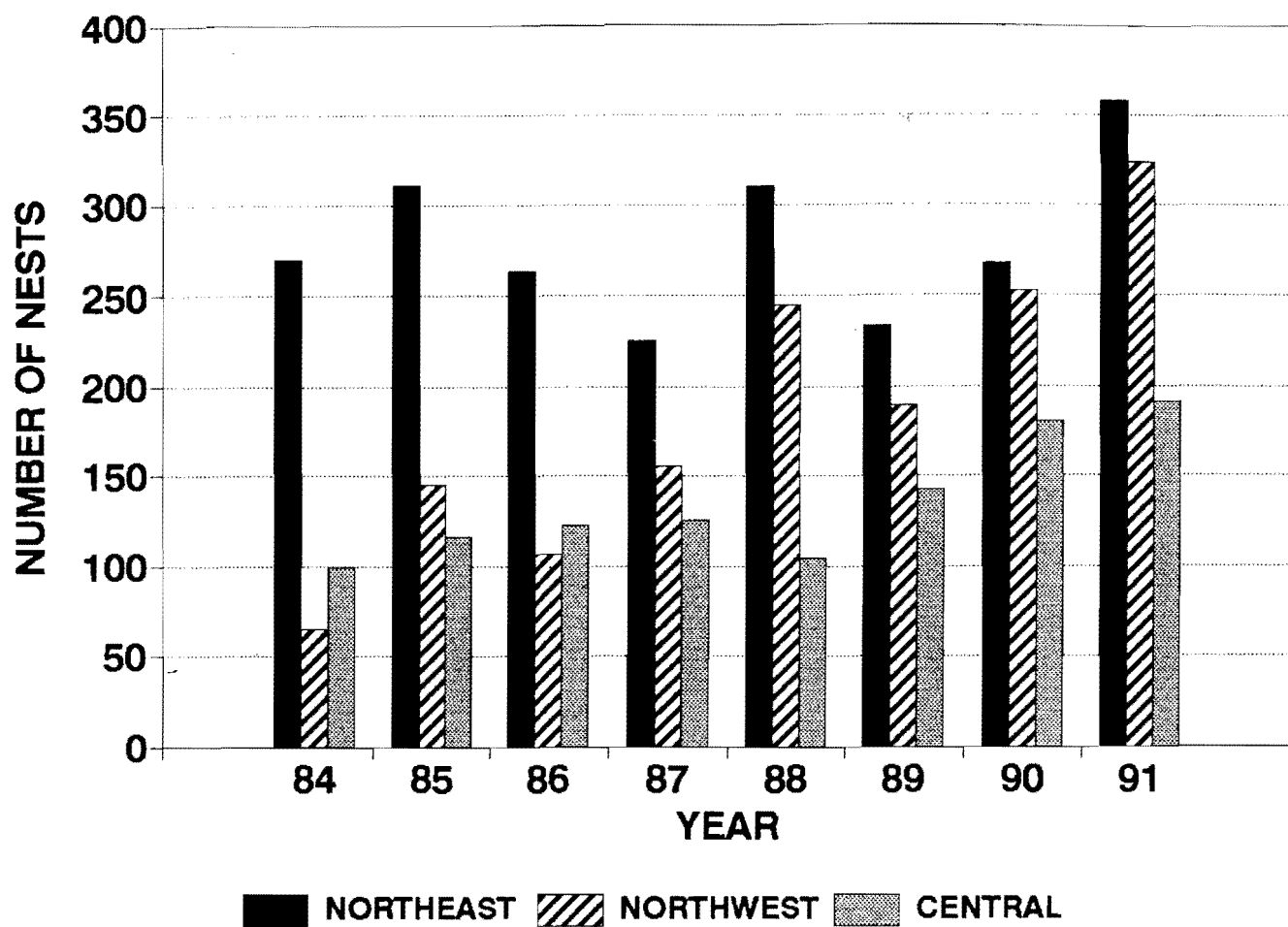


Figure 26. Number of Roseate Spoonbill nests, by region. Refer to Table 4 for specific colonies and numbers within each region.

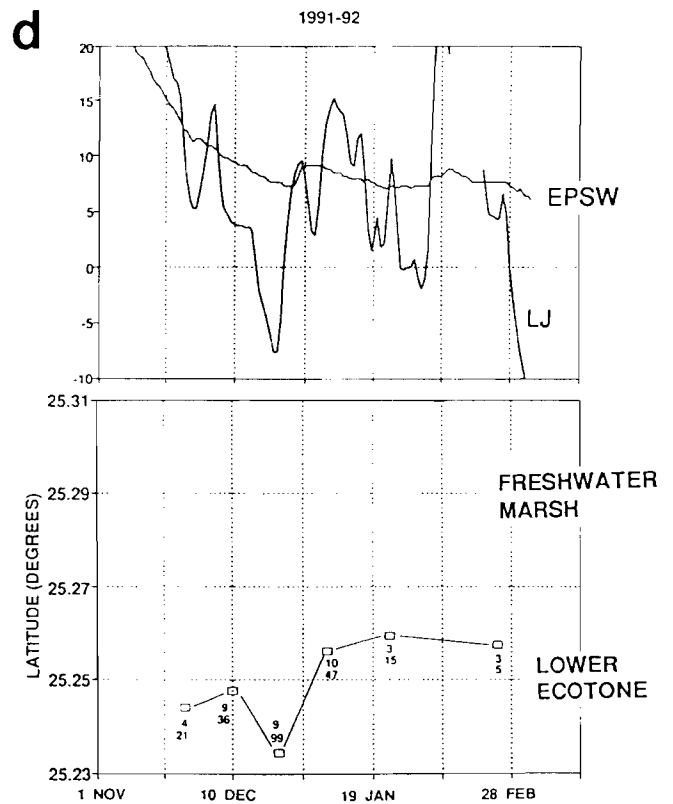
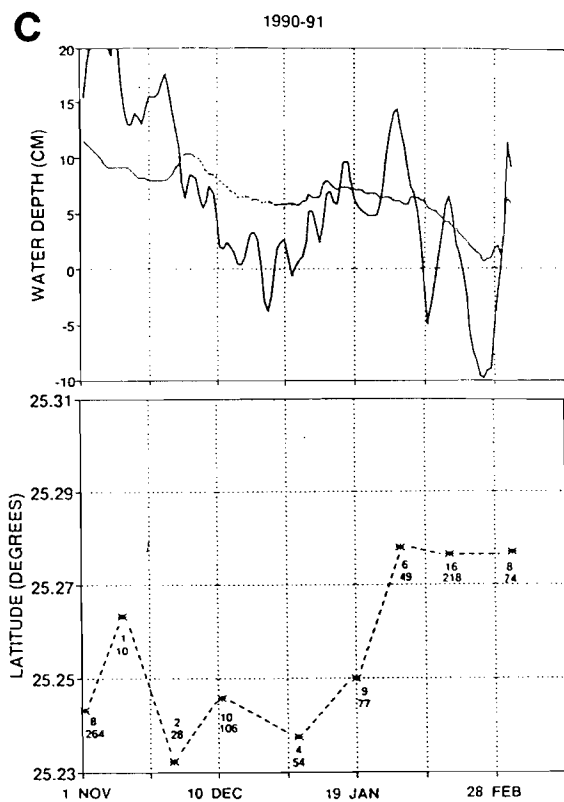
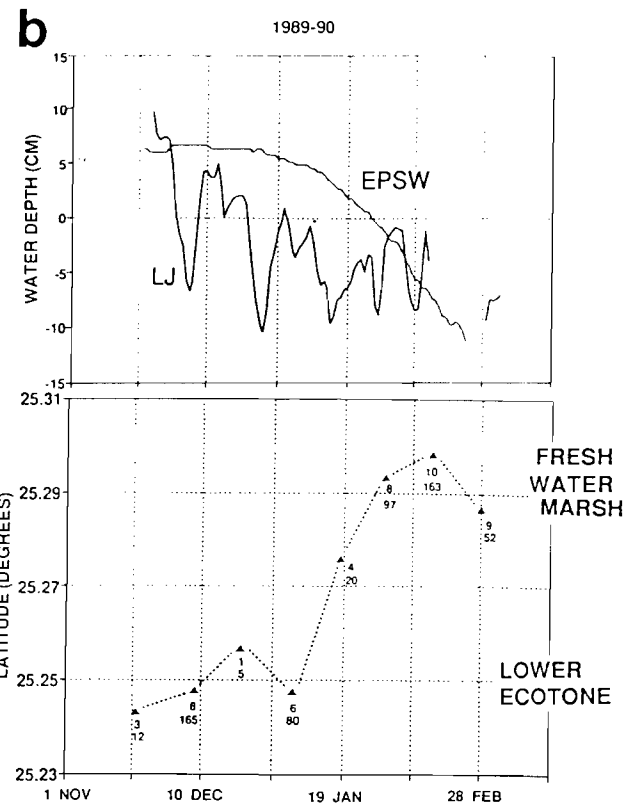
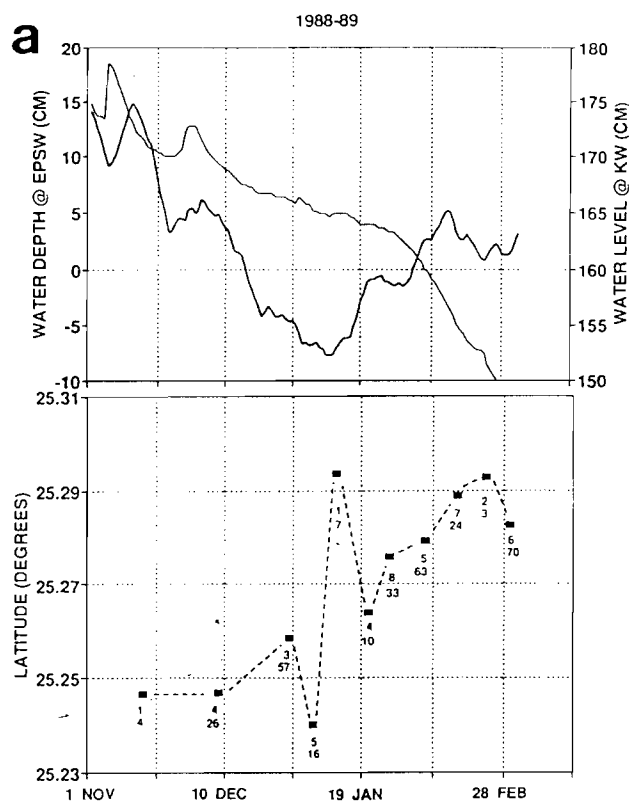


Figure 27. Surface water hydrographs (top boxes) of freshwater marsh (recorder EPSW) and ecotone (recorder LJ) and mean latitude of Roseate Spoonbills in C-111/E and C-111/W Zones, combined (bottom boxes), recorded during aerial surveys for 4 nesting seasons. Latitude of 0.02 degrees (horizontal grid size of lower boxes) = 2.3 km. See Figure 7 for delineation of Zone.

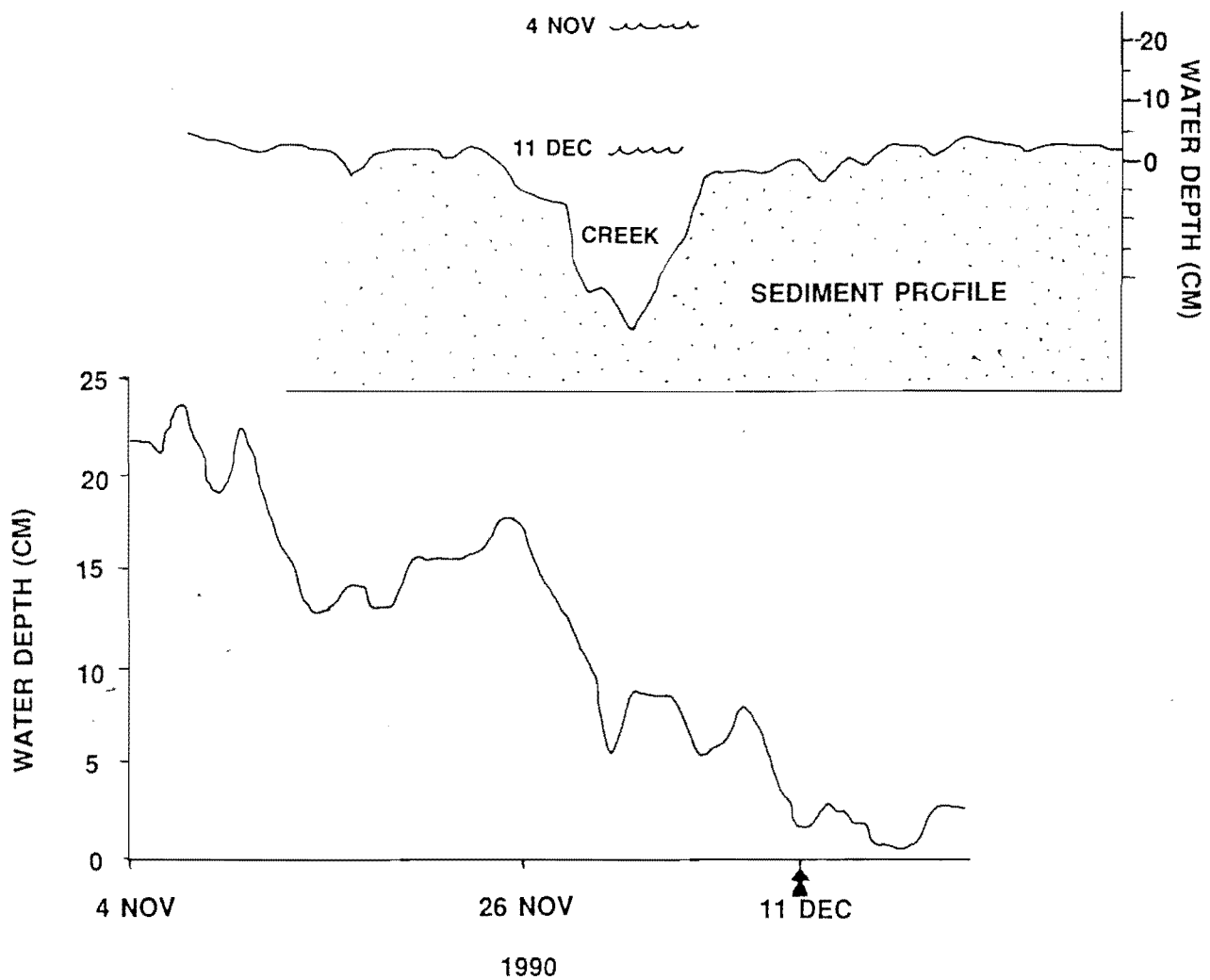


Figure 28. Water level trace from recorder LH (lower graph). On 11 December 1990, wading birds were first observed foraging in the vicinity of the recorder. The ground profile of a cross section of the creek in the vicinity of the recorder (upper graph) shows the approximate water level early in the season (4 November) and at the time when the birds were there.

