Factors Affecting Breeding Status of Wading Birds in the Everglades

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EXECUTIVE SUMMARY

This goals of this research and monitoring effort are to document nesting effort and roughly categorize success of nesting by wading birds in the central Everglades of Florida, and to investigate the causes of nonbreeding in a high proportion of the adult wading birds in the ecosystem. The latter goal has focussed on breeding of White Ibises (*Eudocimus albus*) and has been approached through 1) understanding the nutritional, behavioral, and hormonal aspects of normal breeding in a captive colony of Scarlet Ibises (considered conspecific to White Ibises) in central Florida, and 2) comparing breeding and nonbreeding wild White Ibises in the Everglades, in their physiology, nutritional state, breeding phenology, contaminant load, and hormonal status. This report covers work on this project between January and November, 2000.

The 2000 nesting season was characterized by a high initial water level in fall 1999, peaking in November, followed by a rapid and nearly continuous drawdown between November 1999 and May 2000. In fact, both early and late drying rates (rate at which surface water recedes) exceeded all records in Water Conservation Area 3, and exceeded 90% of records in WCA 1 and 2.

Numbers of breeding birds were estimated using systematic aerial and ground survey techniques. Aerial surveys were conducted once monthly between January and June. Boat surveys and ground colony counts were conducted between April and June, during which we visited every tree island in the central Everglades. Between January and June 2000, we found many more wading birds nesting than usual in the central Everglades. During the spring, we estimated 32,204 nests of all waders (not including Cattle Egrets, Anhingas or cormorants) in WCAs 2 and 3. For comparison, this level of total nesting

effort in 2000 was 33% greater than in 1999, 2.8 times greater than the 10-year running average, and 20% greater than the last exceptionally large nesting in 1992. The level of nesting in 2000 in the WCAs was about half the estimate for the Everglades as a whole during several years in the late 1940's.

In the Everglades as a whole, there were over 34,800 nests found during 2000. The 2000 nesting was truly exceptional nesting event, and was over 2.5 times as large as the ten-year average, 2 times the five year average, and 14% greater than the very large nesting event that occurred in 1992.

The large increase in numbers of nesting birds generally was true for many but not all of the individual species. Numbers of White Ibises were 4.7 times the ten-year average, and 2.8 times the five year running average. Wood Storks also nested in much larger than normal numbers - over 1,800 pairs nested in a variety of locations. This level of nesting effort by storks has not been seen in the Everglades since the mid-1970's, or almost 30 years, and the 2000 nesting was over six times the ten-year running average for the Everglades as a whole. The storks nested relatively early (February), and were able to fledge large numbers of young this year, despite a large (15 cm) rainfall event in April. Summer rains were somewhat late this year, resulting in a protracted drydown. We hypothesize that this further enhanced survival chances for these young storks.

Numbers of nesting Snowy Egrets were also up considerably this year, with at least three times the ten-year average nesting in 2000. However, numbers of Little Blue Heron nests were less than 66% of the ten year running average. Numbers of Great Egrets and Tricolored Herons were similar to the ten-year mean, and showed no increase in 2000 over other years.

Within the Everglades ecosystem, the vast majority of nesting was concentrated in the Water Conservation Areas (92%), and the vast majority of the remainder in Everglades National Park was in freshwater areas and not in the coastal zone. Within the Water Conservation Areas, the vast majority of nesting was concentrated in WCAs 2 and 3 (92%), and the vast majority of that (96%) was in WCA 3. In LNWR, nesting was about half the 8-year average.

Although we did not measure reproductive success through documentation of individual nest histories, nesting was largely successful throughout WCA 3. However, in Loxahatchee NWR, the strong pulse of rains in mid-April resulted in widespread abandonment, including up to two thirds of the nests destroyed in some closely monitored colonies.

The Systematic Reconaissance Survey team reported that numbers of birds in the Everglades ecosystem were normal to well above normal during the winter and spring of 1999/2000, depending on species and month. Thus there were not exceptionally large numbers of birds in the Everglades during the winter months, and many more than normal during May. The proportion of this total count of birds that actually bred in 2000 was calculated to be 100% or above, suggesting that there were few birds that remained in the system, that also chose not to breed this year. This is in stark contrast to many of the previous years, when only 30% of adults have bred on average.

The reasons for the large nesting event in 2000 are not completely understood, but several contributory factors were evident. The hydrological conditions were generally very favorable, with a long, continuous, and exceptionally rapid surface water recession throughout the winter and spring, beginning from extremely high levels. These hydrological factors apparently created drying and depth conditions that were conducive to making prey animals available to foraging wading birds. In addition, the initially high water conditions also allowed fast drying conditions while maintaining above-average water conditions in most compartments, resulting in a vast acreage of the marsh being in very shallow depths, yet relatively little of it going entirely dry. Drying conditions have not, however, always explained nesting patterns in the past, and we suspect that the 2000 nesting season may have had several contributory sources.

There were at least two other environmental conditions that changed in 2000 that may also have strongly affected the size of the nesting event. The first of these was the extensive drought conditions that prevailed throughout much of the southeastern states, which may have forced many wading birds into the Everglades, that would normally have nested elsewhere. The second condition that has changed during the last several years has been a dramatic reduction in the mercury exposure of birds nesting in the central Everglades. In most colonies sampled during 2000, mercury concentrations in feathers of nestling birds had decreased by almost an order of magnitude, by comparison with samples taken in the same places during 1994 – 1996. Since 1997, mercury concentrations have been plummeting in most colonies. Although the mechanism behind the reduced mercury exposure is not well understood at this point, mercury has been implicated experimentally in reproductive impairment in ducks, as well as health and appetite in birds; a reduction in mercury could therefore have contributed to the increased reproductive effort and success documented in 2000.

The decade of the 1990's has produced only three large nesting events (1992, 1999 and 2000), a rate that is consistent with current predictions that inland freshwater habitats of the Everglades are capable of producing large pulses of prey organisms only in rare combinations of hydrological and meteorological events. This observation further supports the objective of getting wading birds to nest in coastal regions of the Everglades where historical nesting is thought to have been more stable and productive. There was no evidence of increased coastal nesting in 2000.

The breeding season of 1992, and the historical record of nesting events have previously suggested a distinct relationship between strong droughts, and large breeding events which follow 1 – 2 years behind. Using statistical definitions, we have identified during this century 8 extreme droughts, and 8 extremely large nesting events; the large nesting events immediately followed the droughts in all but one of the cases. This strong and statistically significant association suggests that antecedent droughts create conditions which result in large pulses of prey becoming available to birds for a short period following the droughts. This suggests strongly that droughts serve a critical function in the ecology of the ecosystem, and should be an important feature to be retained in any healthy water management scheme for the Everglades.

While this relationship is probably biologically significant, the 1999 and 2000 nesting events have demonstrated that preceding droughts are not necessarily needed to stimulate large nesting events and the pulse of prey availability implied by nesting. The mechanisms by which the 1999 and 2000 pulses of prey were organized remains unknown, and the 1999 and 2000 seasons therefore present a significant departure from predictions.

We have continued to refine our ability to accurately estimate the breeding population of birds. During both 1999 and 2000 we have become increasingly aware of the difficulties in counting very large colonies (>5000 pairs), and since no standardized software is available for this purpose have constructed a tool designed to specifically measure interobserver bias in estimating numbers of birds over a wide range of true numbers. We constructed a scale model of a wading bird colony, designed after the approximate dimensions of the Alley North colony. The scale used was 1:158, and the birds, grass and trees are all to scale. We used white alfalfa seeds to represent White Ibises to scale as seen from 800 ft above the colony during an aerial flight. The advantage of this model is simply that the numbers of birds (seeds) used in any estimation run can be determined with a high degree of accuracy, using a commercial seed counter. Seeds are then typically spread on the surface of the colony at realistic densities, using a flour sifter and a monofilament overlay grid. Observers are then allowed realistic time periods to walk around the model and estimate through repeated "passes" the numbers of birds on the colony. Preliminary tests have demonstrated that this methodology works, and have initiated a more refined study of interobserver bias with this tool.

We believe that these data will allow us to either come up with a scaled correction factor for current and past records, or failing that, will produce guidance on the responsible interpretation of wading bird colony estimates.

We have recently observed that the number of ibises breeding in the Everglades has been considerably lower than the number of ibis present within the Everglades system . There are several hypotheses that might explain this observation including: 1) a large proportion of White Ibises never attempts to breed, 2) many ibises attempt to breed but fail early, 3) within a colony White Ibis reproduction is asynchronous so that it is difficult to estimate the total number of breeding pairs, 4) the number of breeding pairs in large colonies are underestimated.

A combination of the above hypotheses may best explain the observed patterns of seemingly small numbers of breeding birds, and one objective of this project is to evaluate the above hypotheses by examining in detail the reproductive behavior and physiology of White Ibises. This is our third year studying White Ibis reproductive physiology and behavior in the Everglades. Last year we developed methods of capturing adult ibises on the marsh, marked birds with radio-transmitters, and identified significant changes in bill and leg color associated with stage of reproduction (Frederick et al. 1999). This year we successfully followed the reproductive behavior of birds marked in 1999, used a new technique, laproscopy, to visually examine gonad condition, and we developed a discriminant function model based on color changes to classify stage of reproduction. The latter accomplishment provides us with a very important tool for studying ibis reproduction. Identifying stage of reproduction allows us to distinguish breeding birds from non-breeding birds, gives us a better understanding of stage-specific changes in hormone levels and body condition and, potentially, will allow us to estimate variability in date of nest initiation.

Seventy-nine percent of the birds we marked with radio-transmitters in 1999 and 2000 were located in a breeding colony this year. These data suggest that ibises are able to breed in consecutive years and may show philopatric tendencies. We were also able to verify that reception of a radio signal from a colony is a good measure of nest attendance. This has allowed some insight into rates of nest attendance and rates of attendant exchanges between breeding adults at our largest colony, Alley North.

Consistent with our findings from last year, White Ibises went through significant changes in body condition over the course of the breeding season. Both male and female birds gained mass (probably in the form of fat) during the display stage. This is most likely an important energy store for males who may fast as they stay at the nest for long periods of time during the copulation and egg-laying stage. Females may metabolize this fat while producing eggs. During incubation body condition scores were at their lowest and then slowly appeared to increase during later chick rearing.

Gonad size also showed a seasonal pattern. Both testes and ovaries were largest during the copulation and egg-laying stage, as one might predict from other studies. Ovaries and testes then regressed during incubation and chick rearing stage.

As our ability to classify stage of reproduction based on morphological traits and gonad condition has become refined, we recognized that ibises often molt body feathers while breeding. Thus, our assumption last year that a molting bird was a non-breeding bird was probably incorrect. It is extremely unusual for birds to molt while reproducing because it is thought that both activities require high amounts of energy. Thus the ibises provide a very interesting exception to this rule.

The information we have gathered over the past three years has given us a better understanding of the reproductive biology of White Ibises in the Everglades. During the past two years it seems that the majority, if not all, of the White Ibises present in the Water Conservation Areas attempted to breed. This is inconsistent with the hypothesis that a large proportion of adult ibises makes no attempt to breed. However, in both 1999 and 2000, the proportion of birds breeding (as independently calculated from SRF and breeding survey results) was at or above 100%.

We are continuing to investigate alternative explanations to the hypothesis that large proportions of ibises remain in the Everglades during the breeding season, but do not breed. For example, we may be underestimating total breeding effort, either through errors associated with observer bias (see above) or through error associated with counting birds in a colony at a single point in time (i.e. asynchronous breeding).

We suggest that there may be more than one explanation for why there are large apparent differences between the SRF counts and the breeding bird estimates. In years of excellent breeding conditions, when birds may constantly be immigrating into the area we may underestimate numbers of breeding birds because of breeding asynchrony and observer error at large colony sizes. In years of poor breeding conditions, our counts of breeding birds are probably much more precise. In these situations interactions among prey abundance, hydrology, and toxicological factors may prevent birds from coming into reproductive condition, or may cause high abandonment rates.

Information we have gathered on ibis reproduction has led us to reshape our initial hypothesis and given us insight into new, unusual relationships. For example, we suspect that mercury may have an effect on abandonment rates, causing relatively low nesting success in the Everglades for wading birds. We are currently planning future research to evaluate this hypothesis, and to help reduce uncertainties associated with estimating numbers of breeding birds.

CHAPTER I. INTRODUCTION

Purpose of this study

This study was initiated in January of 1998, as a continuation of a long-term monitoring and research program. The current project was designed with two general goals in mind - continued monitoring of nesting populations of wading birds in the Water Conservation Areas of the Everglades, and the pursuit of directed research questions aimed at understanding the factors associated with large proportions of the adult population of wading birds not coming into reproductive condition.

Both goals have immediate value to the larger purpose of restoring wading bird populations to the Everglades. Continued monitoring of wading bird populations is essential, as a tool for measuring the effect of different water management strategies, as a method for better understanding the local ecology of this group of birds, and as a way to detect changes that may be due to novel influences that may be unrelated to water management (eg, exotic fish dynamics, contaminants, etc).

The research component of the project has arisen as a result of a recent, and particularly disturbing observation about wading bird populations in the Everglades. During the last several years, it has become increasingly apparent that large numbers of adult wading birds are not coming into reproductive condition – on average over 70% during the past ten years (methodology, data and details that have yielded this observation are given later in this report). An understanding of why the majority of adult birds are apparently not coming into reproductive condition is of key importance in restoring populations of wading birds to the south Florida ecosystem. Two main families of hypotheses are proposed to explain the observation – one suggests that the problem is that not enough food is available at the right time to stimulate breeding. If this hypothesis is correct, then the current restoration process (= hydrological restoration) should be effective. However, a second group of hypotheses contend that the problem is due to or at least is worsened by some other, unknown effects, that may keep birds from coming into reproductive condition even when hydrological conditions are restored. If this latter possibility is even partly true, then a very thorough and expensive hydrological restoration may be inadequate to achieve restoration of wading bird breeding.

The research aspects of this project have been aimed at understanding both the characteristics of birds with abnormal reproduction in the field, and normal reproduction in a captive situation. For the latter, we have chosen to work on the largest captive flock of Scarlet Ibises in the world (*Eudocimus ruber,* of which the White Ibis is now considered a race) at Disney World's Discovery Island. For the field work, our plan has been to capture and identify both breeding and nonbreeding birds, and to compare their body condition, contaminant loads, and hormonal profiles in an effort to ascertain the relative effects of food supply and contaminants to breeding.

Because the monitoring of population dynamics and breeding dispersion, reproductive ecology of captive and wild birds are essentially different in approach and methodology, the results of these efforts are presented as separate chapters, each with their own introductions and justification. However, a review of the history of wading bird populations, and the probable causes of breeding population decline are common to all three, and should be presented at the outset.

History of wading bird populations in the Everglades.

The Everglades of southern Florida has historically supported very large populations of wading birds (herons, egrets, ibises, storks and spoonbills, order Ciconiiformes), numbering in the hundreds of thousands of pairs in some years (Robertson and Kushlan 1974, Ogden 1994). While there was typically large variability in numbers nesting from year to year during the pre-drainage period, a core population of at least one hundred thousand pairs seems to have been typical of the Everglades ecosystem in many years from 1930-1948 (Kushlan et al. 1984, Ogden 1994). Since that time, breeding wading bird populations have declined to less than 5% of their former numbers (Figure 1.1), nesting success of storks has been drastically reduced, the timing of nesting by storks has been shifted by as much as two or three months into the spring, Wood Stork nesting success has declined dramatically, and the location of nesting by nearly all species has shifted from the estuarine areas of Everglades National Park to Water Conservation Areas (WCAs) one and three (Frederick and Collopy 1988, Bancroft 1989, Frederick and Spalding 1994, Ogden 1994, see Figure 1.2).

These dramatic changes in breeding dynamics and numbers have been accompanied by an intensive period of manmade hydrological changes (Gunderson and Loftus 1993, Light and Dineen 1994). In the space of approximately 30 years, the South Florida Project resulted in large portions of the freshwater marsh being diked and impounded, the majority of the northern freshwater marshes drained and put into agricultural production, and huge acreages of surface water flows coming directly under the control of human management. This has resulted in an outright loss of 30% of the marsh surface to other land uses (Browder 1978), a drastic cutoff of freshwater flows to the formerly productive estuarine zone of Everglades National Park (Walters et al. 1992), and the loss of the majority of short-hydroperiod marshes in the system (Fleming et al. 1994, Ogden 1994).

The record of population monitoring is both lengthy and rich, and has been summarized in detail by Kushlan et al. (1984), and Ogden (1978, 1994). These summaries show that many of the heron and egret species went through a severe decline during the plume-hunting period from 1875 to 1910, after which many populations (Reddish Egret Egretta rufescens excepted) rebounded quite rapidly by the 1930's. An obvious conclusion from this part of the history is that once constraints on reproduction are removed, many of the species have the potential to increase rapidly and, in a healthy Everglades environment, could presumably be sustained in large numbers.

During the 1930's and 1940's, the emerging picture was one of high variability in annual nesting numbers. However, we also believe that a population of at least 100,000 pairs (all species combined) bred with some regularity (Kushlan et al. 1984, Ogden 1978, 1994). The largest colonies were located almost entirely in the mangrove zone along the coast of what is now Everglades National Park. In addition, substantial summer breeding by several species, and large summer roosting groups of White Ibises (Eudocimus albus) were a regular feature of this period. Another consistent characteristic was that Wood Storks were recorded initiating breeding during the late fall (November - December). Careful analysis of breeding and hydrological records during this period suggests that larger aggregations bred in wetter years, and that the size and success of breeding had only a weak association with the rapidity of drying of the interior marsh surface (Ogden 1994). In fact, the impression Ogden gives is that breeding occurred not so much under different hydrological and weather conditions than at present, as under a much wider range of conditions.