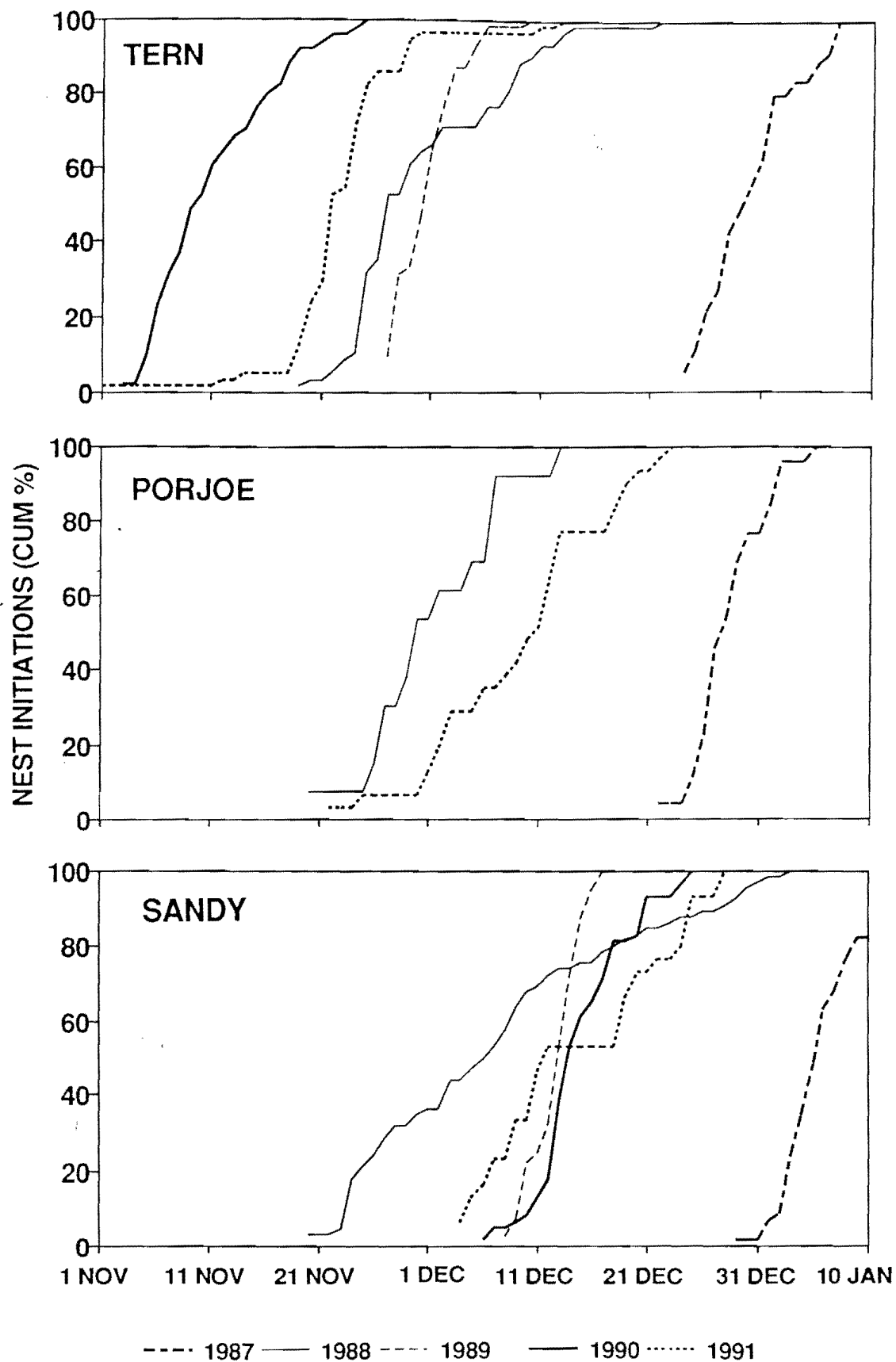


Figure 29. Percent cumulative nest initiations at 3 colonies in Florida Bay during 5 years.

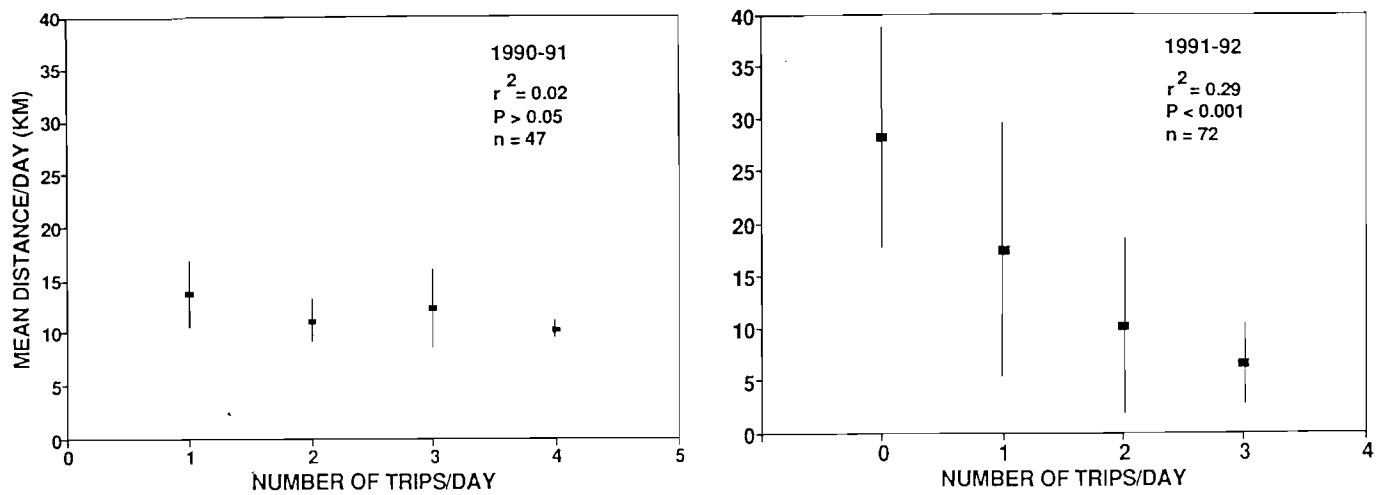
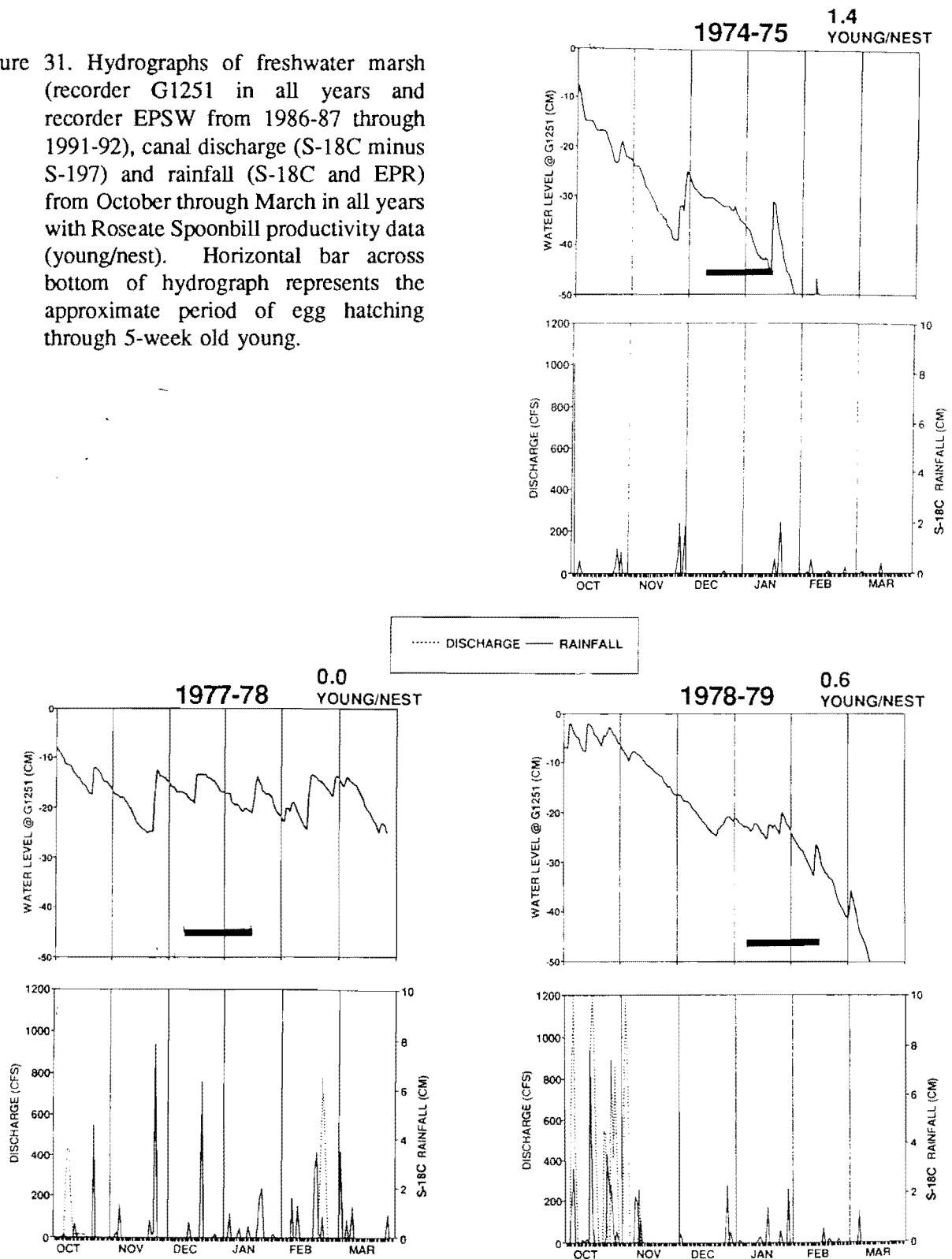
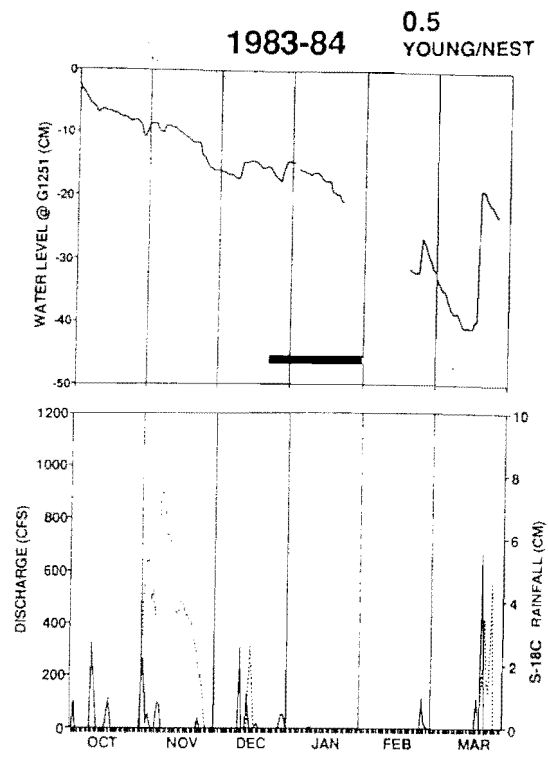
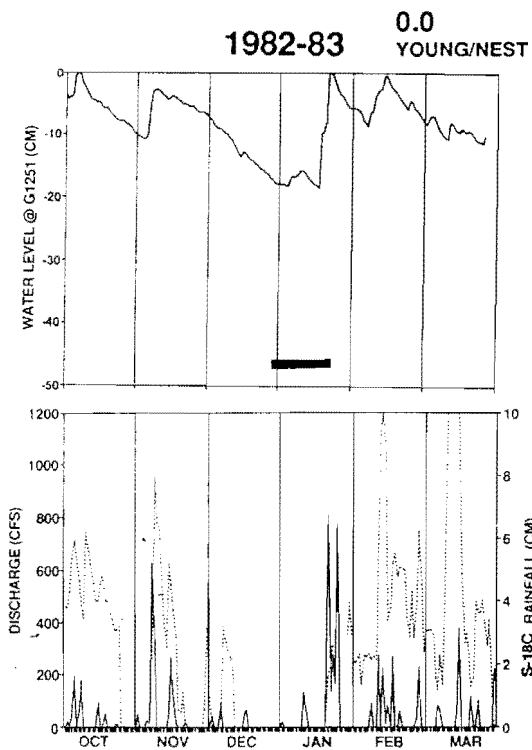