The period of the 1950's and early 1960's was one of very sporadic and almost always incomplete surveys. At some point during this period, Wood Storks began to decline (there is some disagreement as to the timing, see Ogden 1994). White Ibises began showing up in South Carolina and Georgia in more than token numbers, and in central Florida in several very large colonies (Frederick et al. 1995). By the late 1970's, colonies of White Ibises in the Carolinas had grown to over 50,000 birds annually, Central Florida ibis colonies were in the hundreds of thousands of birds, and Wood Storks had increased breeding numbers and numbers of colonies in north Florida, and expanded their breeding range into Georgia and South Carolina. These movements are most parsimoniously interpreted as an exodus of southern Florida breeding populations, (or at some point, the progeny of the southern Florida aggregations), in part in response to environmental degradation, rather than solely because the northern sites offered superior nesting opportunities (Walters et al. 1992).

By the late 1970's within the Everglades, the timing of Wood Stork breeding had also clearly shifted from starting in November and December to starting in February and March, and colonies of Wood Storks in Everglades National Park began to have very poor breeding success as a result (Ogden 1994). A dramatic change in nesting location within the Everglades was also obvious - the large mixed-species nesting colonies on the coast of Everglades National Park had shifted to the interior freshwater Everglades, and the size of colonies had generally decreased. Finally, the period of the late 1960's and 1970's showed a strong and previously unrecorded relationship between nesting numbers of Wood Storks and White Ibises, and speed of drying of the marsh surface (Kushlan et al. 1975, Frederick and Collopy 1989a). Studies during the 1980's also revealed frequent interruptions in nesting during wet springs, and during any reversals in the drying trend (Frederick and Collopy 1989a, Ogden 1994).

Why have wading birds declined?

The reasons for these dramatic changes in wading bird distributions, timing of reproduction, and breeding numbers are related to changes in amount of available foraging habitat, agricultural displacement, and marsh surface hydrology and water management, all of which have affected both the robustness of prey populations, and the ability of the birds to capture prey. The rough coincidence of massive structural changes to surface water flows in the Everglades during the 1960's, with declines in nesting, changes in timing of nesting, changes in nesting responses to hydrological variables, and movements of birds into other nesting regions certainly suggests a causal relationship with hydrology.

During the late 1970's and throughout the 1980's, considerable research was devoted to understanding the causes of poor wading bird reproduction, both within the Everglades and elsewhere. Much of this work has been summarized in various works reported in Davis and Ogden (1994), and the salient points are listed here:

1. Wading bird reproduction is strongly dependent upon the availability of food. Powell (1983) found that clutch size and productivity of Florida Bay Great White Herons (*Ardea herodias*) could be increased by food supplementation, and Frohring (unpublished Everglades National Park Research Center report) found that prey densities in close proximity to colonies was the environmental factor most strongly correlated with growth rate and productivity of young. Hafner et al. (1993) found that increases in productivity

of Little Egrets (Egretta garzetta) were associated with increased food delivery rates. Hoyer and Canfield (1990) found that the number of wading bird species on Florida lakes was positively influenced by eutrophic status and attendant high secondary productivity. In the central Everglades, the timing and nature of nesting abandonments in the Everglades are consistent with interruptions in the availability of food through increases in water depth, dispersal of prey, increased rainfall, and low temperatures (Frederick and Spalding 1994, Frederick and Loftus 1993). Conversely, there is direct and/or indirect evidence that predation, human disturbance, and lack of appropriate colony substrate have a minor influence on breeding in the Everglades (Frederick and Collopy 1989b, Frederick and Spalding 1994). This evidence taken together suggests strongly that numbers of nesting birds and nesting success are driven by food supply, and that problems with nesting can often be traced to inadequacies or interruptions in food availability.

2. Wading bird foraging and nesting was often centered in coastal regions during the past. Of all the ecosystem habitat types, wading bird prey were probably most consistently available in the mangrove interface during the pre-drainage period, offering pre-breeding foraging habitat and feeding alternatives during periods of high freshwater levels, that the deeper parts of interior marshes could not. This notion is supported by the few notes on the historical pattern of feeding in the ecosystem (Kushlan et al. 1984, Ogden 1994, W. B. Robertson pers. comm.), recorded densities of fishes (Loftus et al. 1986), modeling of predrainage interior marsh water depths (Walters et al. 1992) and by investigation of the foraging behavior of birds breeding on the coast (Bancroft et al. 1994).

3. The productivity of the estuarine zone has been severely compromised by a lack of freshwater flows (see review by McIvor et al. 1994). Modeling of surface water dynamics by two different groups of investigators has shown that historic flows to the estuary were vastly larger than at present (Walters et al. 1992, Fennema et al. 1994). Declines in sport fisheries, commercial shrimp fisheries, and a number of biological measures of Florida Bay salinity, provide further evidence that the productivity of the estuarine zone has been severely compromised by the lack of fresh water (Browder 1985, Tilmant 1989, Rutherford et al. 1989, Bowman et al. 1989, Smith et al. 1991). Lastly, Lorenz (1997) has shown direct increases in fish productivity and standing stocks in areas and during years of higher freshwater outflows in the mangrove swamps fringing the northern border of Florida Bay.

4. Within some bounds, productivity of small "bird forage" fishes in the freshwater marshes is related to hydroperiod (Loftus et al. 1986, Loftus et al. 1992, Loftus and Eklund 1994). Shortened hydroperiods over much of the southern Everglades may well have reduced the productivity of the prey that wading birds feed upon, particularly in the interface between freshwater marsh and mangroves, where the large historical colonies were located. The presence of dikes is also hypothesized to impair the ability of prey fishes to travel in the freshwater parts of the Everglades, and so may obstruct recolonization between compartments, particularly from areas of long hydroperiod to those of short hydroperiod.

5. Short hydroperiod freshwater marshes were also critical pre-breeding and early - breeding season foraging habitat for wading birds (Kushlan 1974, Kushlan et al. 1984, Ogden 1994, Fleming et al. 1994). These higher-elevation marshes probably once offered

wading birds feeding opportunities during high rainfall years, as well as during reversals in drying trend. Modeling studies have suggested that these short hydroperiod marshes have decreased in abundance far more than have other marsh types. The lack of early and pre-breeding foraging habitat is consistent both with the dramatic shift towards later breeding of Wood Storks, the early departure of the majority of the wintering population in most years, and the extreme sensitivity of the current breeding efforts to minor changes in drying trend.

6. A combination of man-made ecological changes have led to instability in the production and availability of wading bird food. This hypothesis suggests that the cumulative effect of many man-induced changes has been responsible for a lack of productivity in the Everglades marsh, and eventually, for the decline of wading birds. The impoundment of much of the marsh into deeper pools, the tremendous reduction in area and hydrological isolation of short hydroperiod marshes, the shortened hydroperiod of lower Shark River Slough, and the degradation of the coastal estuary, seem to have sharply reduced the conditions under which robust and continuous wading bird feeding (apparently necessary for reproduction), can occur. Such feeding opportunities now seem limited to the impounded freshwater sections of the Everglades, during years of rapid surface water drying in which there are few increases in water level, and infrequent or weak periods of cold (Bancroft et al. 1994, Frederick and Collopy 1989a, Frederick and Loftus 1993, Ogden 1994).

These conclusions have provided a new focus for restoration policy (Walters et al. 1992, Davis and Ogden 1994, Anonymous 1993), which now includes recommendations for increases in short hydroperiod habitat, increased flows to the estuary, greater hydrological connection among compartments, and restoration of long hydroperiods to northern Shark Slough as explicit components.

Nonbreeding by adult wading birds

During the last ten years, research has suggested the possibility that contaminants may also compromise wading bird reproduction in the Everglades (Frederick 2000). Although there seems little question that the decline of breeding wading birds in the Everglades has been related in some fashion to hydrological alteration, there is mounting evidence that contamination may also be having effects on wading bird reproduction.

The first line of evidence does not provide any direct evidence that implicates contaminants as a problem in reproduction, but rather provides evidence that food shortages may not be the only source of poor breeding conditions. The evidence is simply that a very small proportion of the available adult wading birds in the Everglades actually comes into reproductive condition in any year, and this pattern is so consistent as to imply that a large portion of the breeding population remains in the Everglades as nonbreeders nearly every year. This information arises from a comparison of the annual surveys of breeding wading birds, with the annual estimates of all wading birds on the marsh surface, through the Systematic Reconnaissance Flight surveys. These latter surveys are designed to estimate total populations of wading birds on the marsh, and to document the geographic locations of those birds. The SRF surveys are performed monthly between January and June of each year, and have been done by staff of Everglades National Park, the National Audubon Society, Big Cypress National Preserve, and the U.S. Army Corps of Engineers (Vicksburg Office).

Several adjustments must be made in order to derive an estimate of the proportion of adult birds breeding. First, it is likely that the Everglades hosts large numbers of migrant birds in some years, and it would not be surprising if those birds did not breed in the Everglades. In order to ensure that migrants are not included in the counts, the comparison uses estimates of the total population taken in May, when all breeding elsewhere in North America is well under way. In order to avoid including juvenile birds in the estimates, a liberal 10% of the birds are assumed to be juveniles. Both empirical demographic modeling and SRF counts of species in which age is unambiguous, suggest that the actual figure is probably much closer to <1%. And at any point in time, it is assumed that one member of each breeding pair is off the nest, and therefore counted in the SRF surveys. Using only species for which identification is easy in both SRF and breeding surveys, we estimate that over the period 1986 – 1999, an average of 31.2%, 28.7%, and 28.6% of adult Wood Storks, White Ibises, and Great Egrets bred, respectively (see Figure 1.3). Conversely, this suggests that somewhere between 69 and 72% of adult birds are not engaging in nesting activity. This evidence illustrates that one of the main problems with the Everglades breeding population is that many of the adults simply are not breeding. One hypothesis suggests that the birds are not coming into reproductive condition because food is limiting their reproductive energy budgets. While this is certainly a frequently-cited cause of poor breeding success or of no breeding, there are several reasons why this explanation is at least partially inadequate. First, wading birds are notoriously weak in their breeding philopatry, and movement in response to poor breeding conditions is a characteristic of the order. Many of the approximately 70% of adults that do not breed in an average year should be expected to move to better areas to breed – apparently they do not.

A second explanation is that nonbreeding is a typical part of the life histories of these birds. While it might not be surprising for wading birds to occasionally sit out a year, the extent of nonbreeding in this case seems extreme. If the typical adult sits out over two thirds of the available breeding years, this is likely to have an effect on reproduction. The effect of nonbreeding has been modeled using very generous fecundity and optimistic survival and life history parameters (Figure 1.4). Even small deviations from 100% of adults breeding results in negative population growth for models specific to White Ibises, Wood Storks, and Great Egrets. Thus it seems unlikely that these large numbers of adults are foregoing reproduction as part of their natural life history.

A third possibility is that wading birds are kept from breeding by some form of environmental contamination. Although no comprehensive surveys of environmental contaminants have been accomplished in the Everglades, it is known that mercury occurs at extremely high levels throughout the Everglades aquatic food web (Frederick 2000, Frederick et al. 1999, Spalding et al. 1994, Facemeier et al. 1995, Sunlof et al. 1994). Sublethal contamination of mercury is known to predispose wading birds to disease (Spalding et al. 1994). In addition, experimental work on young Great Egrets showed that ambient levels in the Everglades result in reduced red blood cell counts, reduced appetite, increased lethargy, altered maintenance behavior, and reduced hunting activity (Frederick et al. 1997, Spalding et al. 2000 1, 2, Bouton et al. 1999, Williams 1996). It seems plausible that the reduced appetite and increased lethargy that result from sublethal mercury toxicosis could contribute to decreased body condition in prebreeding adult birds.

Mercury could also act as a direct suppressor or disruptor of normal hormonal systems. In recent work, Tim Gross of the National Biological Service has found that estrogen and testosterone ratios in Everglades largemouth bass (*Micropterus salmoides*) are altered by mercury, and that in captive bass, the addition of mercury is enough to result in significant changes in hormonal status. Whether this occurs in wading birds in the same ecosystem is unclear. Nonetheless, the contaminants hypothesis bears evaluation, since there seems to be enough evidence that is suggestive of contaminant effects on reproduction by wading birds in the Everglades.

CHAPTER II. MONITORING OF BREEDING POPULATIONS OF WADING BIRDS IN THE WATER CONSERVATION AREAS OF THE EVERGLADES DURING 1999.

Methods

During 2000, we monitored nesting by wading birds in Water Conservation Areas (WCAs) 2 and 3 using monthly aerial surveys (February through June), flown as a series of east-west oriented transects throughout the Water Conservation Areas of the Everglades (Figure 2.1). The transects were spaced 1.6 nautical miles apart; this spacing had been determined empirically by flying naieve observers at various distances from known colonies until colonies were consistently recognized. Some overlap in detectability between adjacent transects was designed into the spacing. Colony survey flights are flown at 800 feet altitude, with one observer on each side of the aircraft. Once colonies were detected, the location was circled and the colony repeatedly counted by both observers. For larger colonies, several passes were often made at lower altitude to confirm nesting stage, species composition, or to achieve better discrimination among counts of similar species.

These aerial surveys are efficient for detecting and for counting large colonies of white birds. Aerial surveys are far less efficient at detecting and counting smaller colonies, and particularly those of dark-colored species. In the Everglades, these aerial surveys detect on average only 30% of the colonies, and 60% of the total numbers of birds (Frederick et al. 1996). For this reason, we also performed systematic ground surveys of all of WCA 3 and 2 by airboat. These surveys were performed during April and May. Each tree island was approached by airboat to a close enough proximity to either see or flush any nesting birds in the head. Similar airboat surveys are carried out in Loxahatchee NWR by NWR staff.

We compared numbers of nesting birds with numbers of non-nesting birds by using information from the SRF surveys (information supplied by Craig Theriot and Dave Nelson of U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg MS). As discussed above, SRF estimates of the total numbers of any particular species for the month of May are used in the following formula to derive the proportion of the adult population that is breeding (P_b):

$$P_b = \frac{N_b}{[SRF - (0.5 * N_b) - (0.1 * SRF)] + N_b}$$

Where N_b = Number of breeding birds counted

SRF = Number of birds estimated on the marsh surface through SRF surveys in May

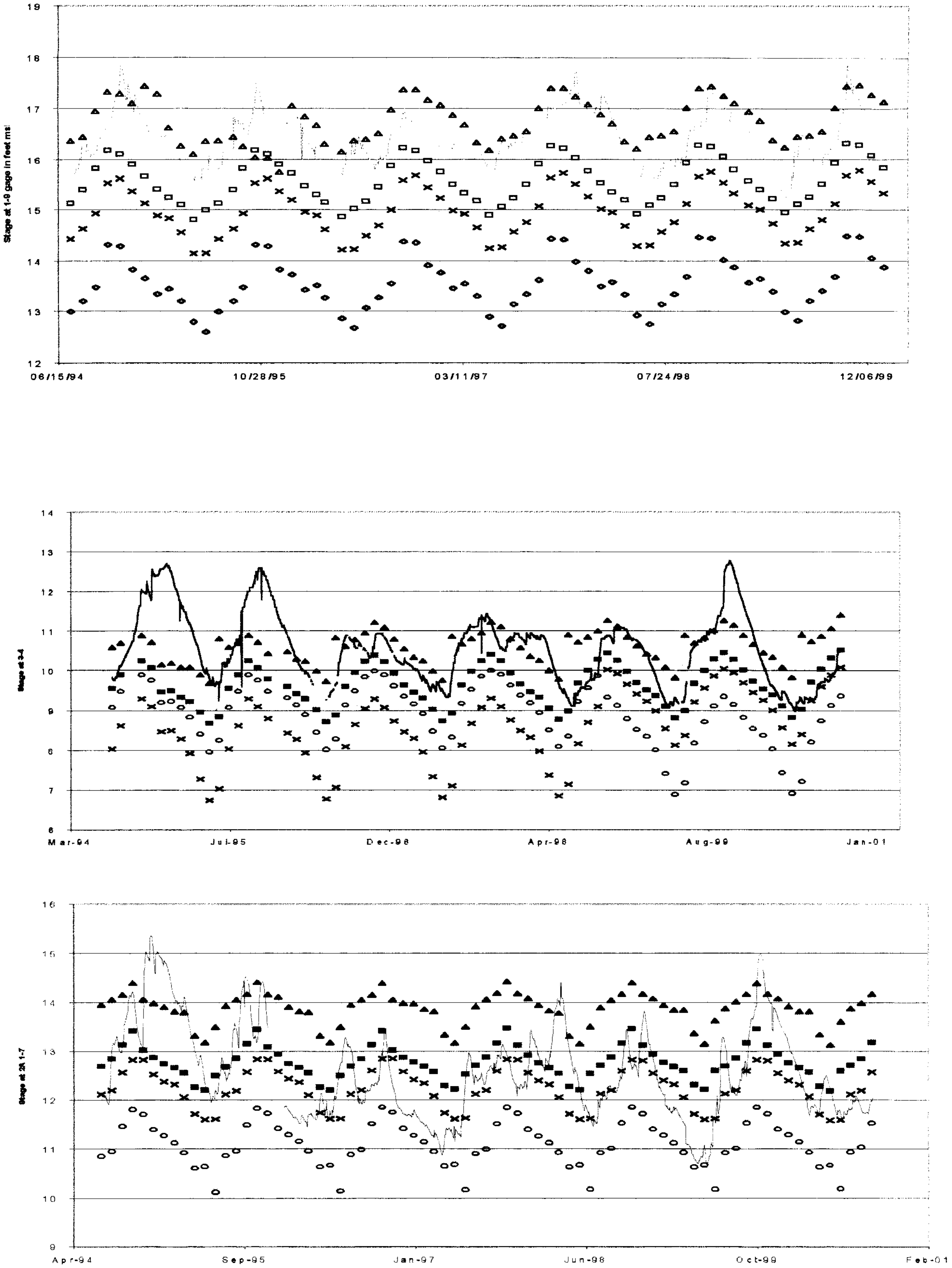
Note that this model assumes that half of the breeding birds are out foraging at any time and are so counted in the SRF estimates, and that 10% of the SRF population is composed of juvenile birds. It should also be clear that most of the potential errors in these estimates tend to bias the estimate of proportion breeding to being larger than the actual value. For example, the SRF estimates are generally conceded to be underestimates of the actual population of birds, in part because the actual counts of birds are assumed to miss some proportion of the birds present. The proportion of the SRF surveys that are juvenile is also probably inflated – it is more likely that less than 1% of the population should be juvenile, than the 10% used. This bias also has the effect of underestimating the true size of the adult population.