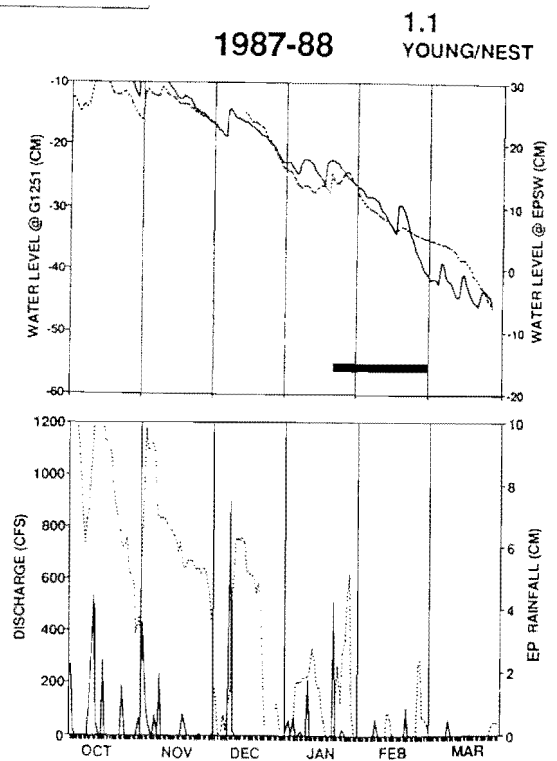
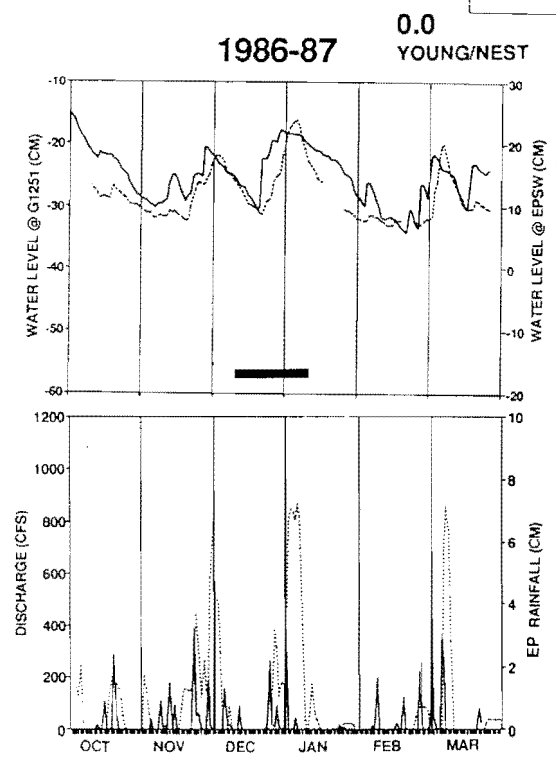
Figure 30. Mean daily distances ($\pm$ S.D.) traveled from colony to foraging site per the number of foraging trips per day (an indication of the number of times adult brought food to its young) of radio-tagged adults from northeastern Florida Bay colonies during 2 nesting seasons.

Figure 31. Hydrographs of freshwater marsh (recorder G1251 in all years and recorder EPSW from 1986-87 through 1991-92), canal discharge (S-18C minus S-197) and rainfall (S-18C and EPR) from October through March in all years with Roseate Spoonbill productivity data (young/nest). Horizontal bar across bottom of hydrograph represents the approximate period of egg hatching through 5-week old young.

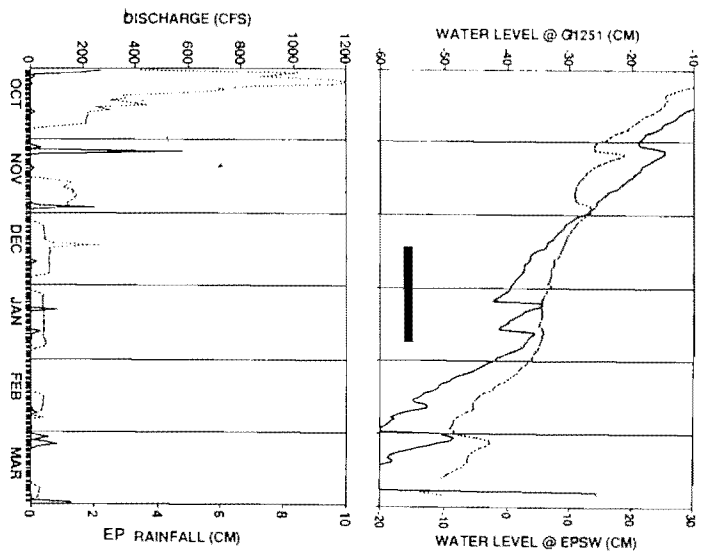




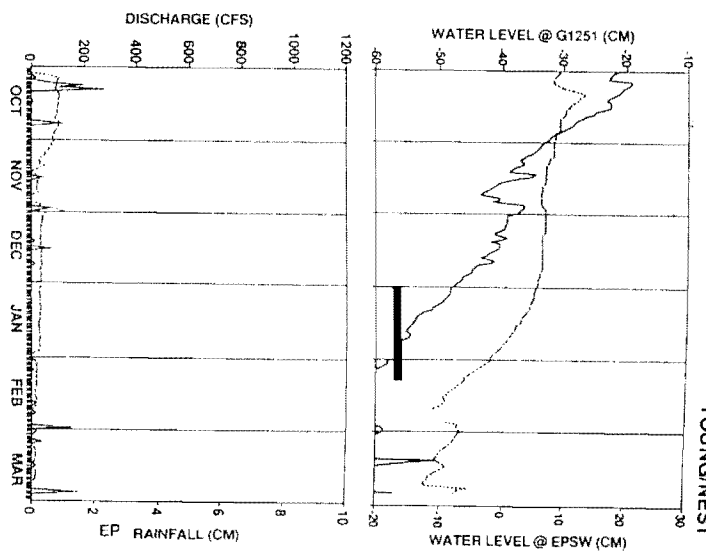
DISCHARGE — RAINFALL
EPSW — G1251



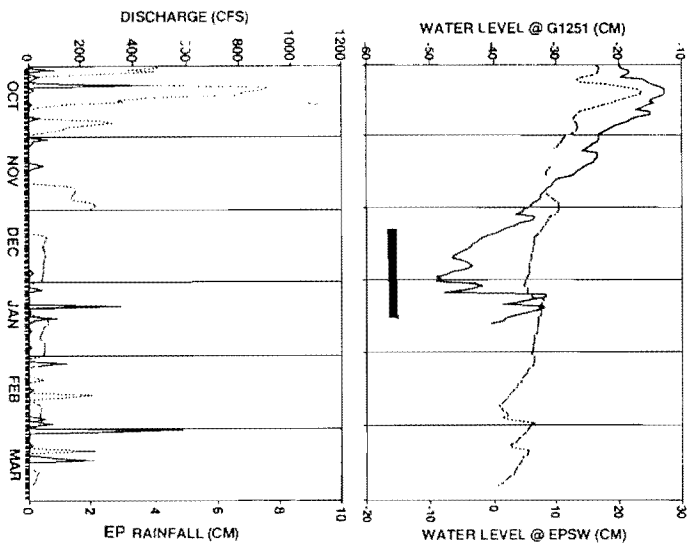
1988-89 1.9 YOUNG/NEST



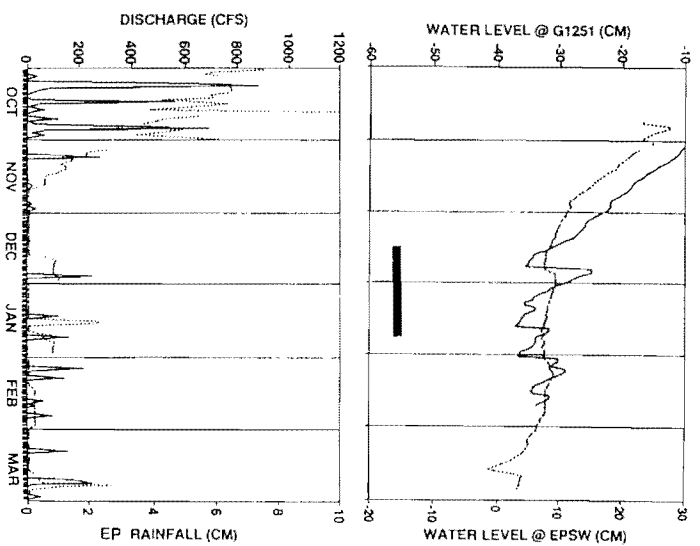
1989-90 2.2 YOUNG/NEST



1990-91 1.8 YOUNG/NEST



1991-92 1.5 YOUNG/NEST



..... DISCHARGE — RAINFALL
 EPSW — G1251

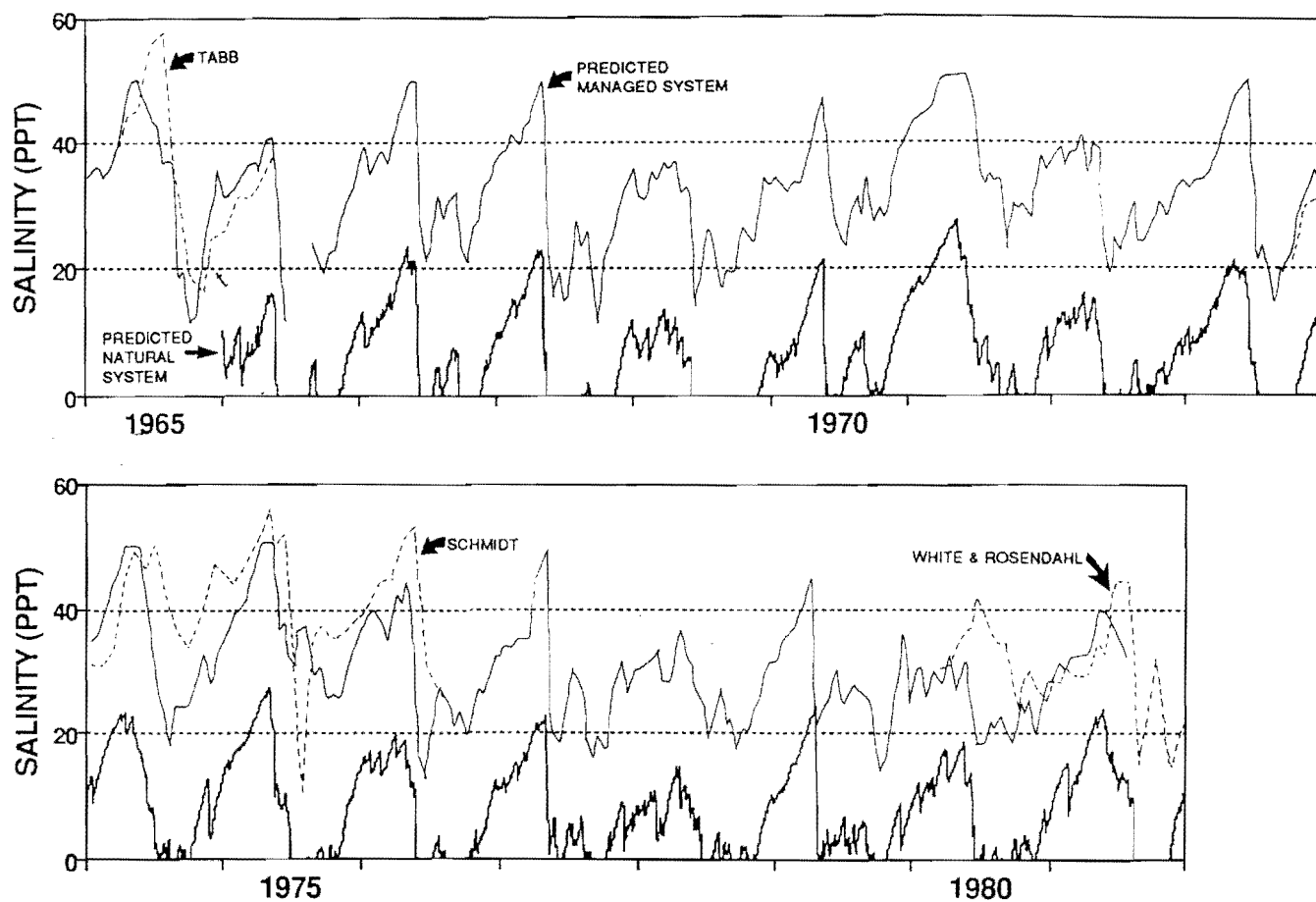


Figure 32. Predicted salinities in Little Madiera Bay, northeastern Florida Bay: Predicted Natural System salinities generated using equation from Tabb (1967) and water levels at the Homestead Well generated by the Natural System Model, Version 3.6 (*model provided by R. Fennema*), Predicted Managed salinities generated by White (1983) using Tabb's equation and water levels at the Homestead Well and actual data from 3 sources (Tabb 1967, White and Rosendahl unpubl. and Schmidt unpubl. *from* White 1983).