We continued a long-term database of food habits of herons, by collecting samples of prey regurgitated from young Great Egrets. These samples were collected by approaching or capturing and handling young birds that were between 18 and 35 d of age. As the birds become disturbed, they generally regurgitate their latest meal. The regurgitant from each chick was collected individually in plastic bags, and frozen for later analysis. Upon analysis, samples were thawed, weighed, and examined individually. All prey items in each sample were patted dry with paper towels, weighed to the nearest 0.10 gm and measured to the nearest mm. We measured total length of fishes, and carapace length for crayfishes. Individual prey items were identified to the finest taxonomic level possible. Items in advanced decomposition were often lumped within samples as "unidentified fish" or "unidentified crayfish".

Results and Discussion

Weather and Hydrology

The 2000 nesting season was characterized by a high initial water level in fall 1999, peaking in November, followed by a rapid and nearly continuous drawdown between November 1999 and May 2000. This pattern was consistent throughout the WCAs



Figures 2.1 – 2.3. Stage at 3 stations in WCAs 3, 2, and 1 (top to bottom, respectively). Stage (solid line) is shown in relation to long term monthly mean highs (squares) mean highs plus one s.d. (triangles), mean monthly lows (x's) and lows minus one s.d. (circles).

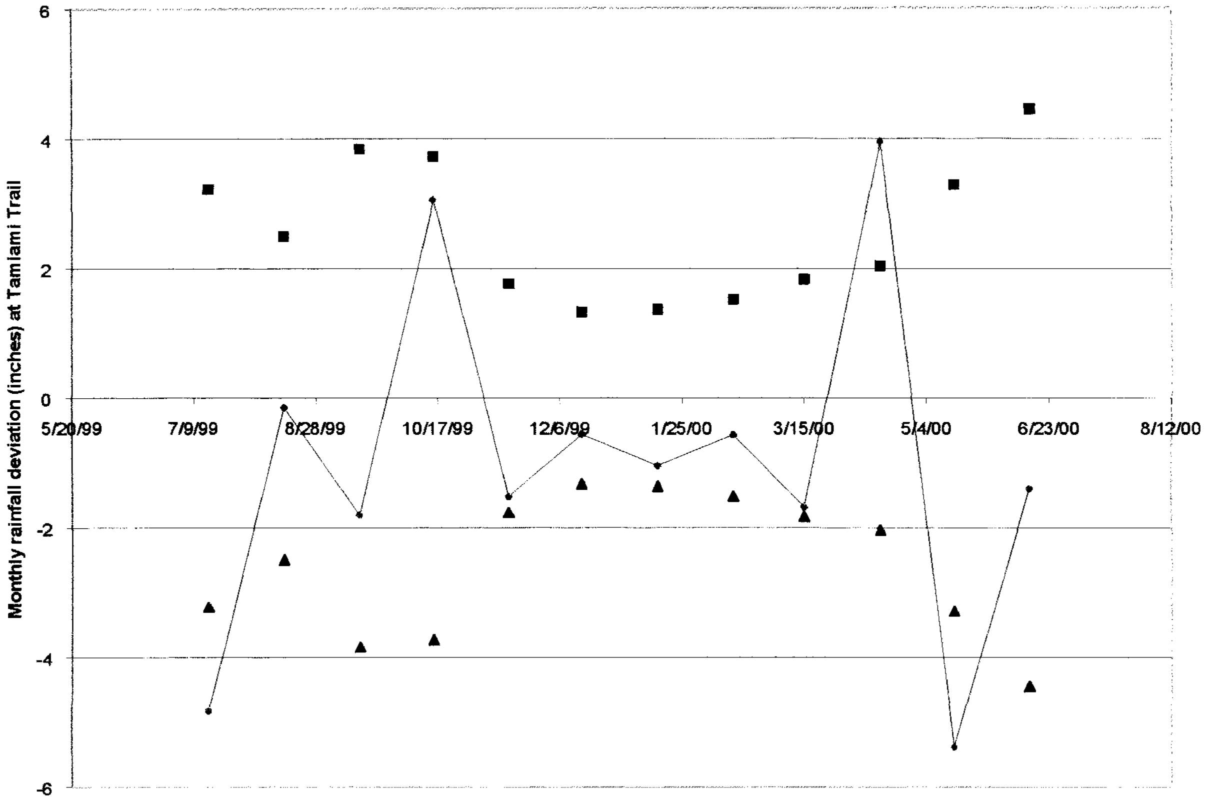


Figure 2.4. Monthly rainfall total deviations at Tamiami Trail ranger station (fluctuating line) shown in relation to monthly period-of-record means (zero), and one standard error in excess (squares) or deficit (triangles) of the monthly means.

in summer 99, followed by a very wet October (> 40 cm). Interestingly, the continuous and rapid surface water recession rates were not the result of extremely low rainfall – though less than average during the winter and spring of 1999/2000, monthly rainfall totals were not below one standard error less than the monthly means during this time (Figure 2.4). Thus the continuous drying pattern was the result of low, but not abnormally low rainfall conditions.

The only real anomaly in rainfall during the 1999/2000 season was a single, very large rainfall event in mid-April. On 14 April, most stations received over 15 cm of rain in a very short period, the result of a strong frontal weather pattern. This resulted in sharp increases in water level, particularly in the northern part of the Everglades.

The rate at which surface water receded (= "drying rate") has in the past been measured as the rate of recession between the highest stage in November to the highest stage in January (early drying rate), and from highest stage in January to highest stage in March (late drying rate). The drying rates in all compartments of the central Everglades were very fast during 2000, with both early and late drying rates exceeding 2 mm/d in WCAs 1 and 2, (Table 2.1) that has been associated with large numbers of nesting attempts by White Ibises and Wood Storks in the past (Kushlan et al. 1975, Frederick and Collopy 1989a). Both early and late drying rates exceeded all records in WCA 3, and exceeded 90% of records in WCA 1 and 2.

The 2000 spring was generally less windy than normal, with totalized wind being less than the long-term average, and often close to one standard deviation in deficit of the long term average for the entire nesting season.

Table 2.1. Water level recession rates (mm/d) in the Water Conservation Areas, with comparisons of the year in question with historical records at each station. Note that negative values indicate rising water, positive values indicate falling water. Percent exceedance refers to the percent of years in the record in which the drying rate was less than that of the current year.

Year	Station	Early Dry	Late Dry	% Exceedance Early Drying Rate*	% Exceedance Late Drying Rate*	% Exceedance Both Early and Late Drying Rate*
2000	3-4	7.935	7.697	100	100	100
2000	1-9	4.54	na	94.1	na	na
2000	2A 1-7	7.595	5.57	94.5	94.8	89.7
1999	3-4	2.13	3.83	41.7	91.7	38.9
1999	1-9	2.19	4.24	18	29	14
1999	2A 1-7	7.77	7.46	97.2	94.5	97.1
1998	3-4	n.a.	n.a.	n.a.	n.a.	n.a.
1998	1-9	1.48	-0.516	34.3	2.85	0
1998	2A 1-7	-4	-0.043	2.9	20	0
1997	3-4	2.63	1.419	57	42	36
1997	1-9	2.19	0.581	51.5	15.2	3.03
1997	2A 1-7	4.12	2.77	94.1	73.5	70.5
1996	3-4	6.99	5.68	100	100	100
1996	1-9	0.14	0.383	25.0	3.5	0.0
1996	2A 1-7	11.50	0.646	96.9	34.4	34.4
1995	3-4	-0.90	5.95	0.0	100.0	0.0
1995	1-9	0.97	0.21	32.1	10.7	3.6
1995	2A 1-7	0.55	3.50	28.1	87.5	29.0
1994	3-4	2.56	-1.08	58.6	6.9	3.6
1994	1-9	1.49	0.42	21.8	9.3	3.1
1994	2A 1-7	3.32	-4.67	90.0	3.3	3.3
1993	3-4	0.22	-0.40	10.0	10.0	3.3
1993	1-9	-0.33	3.91	14.8	7.8	0.0
1993	2A 1-7	-1.45	0.22	12.9	29.0	3.2
1992	3-4	2.29	2.63	24	38	14
1992	1-9	2.01	1.47	46	54	21
1992	2A 1-7	3.16	2.09	82.1	53.5	44.4

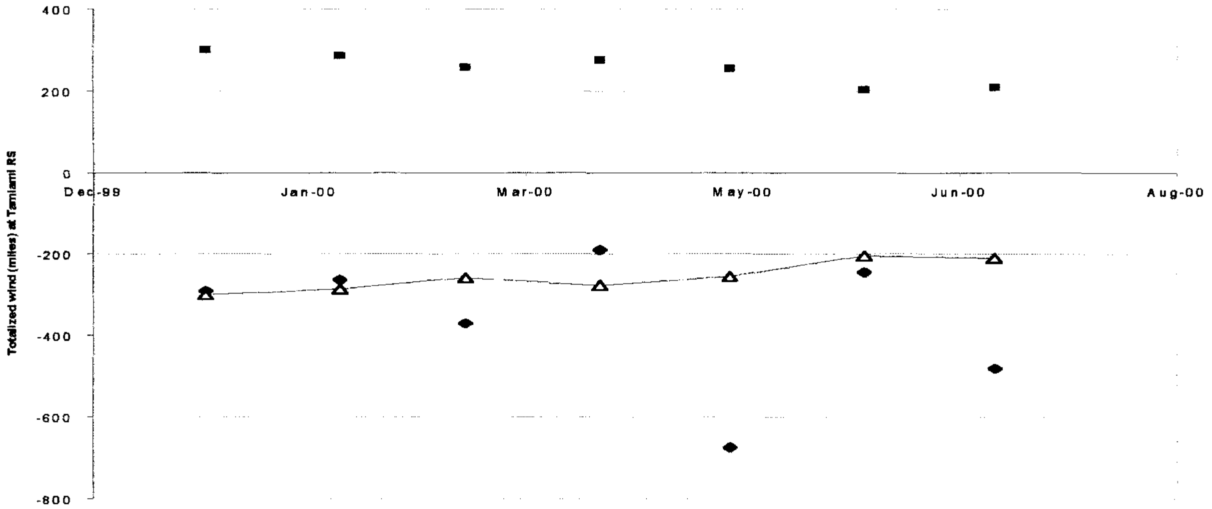


Figure 2.5. Monthly deviations in totalized wind during spring 2000 (line) in relation to long-term mean (zero line), and one standard deviation in excess (squares) or deficit (triangles) of the mean.

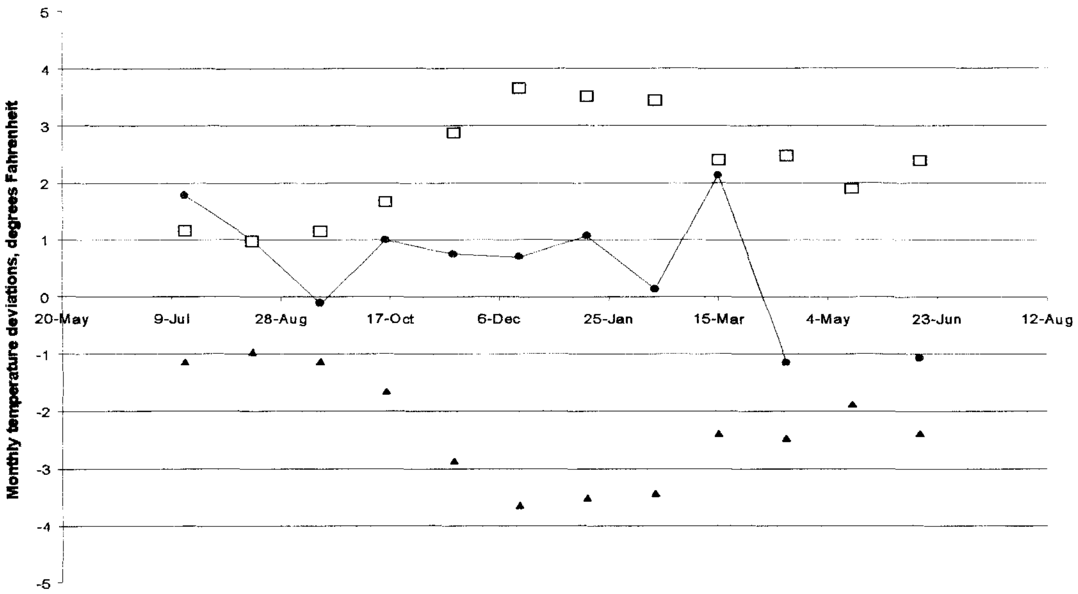


Figure 2.6. Monthly deviations in temperature during spring 2000 at the Tamiami Trail Ranger Station (line) in relation to the long term mean (zero line) and one standard deviation in excess (squares) or deficit (triangles) of the mean.

Nesting Activity

Between January and June 2000, we found many more wading birds nesting than usual in the central Everglades (Table 2.2, Figure 2.8, see Appendix I for colony specific counts by species). During the spring, we estimated 32,204 nests of all waders (not including Cattle Egrets, Anhingas or cormorants) in WCAs 2 and 3. For comparison, this level of total nesting effort in 2000 was 33% greater than in 1999, 2.8 times greater than the 10-year running average, and 20% greater than the last exceptionally large nesting in 1992. The level of nesting in 2000 in the WCAs was about half the estimate for the Everglades as a whole during several years in the late 1940's.

In the Everglades as a whole, there were over 34,800 nests found during 2000. The 2000 nesting was truly exceptional nesting event, and was over 2.5 times as large as the ten-year average, 2 times the five year average, and 14% greater than the very large nesting event in 1992.

The vast majority of the abundance in the WCAs (almost two thirds) was made up by White Ibises, most of which nested at the Alley North colony (approximately 20,000 pairs). However, ibises also nested in several novel locations for ibises, including Hidden colony, Heron Alley colony, and a new colony at the Shark Slough tower in Everglades National Park. Numbers of White Ibises were 4.7 times the ten-year average, and 2.8 times the five year running average.

Wood Storks also nested in much larger than normal numbers - over 1,800 pairs nested in a variety of locations, including over 1,300 pairs at the Tamiami West colony, and 500 at a novel location in western WCA 3. This level of nesting effort by storks has not been seen in the Everglades since the mid-1970's, or almost 30 years, and the 2000 nesting was over six times the ten-year running average for the Everglades as a whole. The storks nested relatively early (February), and were able to fledge large numbers of young this year, despite a large rainfall event in April. Summer rains were somewhat late to normal this year, resulting in a protracted drydown. We hypothesize that this further enhanced survival chances for these young storks.

Snowy Egrets numbers were also up considerably this year, with at least three times the ten-year average nesting in 2000. The largest colony was at Alley North, but there were also sizeable aggregations at Hidden colony, and Tamiami West.

Not all species showed obvious increases this year. Numbers of Little Blue Heron nests were less than 66% of the ten year running average. Numbers of Great Egrets and Tricolored Herons were similar to the ten-year mean, and showed no increase in 2000 over other years.