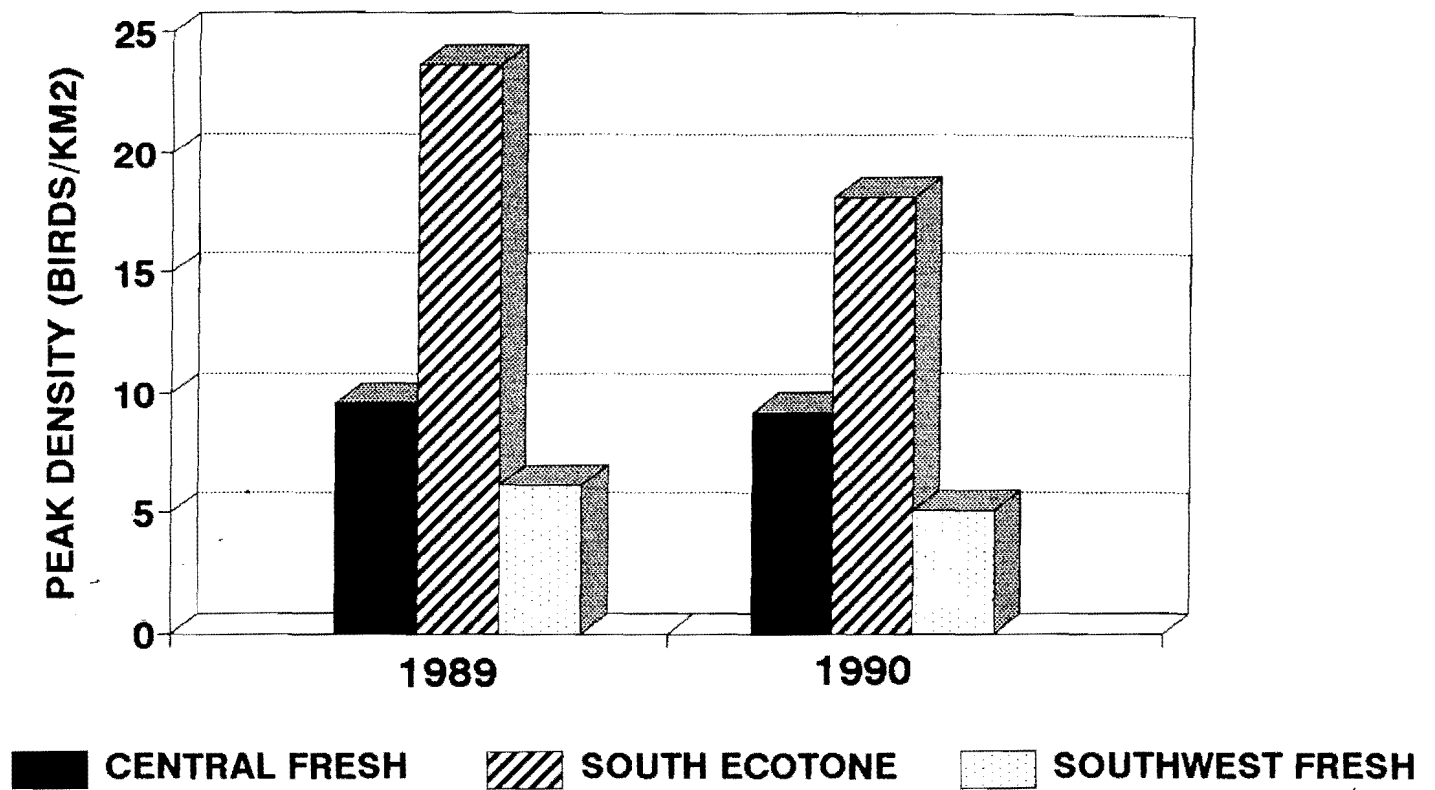


Figure 33. Peak densities of foraging wading birds in 3 different habitats of south Florida (*adapted from* Fredrick and McGehee 1992).

Appendix A. Habitat categories for Roseate Spoonbill/wading bird aerial survey.

BAY EDGE (BE): relatively nontidal coastline (e.g. northern edge of Long Sound).

BEACH (BC): tidal coastline (e.g. East Cape).

CANAL/CANAL EDGE (CA): human-made structures (e.g. C-111 canal, Homestead canal)

CLOSED MANGROVE (CM): mangrove trees with the canopy relatively closed and understory usually open. Foraging birds cannot be accurately counted in this habitat.

COASTAL PRAIRIE (CP): treeless areas of salt-tolerant plants and shrubs such as *Batis* and *Salicornia* (e.g. along northeast shore of Lake Ingraham).

DWARF OPEN (DO): non-uniform clumps of mangroves (avg. height < 2 m) with open areas of pools and interconnected channels of water

DWARF UNIFORM (DU): relatively evenly scattered mangroves (avg. height < 2 m) without closed canopy.

DWARF CLOSED (DC): mangrove trees (avg. height < 2m) with the canopy relatively closed.

FRESHWATER MARSH (FM): stand of > 75% freshwater marsh vegetation (e.g. north of the C-111 canal).

HAMMOCK (HA): distinct patch of shrubs and trees in a treeless or dwarf mangrove area, often teardrop-shaped.

MANGROVE LAKE (ML): large, nontidal body of water within mangrove belt (e.g. Seven Palms Lake, Gator Lake).

MANGROVE POND (MP): opening in canopy of closed mangrove exhibiting somewhat small, disjunct pond.

MOAT (MO): narrow band of deeper water surrounding a hammock and often pooled at the south end of the hammock (trailing from a moat might be a Vegetated Creek).

MUD FLAT (MF): open area that is generally nontidal or receives wind-derived tides and often supports sparse dwarf mangroves (e.g. flats on Boggies).

OPEN MANGROVE (OM): clumps of mangrove trees with open areas of pools and interconnected channels of water (e.g. south of Gator Lake).

OPEN WATER (OW): areas of Florida Bay considered to be too deep for foraging by wading birds. This category was usually applied to birds in flight over the Bay.

TIDAL FLAT (TF): open coastal (with the exception of the coastline - see Bay Edge and Beach) areas subjected to daily fluctuating tides (e.g. Snake Bight, Lake Ingraham).

TRANSITIONAL MARSH (TM): region of mixed mangrove and freshwater marshes, typically with mangrove fingers interdigitating with sawgrass meadow (e.g. north of Little Madeira Bay).

VEGETATED CREEK (VC): channel of water connecting distinct ponds, lakes, or bays or draining higher adjacent areas; often associated with a hammock or moat.

Appendix B. Number of birds per species by region recorded during aerial surveys of the ecotone during the dry season in each of 4 years. Note: only the eastern region was surveyed in 1991-92. Survey regions delineated in Figure 6. RS=Roseate Spoonbill, WS=Wood Stork, LWW=Large white waders, SWW=Small white waders, WI=White Ibis, GBH=Great White Heron, WPEL=White Pelican (See Methods for species included in LWW & SWW)

	Numbers of birds							
	RS	WS	LWW	SWW	WI	GBH	WPEL	Survey Totals
1988-89								
EASTERN REGION								
10 Nov	300	0	387	229	719	4	0	1639
16 Nov	21	3	414	526	296	6	0	1266
28 Nov	152	14	469	317	951	9	0	1912
8 Dec	115	158	634	937	1327	5	160	3336
19 Dec	51	49	899	293	1275	7	1014	3588
29 Dec	194	9	709	838	1823	88	961	4622
5 Jan	66	14	1013	1812	715	51	1013	4684
12 Jan	118	63	372	188	888	19	376	2024
21 Jan	156	110	437	472	752	46	163	2136
27 Jan	297	53	904	838	669	104	528	3393
6 Feb	198	32	477	636	153	85	117	1698
15 Feb	162	23	387	190	589	49	217	1617
23 Feb	288	40	272	353	677	15	164	1809
2 Mar	151	54	360	161	271	33	57	1087
WESTERN REGION								
10 Nov	123	0	431	1204	40	29	534	2361
16 Nov	240	1	1418	1843	16	20	0	3538
28 Nov	191	21	1475	1218	67	13	676	3661
8 Dec	286	40	2066	2571	262	36	1183	6444
19 Dec	173	37	2511	3353	410	17	839	7340
29 Dec	376	23	2359	5377	686	26	857	9704
5 Jan	242	53	1273	5827	546	16	790	8747
12 Jan	323	28	2375	2894	1190	55	1467	8332
21 Jan	328	51	1192	2267	535	28	947	5348
27 Jan	338	75	1659	4504	224	42	1497	8339
6 Feb	245	13	861	1262	238	49	1312	3980
15 Feb	273	230	236	926	519	37	800	3021
23 Feb	540	90	578	742	1245	94	823	4112
2 Mar	386	7	677	826	322	39	476	2733

Appendix B (continued)

	Numbers of birds							
	RS	WS	LWW	SWW	WI	GBH	WPEL	Survey Totals
1989-90								
EASTERN REGION								
21 Nov	32	20	688	1645	548	16	216	3165
8 Dec	244	172	750	493	491	11	45	2206
21 Dec	349	100	673	370	1126	23	406	3047
5 Jan	240	170	735	652	653	10	220	2680
18 Jan	295	62	903	1649	474	60	594	4037
31 Jan	204	38	759	695	718	7	85	2506
14 Feb	473	166	876	1055	684	7	109	3370
28 Feb	182	66	444	385	507	14	121	1719
WESTERN REGION								
21 Nov	247	58	1644	2593	249	4	793	5588
8 Dec	211	37	2547	3043	17	5	1868	7728
21 Dec	519	163	1776	2910	480	7	974	6829
5 Jan	432	47	2411	2892	463	11	1689	7945
18 Jan	556	189	1552	3123	583	25	981	7009
31 Jan	313	113	1883	2688	642	50	1277	6966
14 Feb	304	91	1035	1807	1137	7	889	5270
28 Feb	502	52	622	416	1727	11	507	3837
1990-91								
EASTERN REGION								
1 Nov	368	105	831	317	1485	22	3	3131
12 Nov	238	80	1036	508	1477	2	0	3341
27 Nov	300	128	997	1436	1280	2	7	4150
11 Dec	234	193	2218	1384	2496	24	415	6964
2 Jan	354	180	1578	1288	1268	51	698	5417
19 Jan	351	241	1258	669	1556	8	416	4499
1 Feb	519	108	1462	1422	1377	37	273	5198
15 Feb	458	503	1183	1631	1173	7	161	5116
5 Mar	403	65	1106	1033	373	1	37	3018

Appendix B (continued)

	Numbers of birds							
	RS	WS	LWW	SWW	WI	GBH	WPEL	Survey Totals
WESTERN REGION								
1 Nov	246	127	1722	1730	361	21	651	4858
12 Nov	375	314	2066	1702	1001	40	573	6071
27 Nov	179	154	1999	1658	509	9	457	4965
11 Dec	80	120	1970	1840	547	15	915	5487
2 Jan	331	69	1106	2034	823	9	1139	5511
19 Jan	351	199	2519	4104	318	30	1331	8852
1 Feb	552	362	2051	3410	387	19	769	7550
15 Feb	628	356	2748	2581	1058	37	900	8308
5 Mar	536	293	1828	2738	100	19	783	6297
1991-92								
EASTERN REGION								
26 Nov	84	53	1332	3063	130	2	115	4779
10 Dec	195	116	1067	1337	1181	2	117	4015
23 Dec	312	318	1026	578	2340	6	746	5326
6 Jan	498	209	1394	989	987	9	1031	5117
24 Jan	363	171	1373	695	944	39	230	3815
11 Feb	289	35	1406	901	429	0	268	3328
24 Feb	393	36	567	1007	833	6	248	3090