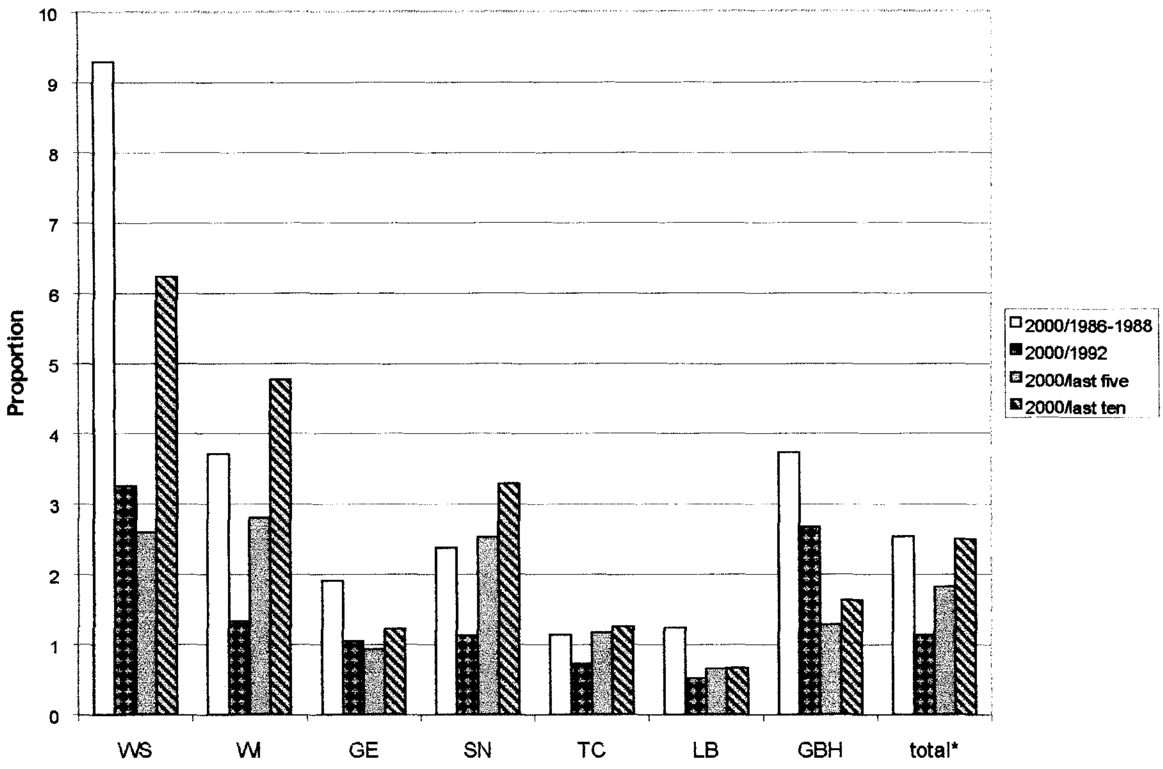


Figure 2.9. Proportion of birds (all species combined) nesting by species in 2000 in the Everglades ecosystem in relation to previous benchmarks. A proportion of 1 would be the same number of nests in both years or periods being compared.

Within the Everglades ecosystem, the vast majority of nesting was concentrated in the Water Conservation Areas (92%), and the vast majority of the remainder in Everglades National Park was in freshwater areas and not in coastal locations. Within the Water Conservation Areas, the vast majority of nesting was concentrated in WCAs 2 and 3 (92%), and the vast majority of that (96%) was in WCA 3. In LNWR, nesting was about half the 8-year average.

Although we did not measure reproductive success through documentation of individual nest histories, we were able to monitor the success of nesting colonies in a coarser way by noting large abandonment events, and general level of productivity. Nesting was largely successful throughout WCA 3 and 2 - we found no complete failures in any colonies, and large numbers of young were produced, particularly at Alley North.

However, in Loxahatchee NWR, the strong pulse of rains in mid-April resulted in widespread abandonment, including up to 2/3 of the nests destroyed in closely monitored colonies.

In WCA 3, however, the April rainfall did not result in widespread abandonment, probably as a result of lower initial stages and less increase in stage due to the rainfall, than was experienced in Loxahatchee. The difference in stage increase in Loxahatchee and WCA 3 may have been partly due to inpumping at Loxahatchee from local agricultural fields.

Numbers of wintering and nonbreeding birds:

The Systematic Reconaissance Survey team reported that numbers of birds in the Everglades ecosystem were normal to well above normal during the winter and spring of 1999/2000. In the case of White Ibises, which were by far the most numerous nester, there were approximately 1.4 more birds than the ten-year mean during January, February and March, and in May over three times as many were counted. For storks however, numbers counted were generally lower than the ten-year average. For Great Egrets, numbers counted were about 25% greater in February, and close to the mean for other months except May, when 2.7 times the average number were counted. Thus there were not exceptionally large numbers of birds in the Everglades during the winter months, and during May there were abnormally large numbers counted. The May counts may well have been higher as a result of the timing of breeding – the large numbers of birds on the nest would have been released to the marsh at this time as a result of the cessation of incubation and brooding duties. In addition, for several species the SRF surveys may have been counting considerable numbers of fledged young of the year by the time of the May survey.

By comparing numbers of birds estimated on SRF surveys with our breeding numbers, we found that nearly all of the birds present in the region were breeding this year (Figure 2.9). This is in stark contrast to many of the previous years, when only 30% of adults have bred on average.

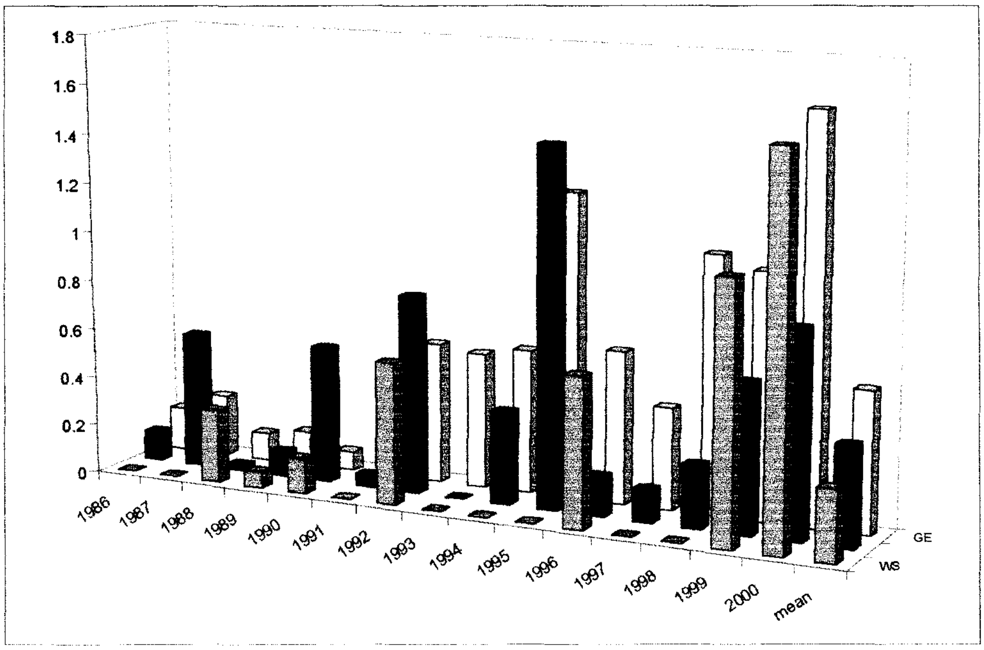


Figure 2.9. Proportion of adult wading birds estimated to be breeding, as derived from a combination of SRF estimates of population, and numbers of breeding birds (see methods).

Reasons for the large nesting event in 2000

The reasons for the large nesting event in 2000 are not completely understood, but several contributory factors were quite evident. The hydrological conditions were generally very favorable, with a long, continuous, and exceptionally rapid surface water recession throughout the winter and spring, beginning from extremely high levels. It should be noted that there are no years in the period of record for stations in WCA 3 which have shown faster drying in either winter or early spring periods.

These factors apparently created drying and depth conditions that were conducive to making prey animals available to foraging wading birds. In addition, the initial high water conditions also allowed fast drying conditions while maintaining above-average water conditions in most compartments, resulting in a vast acreage of the marsh being in very shallow depths, yet relatively little of it going entirely dry. While rapid drying has been repeatedly identified as important for stimulating nesting (Kushlan et al. 1975, Frederick and Collopy 1989a, Frederick and Spalding 1994), there have been many years with rapid drying conditions following very high initial stages (eg 1995) in which we did not observe very large nestings. Thus drying conditions by themselves in any year may not be very predictive of nesting effort, and a discussion of the importance of conditions in years preceding the year of interest follows below (see under "Conditions necessary for large nesting events" below).

There are at least two other environmental conditions that changed in 2000 that may also have strongly affected the size of the nesting event. The first of these was the extensive drought conditions that prevailed throughout much of the southeastern states. This drought resulted in the drying of many marshes, streams and even lakes, leaving much of the usual habitat available to wading birds dry. In most cases, wading bird colonies were not even initiated in these dry or drying areas. For example, by late March only one of the 11 known Wood stork colonies in Georgia had initiated nesting. In north

Florida, most wading bird colonies did not initiate, and those that did were not successful. The drought was severe enough to affect large areas of freshwater wetlands in Georgia, parts of South Carolina, north Florida and Alabama. South Florida was therefore one of the only places in the region that held water during the drought. Thus most of the wading birds in the southeastern U.S. were left with little habitat during spring 2000, and it is quite likely that the large numbers of birds in south Florida included many birds that typically nest in other states. In support of this hypothesis, Corkscrew Swamp sanctuary also had many more storks attempt to nest than usual; this area was also wet, but has obviously not had the same water management history as the Everglades.

The second condition that has changed during the last several years has been a dramatic reduction in the mercury exposure of birds nesting in the central Everglades. In most colonies sampled during 2000, mercury concentrations in feathers of nestling birds had decreased by almost an order of magnitude, by comparison with samples taken in the same places during 1994 – 1996. Since 1997, mercury concentrations have been plummeting in most colonies (see below under "Reductions in Mercury contamination in the Everglades"). Although the mechanism behind the reduced mercury exposure is not well understood at this point, mercury has been implicated experimentally in reproductive impairment in ducks, as well as health and appetite in birds; a reduction in mercury could therefore have contributed to the increased reproductive effort and success documented in 2000.