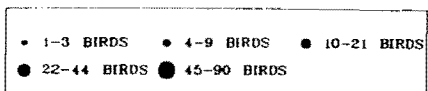
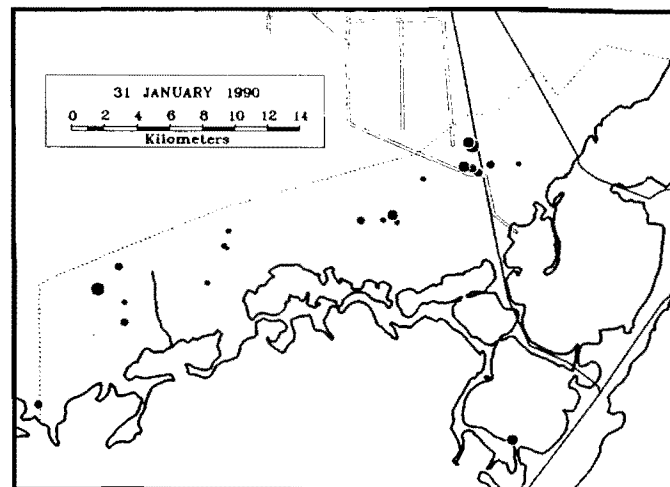
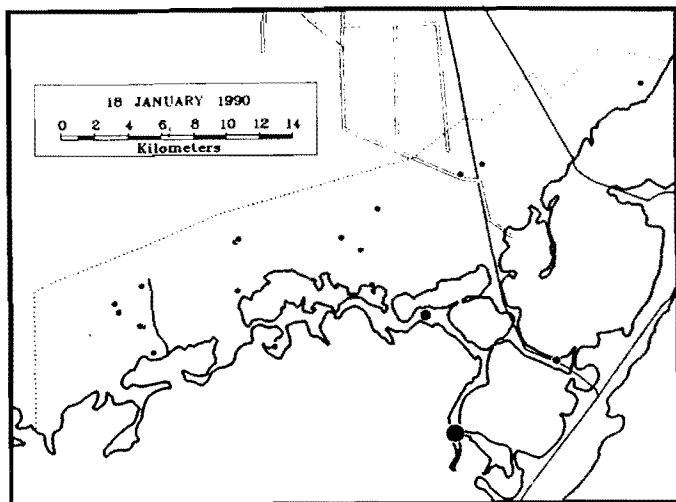
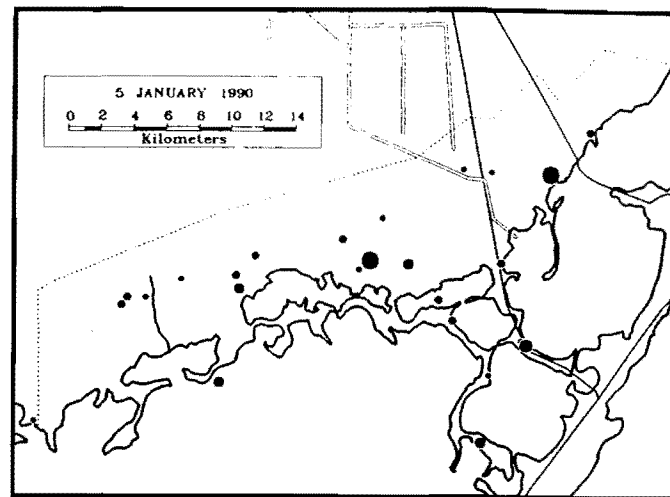
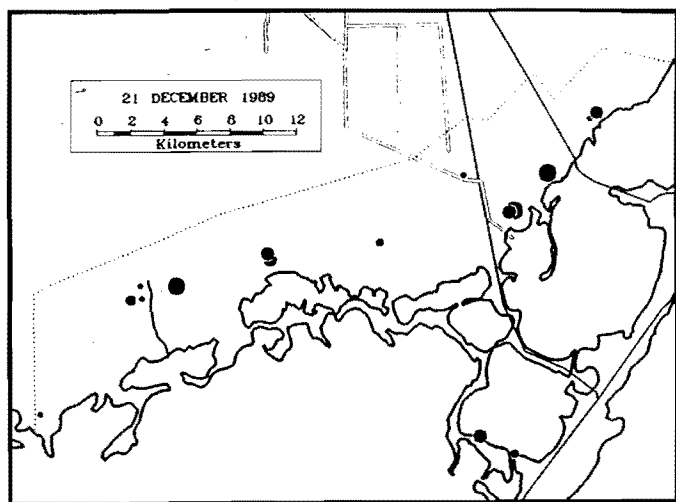
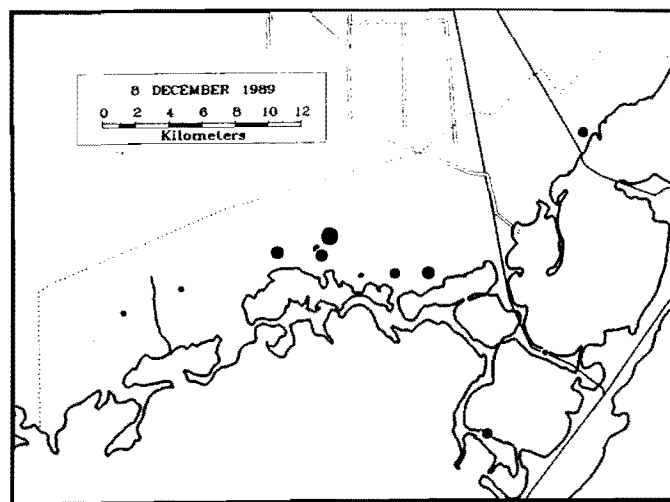
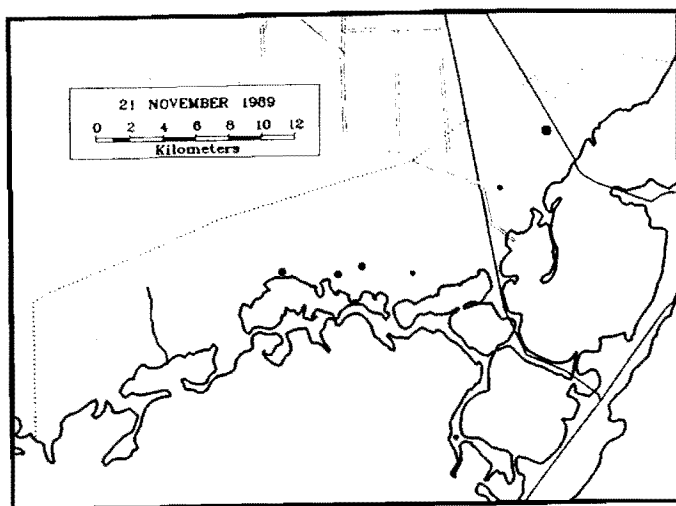
Appendix C. Mean monthly density ($\pm$ S.D.) of birds (birds/km²) per species by region recorded during aerial surveys of the ecotone during the dry season in each of 4 years. Numbers in parentheses are number of surveys flown. Note: only the eastern region was surveyed in 1991-92. Survey regions delineated in Figure 6. RS=Roseate Spoonbill, WS=Wood Stork, LWW=Large white waders, SWW=Small white waders, WI=White Ibis, GBH=Great White Heron, WPEL=White Pelican (See Methods for species included in LWW & SWW)

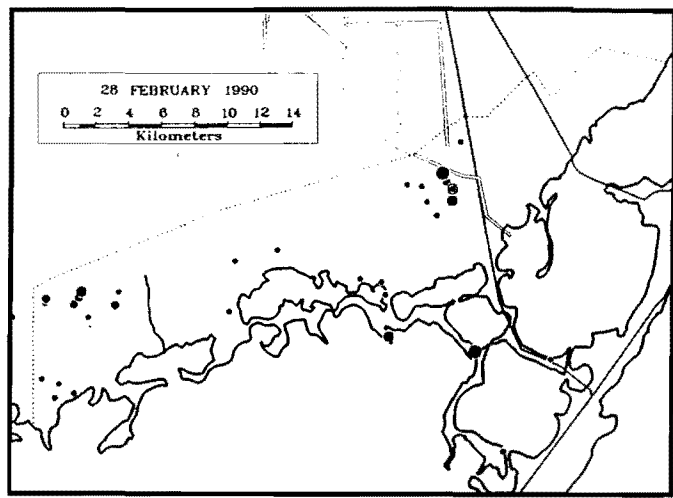
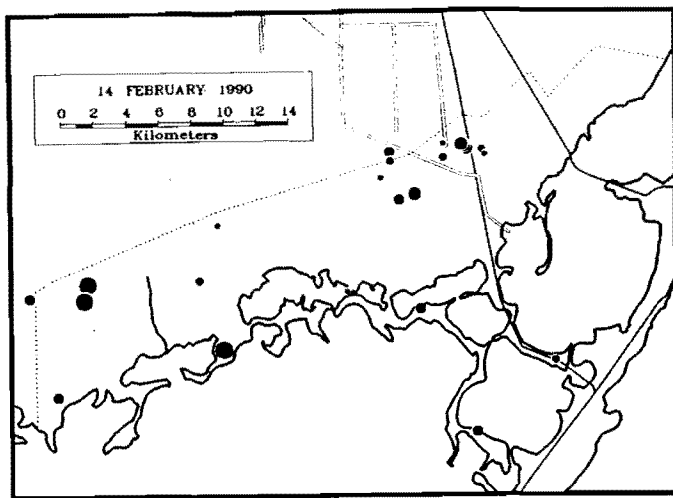
	Numbers of birds						
	RS	WS	LWW	SWW	WI	GBH	WPEL
1988-89							
EASTERN REGION							
(3) Nov	0.6 $\pm$ 0.5	0.0	1.6 $\pm$ 0.2	1.4 $\pm$ 0.6	2.5 $\pm$ 1.3	0.0	0.0
(3) Dec	0.5 $\pm$ 0.3	0.3 $\pm$ 0.3	2.9 $\pm$ 0.5	2.7 $\pm$ 1.4	5.7 $\pm$ 1.2	0.1 $\pm$ 0.2	2.8 $\pm$ 1.9
(4) Jan	0.6 $\pm$ 0.4	0.2 $\pm$ 0.2	2.6 $\pm$ 1.3	3.2 $\pm$ 2.7	2.9 $\pm$ 0.4	0.2 $\pm$ 0.1	2.0 $\pm$ 1.4
(3) Feb	0.8 $\pm$ 0.3	0.1 $\pm$ 0.0	1.5 $\pm$ 0.4	1.5 $\pm$ 0.9	1.8 $\pm$ 1.1	0.2 $\pm$ 0.1	0.6 $\pm$ 0.2
WESTERN REGION							
Nov	0.7 $\pm$ 0.2	0.0	4.2 $\pm$ 2.2	5.4 $\pm$ 1.4	0.2 $\pm$ 0.1	0.1 $\pm$ 0.0	1.5 $\pm$ 1.4
Dec	1.1 $\pm$ 0.4	0.1 $\pm$ 0.0	8.8 $\pm$ 0.7	14.3 $\pm$ 5.5	1.7 $\pm$ 0.8	0.1 $\pm$ 0.0	3.7 $\pm$ 0.7
Jan	1.2 $\pm$ 0.2	0.2 $\pm$ 0.1	6.2 $\pm$ 2.1	14.7 $\pm$ 6.1	2.9 $\pm$ 1.4	0.1 $\pm$ 0.1	4.5 $\pm$ 1.4
Feb	1.3 $\pm$ 0.6	0.4 $\pm$ 0.4	2.1 $\pm$ 1.2	3.7 $\pm$ 1.0	2.5 $\pm$ 2.0	0.2 $\pm$ 0.1	3.7 $\pm$ 1.1
1989-90							
EASTERN REGION							
(1) Nov	0.1	0.1	2.7	6.4	2.1	0.1	0.8
(2) Dec	1.1 $\pm$ 0.3	0.5 $\pm$ 0.2	2.8 $\pm$ 0.2	1.7 $\pm$ 0.3	3.1 $\pm$ 1.7	0.1 $\pm$ 0.0	0.9 $\pm$ 1.0
(3) Jan	1.0 $\pm$ 0.2	0.4 $\pm$ 0.3	3.1 $\pm$ 0.4	3.9 $\pm$ 2.2	2.4 $\pm$ 0.5	0.1 $\pm$ 0.1	1.2 $\pm$ 1.0
(2) Feb	1.3 $\pm$ 0.8	0.5 $\pm$ 0.3	2.6 $\pm$ 1.2	2.8 $\pm$ 1.8	2.3 $\pm$ 0.5	0.0	0.4 $\pm$ 0.0
WESTERN REGION							
Nov	0.9	0.2	6.3	9.9	1.0	0.0	3.0
Dec	1.4 $\pm$ 0.8	0.4 $\pm$ 0.3	8.2 $\pm$ 2.1	11.3 $\pm$ 0.4	0.9 $\pm$ 1.3	0.0	5.4 $\pm$ 2.4
Jan	1.6 $\pm$ 0.5	0.4 $\pm$ 0.3	7.4 $\pm$ 1.6	11.0 $\pm$ 0.8	2.1 $\pm$ 0.3	0.1 $\pm$ 0.1	5.0 $\pm$ 1.4
Feb	1.5 $\pm$ 0.5	0.3 $\pm$ 0.1	3.2 $\pm$ 1.1	4.2 $\pm$ 3.7	5.4 $\pm$ 1.6	0.0	2.7 $\pm$ 1.0

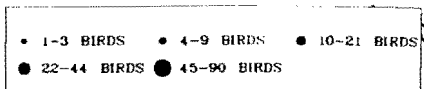
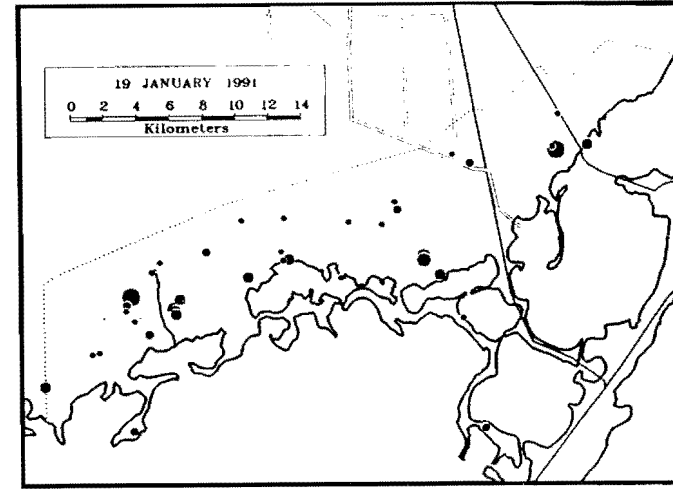
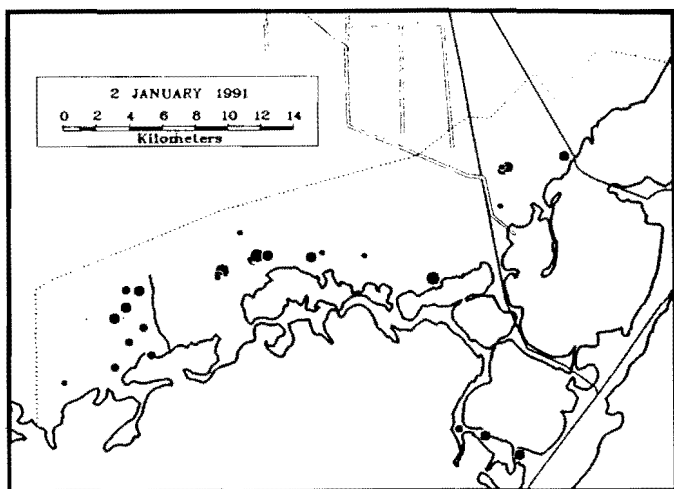
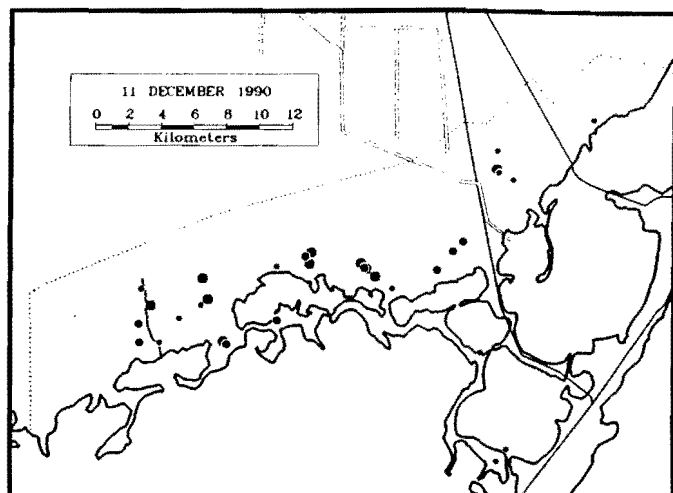
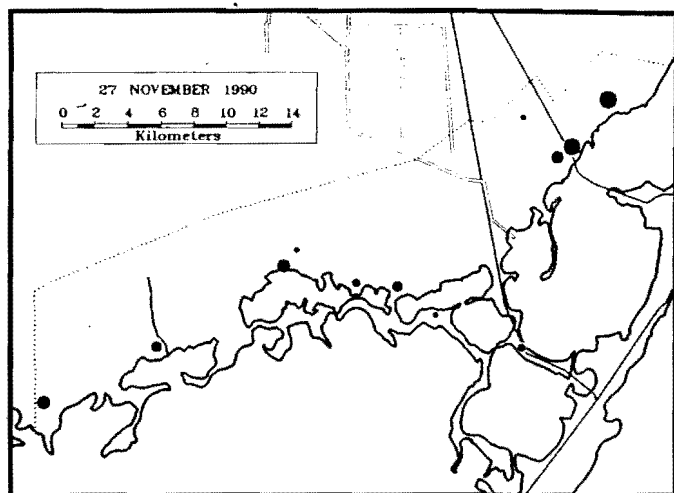
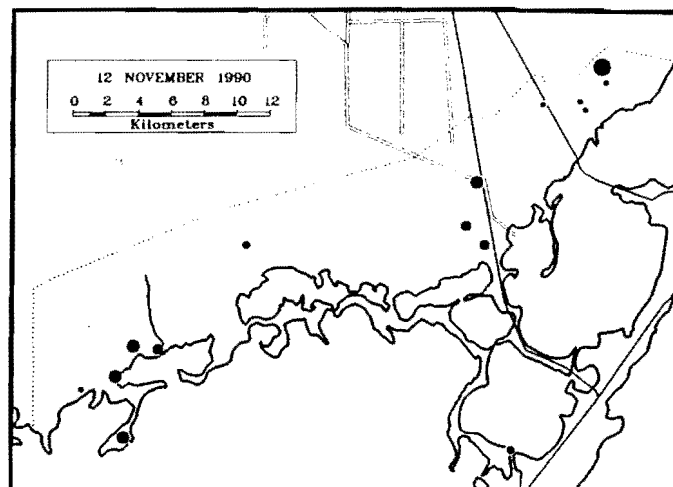
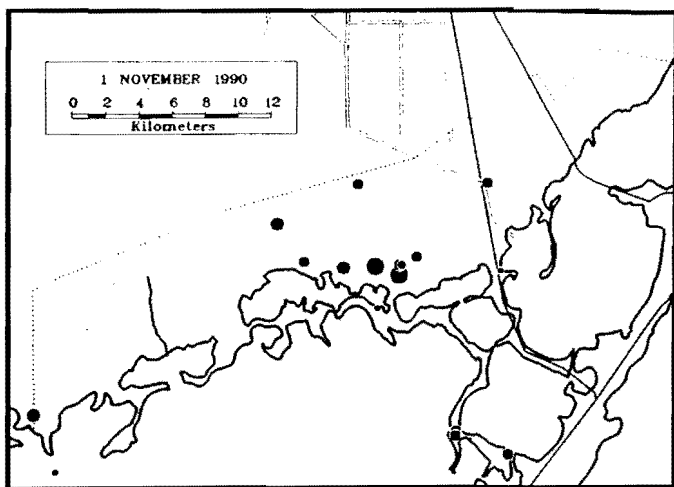
Appendix C (continued)

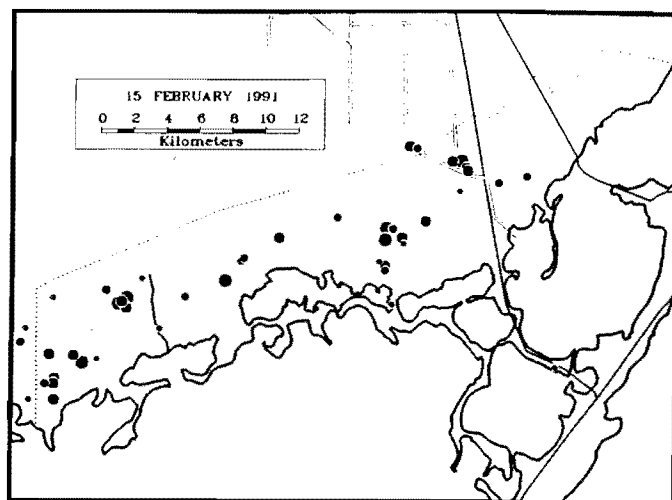
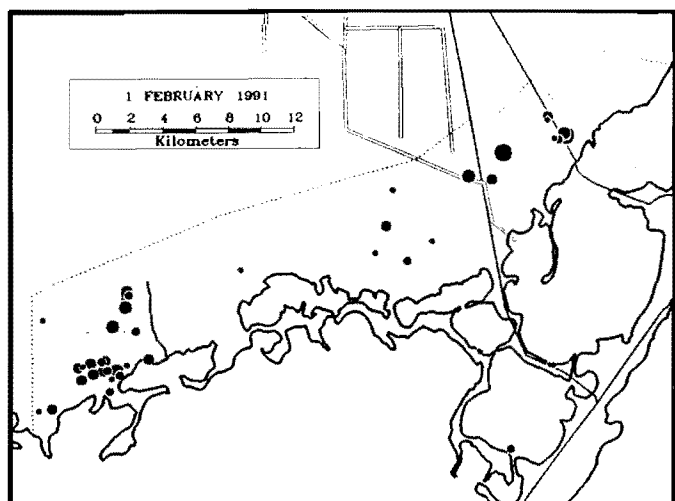
	Numbers of birds						
	RS	WS	LWW	SWW	WI	GBH	WPEL
1990-91							
EASTERN REGION							
(3) Nov	1.2 ± 0.3	0.4 ± 0.1	3.7 ± 0.4	2.9 ± 2.3	5.5 ± 0.5	0.0	0.0
(1) Dec	0.9	0.8	8.6	5.4	9.7	0.1	1.6
(2) Jan	1.4 ± 0.0	0.8 ± 0.2	5.5 ± 0.9	3.8 ± 1.7	5.5 ± 0.8	0.1 ± 0.1	2.2 ± 0.8
(2) Feb	1.9 ± 0.2	1.2 ± 1.1	5.1 ± 0.8	5.9 ± 0.6	4.9 ± 0.6	0.1 ± 0.1	0.8 ± 0.3
WESTERN REGION							
Nov	1.0 ± 0.4	0.8 ± 0.4	7.3 ± 0.7	6.5 ± 0.1	2.4 ± 1.3	0.1 ± 0.1	2.1 ± 0.4
Dec	0.3	0.5	7.5	7.0	2.1	0.1	3.5
Jan	1.3 ± 0.0	0.5 ± 0.4	6.9 ± 3.8	11.7 ± 5.6	2.2 ± 1.4	0.1 ± 0.1	4.7 ± 0.5
Feb	2.2 ± 0.2	1.4 ± 0.0	9.1 ± 1.9	11.4 ± 2.2	2.7 ± 1.8	0.1 ± 0.0	3.2 ± 0.4
1991-92							
EASTERN REGION							
(1) Nov	0.3	0.2	5.2	11.9	0.5	0.0	0.5
(2) Dec	1.0 ± 0.3	0.8 ± 0.6	4.1 ± 0.1	3.7 ± 2.1	6.8 ± 3.2	0.0	1.7 ± 1.7
(2) Jan	1.7 ± 0.4	0.7 ± 0.1	5.4 ± 0.1	3.3 ± 0.8	3.7 ± 0.1	0.1 ± 0.1	2.4 ± 2.2
(2) Feb	1.3 ± 0.3	0.1 ± 0.0	3.8 ± 2.3	3.7 ± 0.3	2.4 ± 1.1	0.0	1.0 ± 0.1

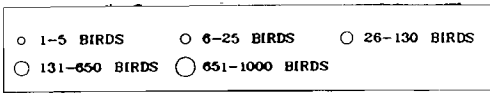
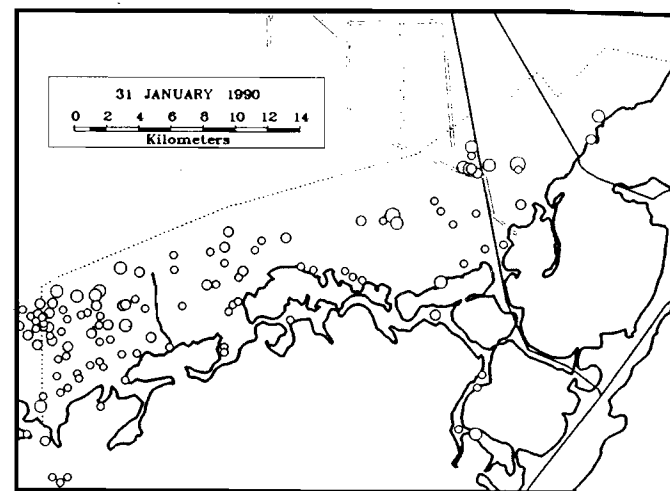
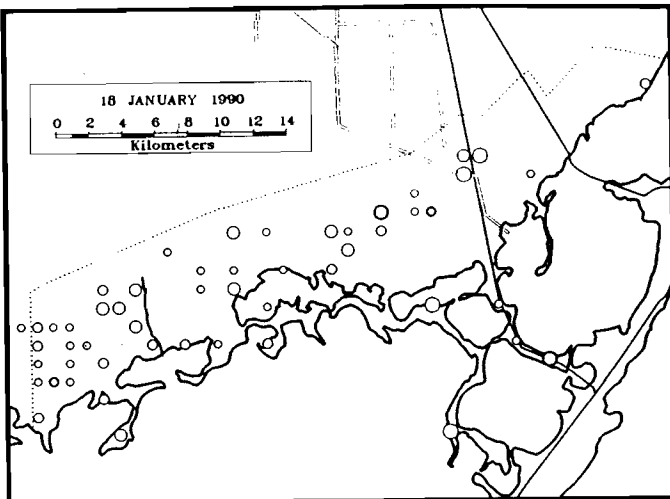
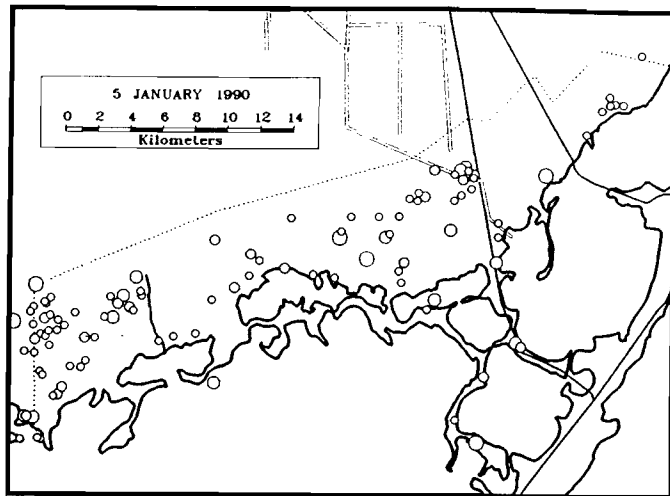
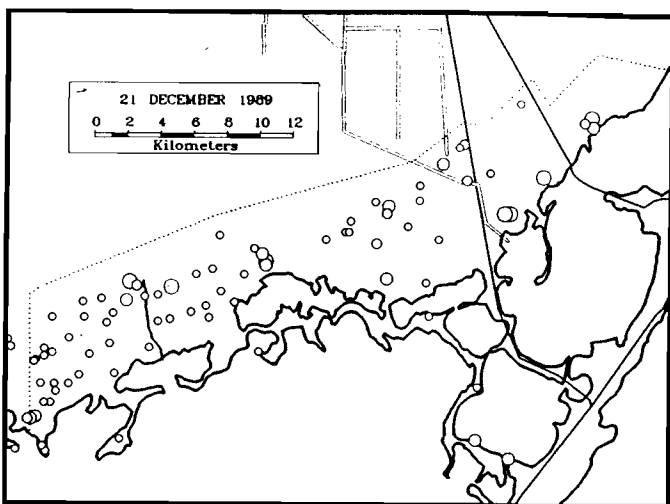
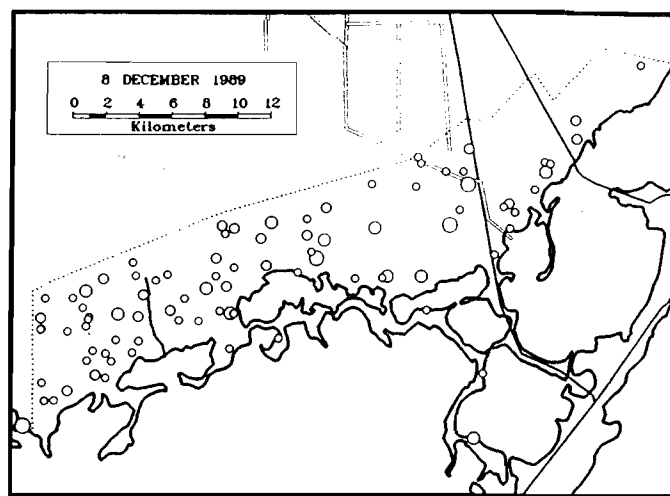
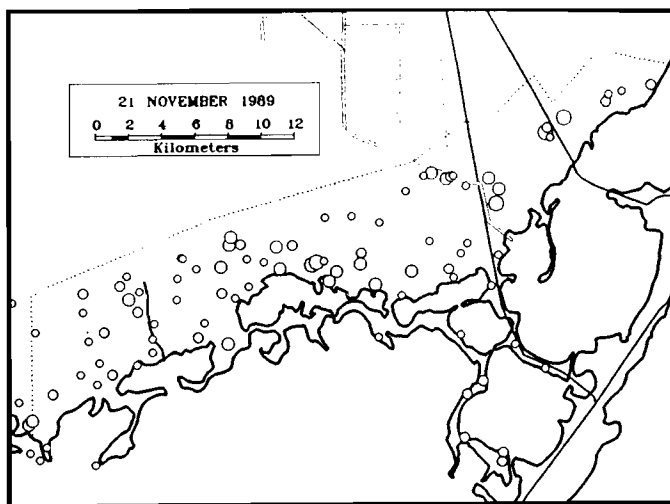
Appendix D1. Distribution of Roseate Spoonbills recorded during aerial surveys of the eastern ecotone region. Flights were flown at approximately 2-week intervals in fixed-wing aircraft at an altitude of 300 feet along transects 1 km apart (Figure 6). Each map displays spoonbill distribution by group size during one aerial survey.

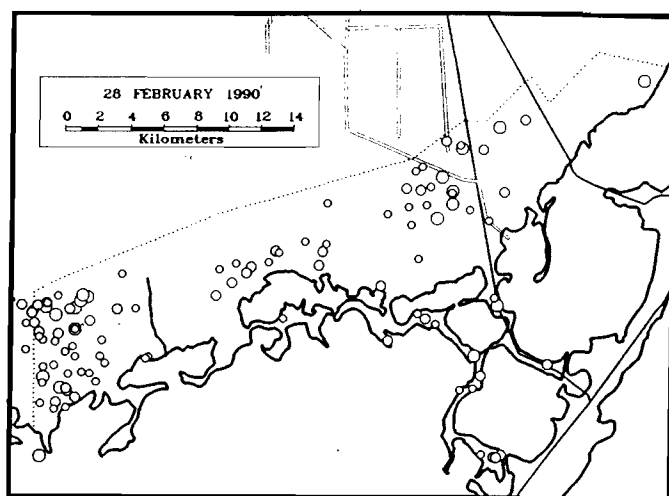
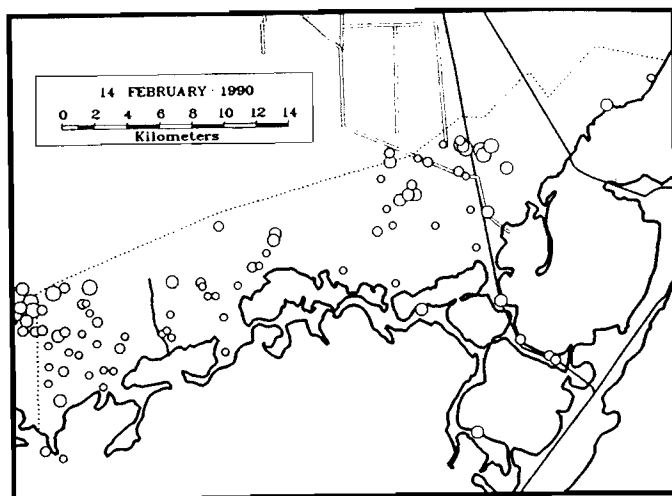


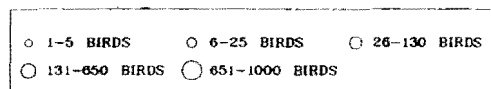
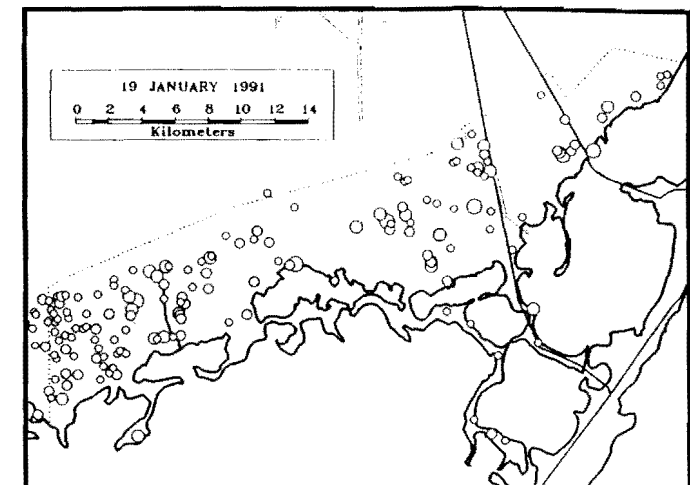
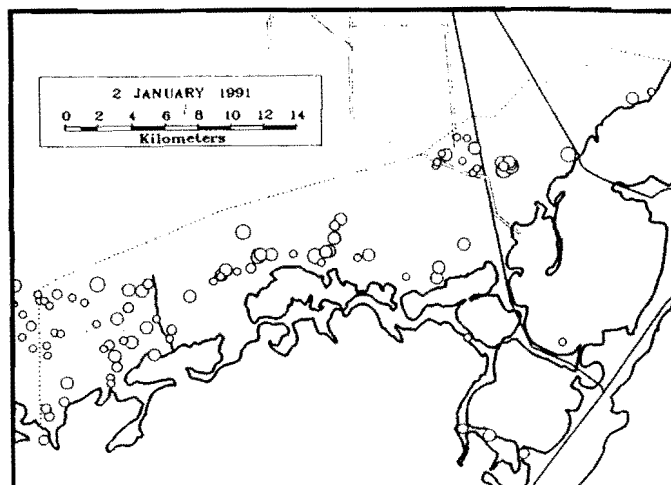
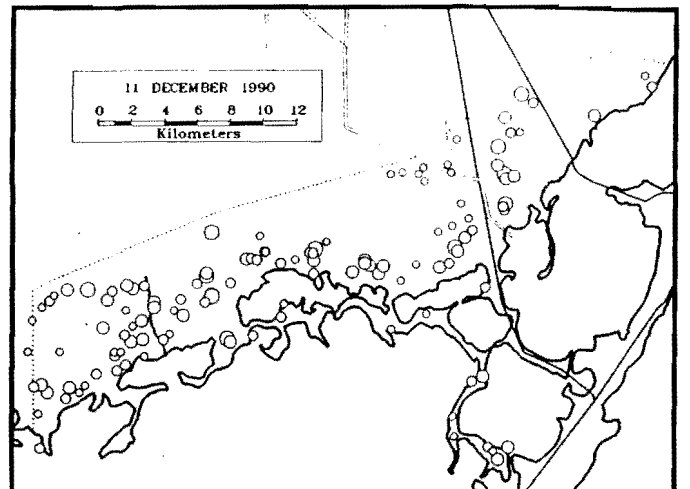
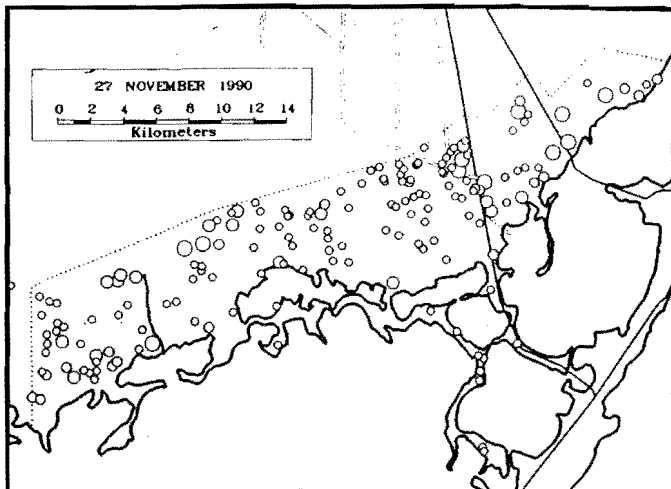
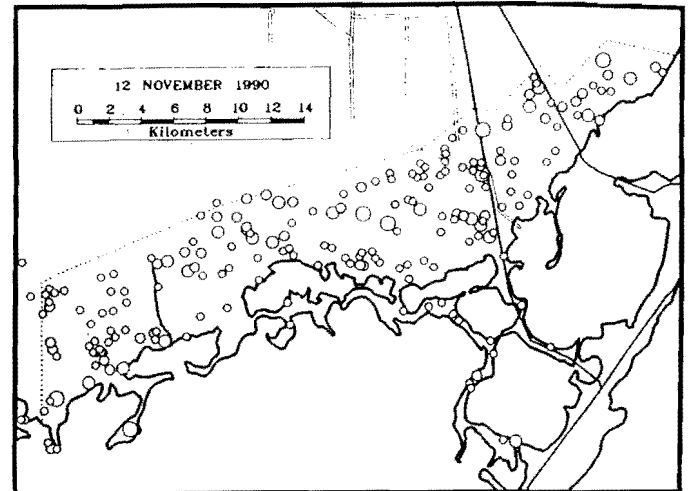
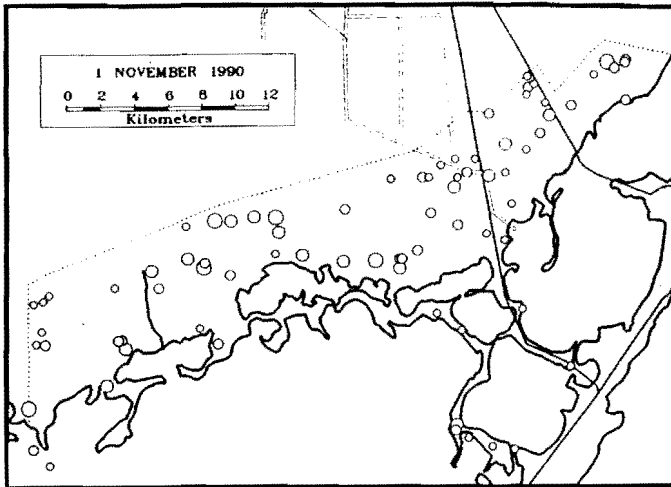


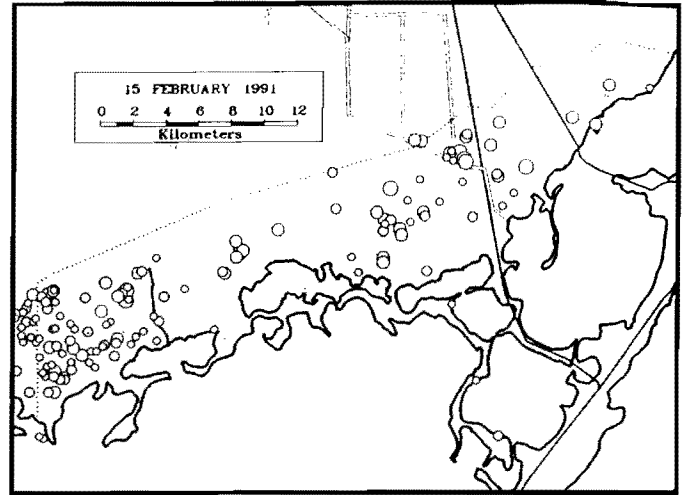
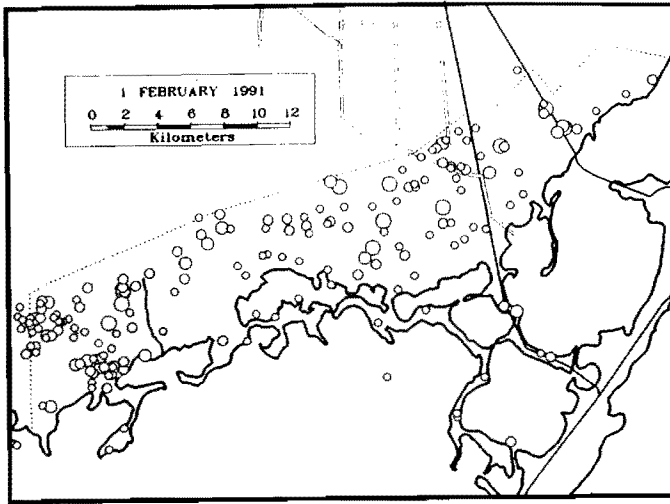


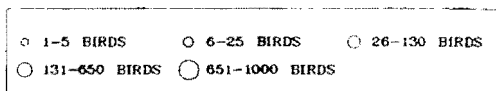
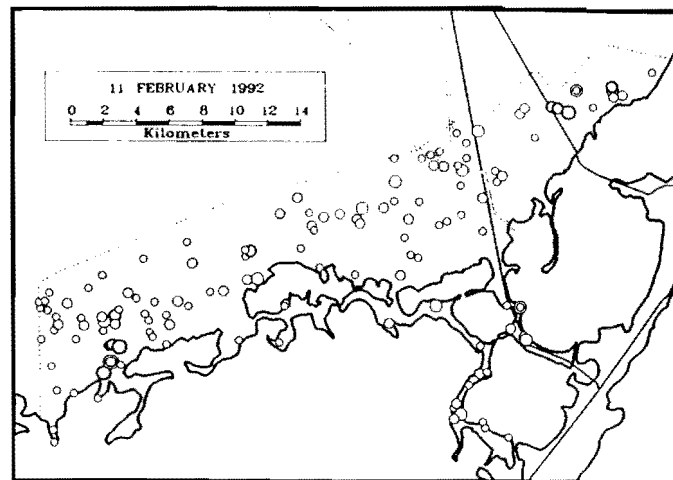
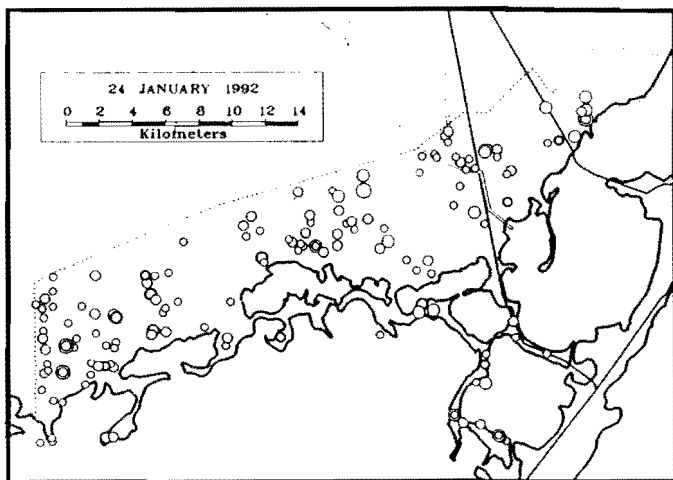
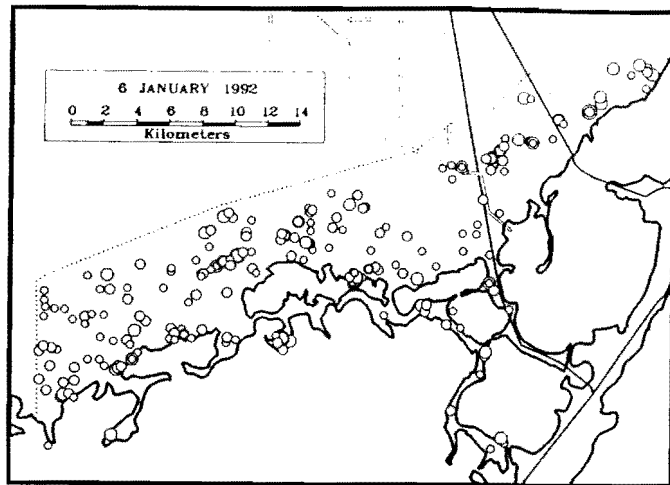
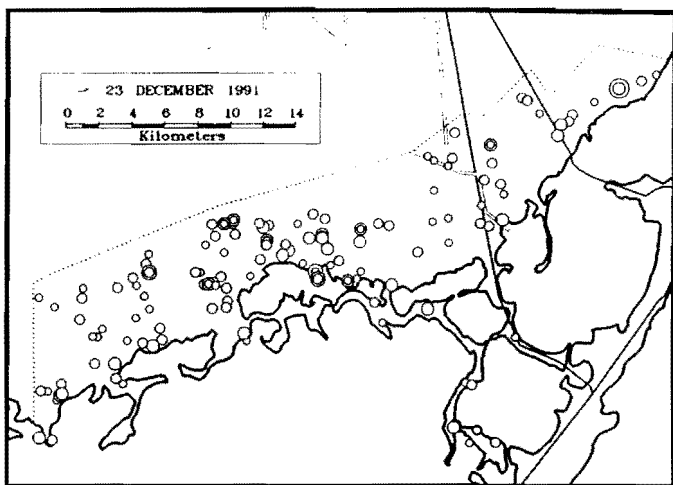
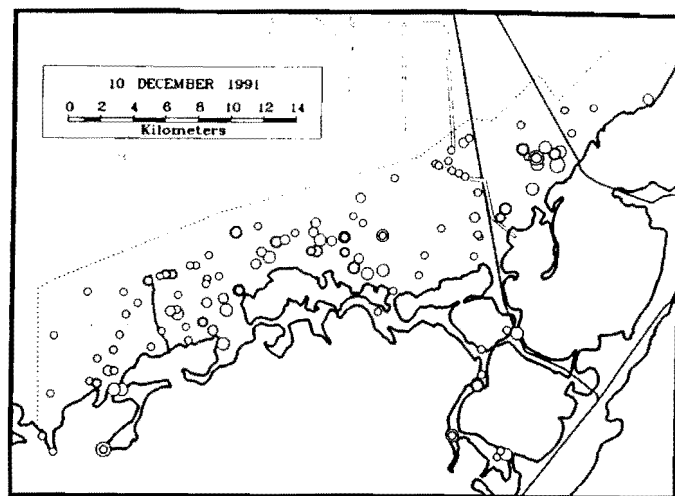
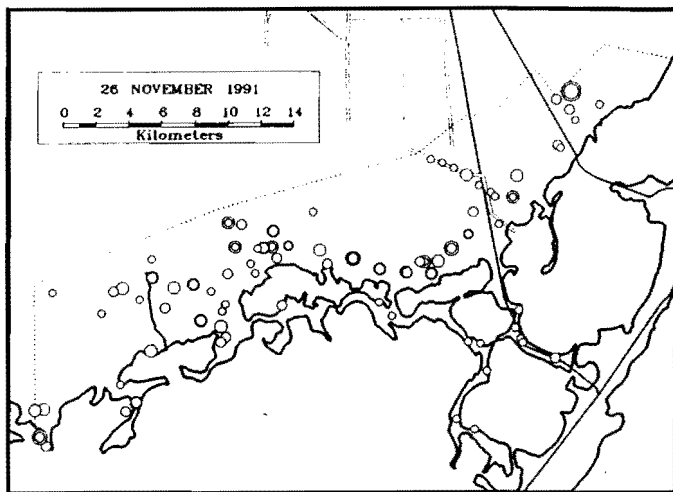












Appendix E. Reproductive success of Roseate Spoonbills at three colonies in Florida Bay for five consecutive nesting seasons. Statistical comparisons made among colonies within years for nestling periods to 14 and 21 days only. See Appendix F for specific P values for each comparison.

TERN KEY		Incubation Period	Nestling period to 14 days	Nestling period to 21 days	Overall success to 14 days	Overall success to 21 days
1987-88	Total nest days of observation	172	764	1081		
	Estimated daily survival probability; p	0.994186	0.990838	0.984274		
	Estimated standard deviation of p	0.005797	0.003447	0.003784		
	Estimated success probability for period p ^j	0.874493	0.879094 ^A	0.71686*	0.768761	0.626889
	Estimated standard deviation of p ^j	0.11727942	0.04281715	0.05787549	0.109364	0.110842
1988-89	Total nest days of observation	790	790	1144		
	Estimated daily survival probability; p	0.992405	0.993671	0.993007		
	Estimated standard deviation of p	0.003089	0.002821	0.002464		
	Estimated success probability for period p ^j	0.839163	0.914947 ^A	0.862975 ^A	0.76779	0.724177
	Estimated standard deviation of p ^j	0.06007285	0.03637145	0.04496355	0.060444	0.063672
1989-90**	Total nest days of observation	737	736	1061		
	Estimated daily survival probability; p	0.994573	0.995924	0.997172		
	Estimated standard deviation of p	0.002706	0.002349	0.00163		
	Estimated success probability for period p ^j	0.882347	0.944422	0.942271	0.833308	0.83141
	Estimated standard deviation of p ^j	0.5522189	0.03117913	0.03234859	0.056958	0.057501
1990-91**	Total nest days of observation	246	617	809		
	Estimated daily survival probability; p	0.979675	0.991896	0.99382		
	Estimated standard deviation of p	0.008997	0.003609	0.002755		
	Estimated success probability for period p ^j	0.623469	0.892334 ^A	0.877926 ^A	0.556432	0.547448
	Estimated standard deviation of p ^j	0.13171077	0.04545926	0.05111638	0.091798	0.093833
1991-92	Total nest days of observation	616	753	1008		
	Estimated daily survival probability; p	0.99513	0.989376	0.984127		
	Estimated standard deviation of p	0.002805	0.003736	0.003937		
	Estimated success probability for period p ^j	0.893788	0.861109 ^{AB}	0.714618 ^{AB}	0.769649	0.638717
	Estimated standard deviation of p ^j	0.05794319	0.04552559	0.06002983	0.065007	0.067338

* No data from Sandy Key for statistical comparison

** No data from Porjoe Key for statistical comparison

A Significantly lower success than Sandy Key

B Significantly greater success than Porjoe Key

Appendix E (continued)

SANDY KEY		Incubation Period	Nestling period to 14 days	Nestling period to 21 days	Overall success to 14 days	Overall success to 21 days
1987-88	Total nest days of observation	124	770	--		
	Estimated daily survival probability; p	0.975806	1.0	--		
	Estimated standard deviation of p	0.013798	0	--		
	Estimated success probability for period p'	0.569331	1.0 ^{AB}	--	0.569331	--
	Estimated standard deviation of p'	0.18516108	0	--	0.105418	--
1988-89	Total nest days of observation	437	645	769		
	Estimated daily survival probability; p	0.990847	1.0	1.0		
	Estimated standard deviation of p	0.004556	0	0		
	Estimated success probability for period p'	0.809373	1.0 ^A	1.0 ^A	0.809373	0.809373
	Estimated standard deviation of p'	0.08558974	0	0	0.069274	0.069274
1989-90*	Total nest days of observation	347	462	575		
	Estimated daily survival probability; p	1	0.997835	0.998261		
	Estimated standard deviation of p	0	0.002162	0.001738		
	Estimated success probability for period p'	1	0.97012	0.96416	0.97012	0.964106
	Estimated standard deviation of p'	0	0.02942943	0.0352415	0.02855	0.033977
1990-91*	Total nest days of observation	501	746	913		
	Estimated daily survival probability; p	0.998004	1	0.998905		
	Estimated standard deviation of p	0.001994	0	0.001095		
	Estimated success probability for period p'	0.955086	1 ^A	0.977249 ^A	0.955086	0.933357
	Estimated standard deviation of p'	0.04389008	0	0.02249012	0.041919	0.047341
1991-92	Total nest days of observation	226	432	628		
	Estimated daily survival probability; p	1	0.997685	0.993631		
	Estimated standard deviation of p	0	0.0022312	0.003175		
	Estimated success probability for period p'	1	0.968076 ^{AB}	0.874428 ^{AB}	0.968076	0.874428
	Estimated standard deviation of p'	0	0.0314092	0.05866797	0.030406	0.051301

* No data from Porjoe Key for statistical comparison

A Significantly greater success than Tern

B Significantly greater success than Porjoe

Appendix F. Level of significance for differences in reproductive success for nestling periods 14 and 21 days among colonies (Sandy, Tern and Porjoe keys) within years. See Appendix E for reproductive success values.

	Nestling Period	
	14 day	21 day
1987-88	Sandy > Tern P < 0.005	*
	Sandy > Porjoe P < 0.005	
1988-89	Sandy > Tern P < 0.01	Sandy > Tern P < 0.001
1989-90**	No differences between Sandy and Tern	
1990-91**	Sandy > Tern P < 0.01	Sandy > Tern P < 0.05
1991-92	Sandy > Tern P < 0.05	Sandy > Tern P < 0.05
	Sandy > Porjoe P < 0.001	Sandy > Porjoe P < 0.001
	Tern > Porjoe P < 0.05	Tern > Porjoe P < 0.05

* No data for Sandy Key colony

** No data for Porjoe Key colony

Appendix G. Z-scores and level of significance for differences in reproductive success for nestling periods 14 and 21 days among years at each colony (Sandy, Tern and Porjoe keys). ND means no data.

Season Comparisons	14-DAY NESTLING PERIOD		
	Tern Key	Sandy Key	Porjoe Key
1987-88 to 1988-89	-0.638	0.0	-1.363
1988-89 to 1989-90	-0.615	1.105	ND
1989-90 to 1990-91	0.944	-1.015	ND
1990-91 to 1991-92	0.485	1.016	ND
1987-88 to 1989-90	-1.233	1.015	ND
1987-88 to 1990-91	-0.212	0.0	ND
1987-88 to 1991-92	0.288	1.016	0.839
1988-89 to 1990-91	0.388	0.0	ND
1988-89 to 1991-92	0.924	1.016	2.166 (P<0.05)
1989-90 to 1991-92	1.510	0.047	ND
	21-DAY NESTLING PERIOD		
	Tern Key	Sandy Key	Porjoe Key
1987-88 to 1988-89	-1.994 (P<0.05)	ND	-0.877
1988-89 to 1989-90	-1.432	1.017	ND
1989-90 to 1990-91	1.064	-0.313	ND
1990-91 to 1991-92	2.071 (P<0.05)	1.636	ND
1987-88 to 1989-90	-3.400 (P<0.001)	ND	ND
1987-88 to 1990-91	-2.086 (P<0.05)	ND	ND
1987-88 to 1991-92	0.027	ND	1.692 (P<0.05)
1988-89 to 1990-91	-0.220	1.012	ND
1988-89 to 1991-92	1.978 (P<0.05)	2.140 (P<0.05)	2.421 (P<0.005)
1989-90 to 1991-92	3.339 (P<0.001)	1.311	ND