Current nesting in relation to restoration goals

The numbers of nesting birds in 2000 continued an encouraging trend, since any increase in nesting effort or nesting success is a step in the direction of restoration goals (Ogden et al. 1997). Numbers of pairs of Great Egrets for 2000 (4,709) exceeded the target for the ecosystem (4,000 pairs breeding regularly), while the 3-year running average was 5,779, or slightly above the target. Nesting effort by White Ibises in 2000 (22,037) was solidly in the middle of the restoration range (10,000 – 25000 nesting pairs), and the running 3-year average (11,333) was at the low end of that range. Nesting by Wood Storks (1,847 pairs) was a tremendous increase over the ten-year average of 296 pairs, and well in the range of restoration targets (1,500 – 2,500 pairs). However, it is also clear that 2000 was something of an anomaly for storks. The three-year running average was 802 pairs, or only slightly over half the bottom end of the restoration target range.

Timing of nesting was also earlier than most years, with storks beginning in late January and very early February rather than the middle to late February and March that is typical of most recent years. This is also a step in the right direction for restoration, though the goal of nesting in November and December remains a distant target by comparison even with the 2000 nesting. It is significant that the rains in 2000 were relatively late – without the late onset of rains, many of the later nesting storks would have failed.

One of the restoration targets for wading birds is a higher proportion of nesting in coastal regions of the Everglades. There was no evidence of any movement of nesting colonies to the coastal regions of the Everglades during. In fact, 2000 continued the long trend of much higher proportions of wading birds in the Water Conservation Areas than are in Everglades National Park.

Conditions necessary for large nesting events: the 1999 and 2000 events in context.

During the large 1992 nesting event, birds nested in unprecedented numbers in a year following one of the most severe and long droughts in the recorded history of the Everglades. This was not in accordance with current predictions, since it was thought that the drought would have killed off most prey animals. The 1992 nesting spawned the hypothesis that droughts somehow organize the ecosystem to produce large amounts of prey animals that are available to wading birds.

During the last year, we have completed an analysis of that prediction by looking at other large nestings in the history of the Everglades, and studying the conditions that preceded those nestings. We have a priori defined large nesting events as being those with nests greater than one standard deviation in excess of the period mean, and have categorized hydrology as wet or dry in a similar fashion. In the 38-year history in which we have been able to categorize both nesting and hydrology with confidence, we have identified 8 supernormal nesting events, and 8 severe droughts. The supernormal nestings followed the droughts in all but one case within 2 years.

This extremely significant association does not imply causation. However, the near-exactness of the association seems to imply a strong temporal connection, and demands some kind of explanation. One is that the preceding drought had probably killed off most of the large predatory fishes, as well as the forage fishes in much of the Everglades. Following the drought, the smaller "forage" fish may have been able, with very short generation times (1 – 4 months), to breed explosively and achieve very dense populations. During the 1992 season, we have hypothesized that this ephemeral crop of fish were then made available to the birds by rapid drying rates. The thinking since 1992 has been that droughts are very important in organizing enough food (at least in the freshwater marsh) to stimulate large nesting events by the wading birds.

However, the 1999 and 2000 seasons have demonstrated that antecedent droughts may be sufficient but they are not absolutely necessary to stimulate nesting. 1999 and 2000 were preceded by at least six previous years without a significant drought, or even a drydown event. Thus there appear to be at least two hydrological mechanisms for stimulating nesting by wading birds – drought followed by at least a year of wet conditions, and several years of wet conditions followed by rapid and uninterrupted drying. However, the latter mechanism is poorly understood. We have prolonged wet conditions followed by extremely rapid drying (faster than in 1999) during several years of the past seven (1994 and 1995 are good examples) without a major nesting event. The mix of key features that resulted in the 1999 and 2000 nesting events therefore remains something of a mystery.

Degradation of colony substrate

In past reports, we have noted considerable degradation of active or former colony substrate in WCAs 2 and 3. This is a continuing trend that appears to be posing some limits on available nesting substrate for wading birds. The process seems to be characterized by prolonged hydroperiods (>>4 yr) in the moderate to deeper elevational depths of the WCAs, leading to increased mortality of vegetation. Although willow is highly tolerant of flooded conditions, it will die if its roots are not dried with some frequency. The prolonged high water of the past seven years has apparently resulted in mass mortality of willow in several colonies (see Table 2.3).

Table 2.3. Current condition of large willow heads in WCAs 2 and 3, as estimated from aerial surveys.

Colony or former colony name	Estimated percentage of Former willow left
Big Melaleuca	< 1/3
L-67	<1/8
False L-67	<1/8
Andytown	0
Cyress City	<1/8
Alley North	<2/3
Pocket	<1/2

For example, both Andytown and Cypress City (immediately south of Alligator Alley in NE WCA 3) are virtually gone, and all nesting there has ceased. L-67 in central WCA 3 was, up until the mid 1990s, a very large willow tree island (>0.5 km in length) and a large, active colony. With the exception of a tiny island at the north end, the willow and buttonbush vegetation has now been killed entirely, and nesting has all but ceased at this location. To a lesser extent, the same process has occurred at Big Melaleuca colony, to the extent that we had some trouble finding the colony from the air for the first time in 1999. The Alley North colony has had considerable die-back of willow in the central part of the colony, and willow coverage has been reduced by at least one third. These colonies are the only large willow heads left in WCA 3. When they are gone, there are no other sites for large colonies that are apparently available. These large willow heads are also important roost and nesting sites for the endangered Snail Kite (*Rostrhamus sociabilis*). We see no evidence that large willow heads are being regenerated under the current hydrological conditions.

Reductions in mercury contamination in Everglades wading birds

Nearly all animals that are high in the Everglades food web are known to be heavily contaminated with mercury, including wading birds (Frederick 2000). As part of a contract with the Florida Department of Environmental Protection, we have monitored both food habits and mercury contamination levels in wading birds during the past six years. Though that work is not strictly part of this report, we report here that mercury levels have fallen dramatically between 1999 and any of the previous monitoring years.

We have monitored mercury in young Great Egrets, by measuring concentrations in growing scapular feathers collected at 25 – 35 d of age. The mercury determinations were made by the Florida Department of Environmental Protection Chemistry section in Tallahassee. In the past, we have found significant differences among colonies within the Everglades, and so monitoring is accomplished at a variety of colonies that are sampled every year.

We have collected 445 feather samples from as many individuals in total (Table 2.4), with 76, 71, 53, 130, 117 and 86 collected in 1994, 1995, 1997, 1998, 1999, and 2000, respectively.

Table 2.4. Summary of numbers of feather samples collected and analyzed for mercury content from Everglades colonies, 1994 – 1999.

Colony name	1994	1995	1997	1998	1999	*2000*	*Total*
Alley North	10	12	25	29	20	21	*117*
JW2	9	14	11	24	13	14	*85*
3b Mud canal			5		13		*18*
Hidden	23	24	7	25	22	16	*117*
TTE		16					*16*
TTW				26	18		*44*
Mud canal	7	5	5			21	*38*
Starter Melaleuca					11		*11*
L-67	25	14		26	20	14	*99*
Total	*74*	*71*	*53*	*130*	*117*	86	***545***

We found that geographic location of colony, year, and colony X year interactions had strong effects on mercury values, but that age of chick (culmen length) did not (ANOVA, $p<0.0001$ for all significant effects). Since these effects were strong, we express mean values for any year or colony as a Least-square adjusted mean. We tested for differences among years using t-tests (Figure 2.10).

We found no significant differences in mercury concentrations among years within colonies for TTE or Mud Canal colonies. These locations had only two and three years of sampling effort, respectively, and Mud Canal had small numbers of samples in any year, so perhaps it is not surprising that we found no differences at these sites. We found significant decreases in mercury from 1997 – 2000 among four of the five remaining colonies. The extent of these declines is dramatic in some cases – at JW1 colony, LS mean mercury declined from over 32 mg/kg to less than 11 mg/kg in three years. Similarly at 3B Mud Canal, mercury concentrations declined from over 28 to less than 6 mg/kg in two years. The cause of these decreases is not immediately obvious, but anecdotal reports suggest that mercury concentrations have also decreased in tissues of various marsh fishes in the Everglades during 1999. The reason for declines in mercury in fishes is not known. The association between declines in mercury exposure at colonies and increased nesting effort and success is currently nothing more than an association, but the possibility of a mechanistic connection should be investigated.

Monitoring of prey composition of Great Egrets

As part of a continuing study of the food habits of Great Egrets, we have continued to collect regurgitant samples opportunistically from young Great Egrets aged 20 – 28 d of age in various colonies in the Everglades. The results from 2000 (9 boluses) are compared with those from 1998 and 1999 in Appendix 2.

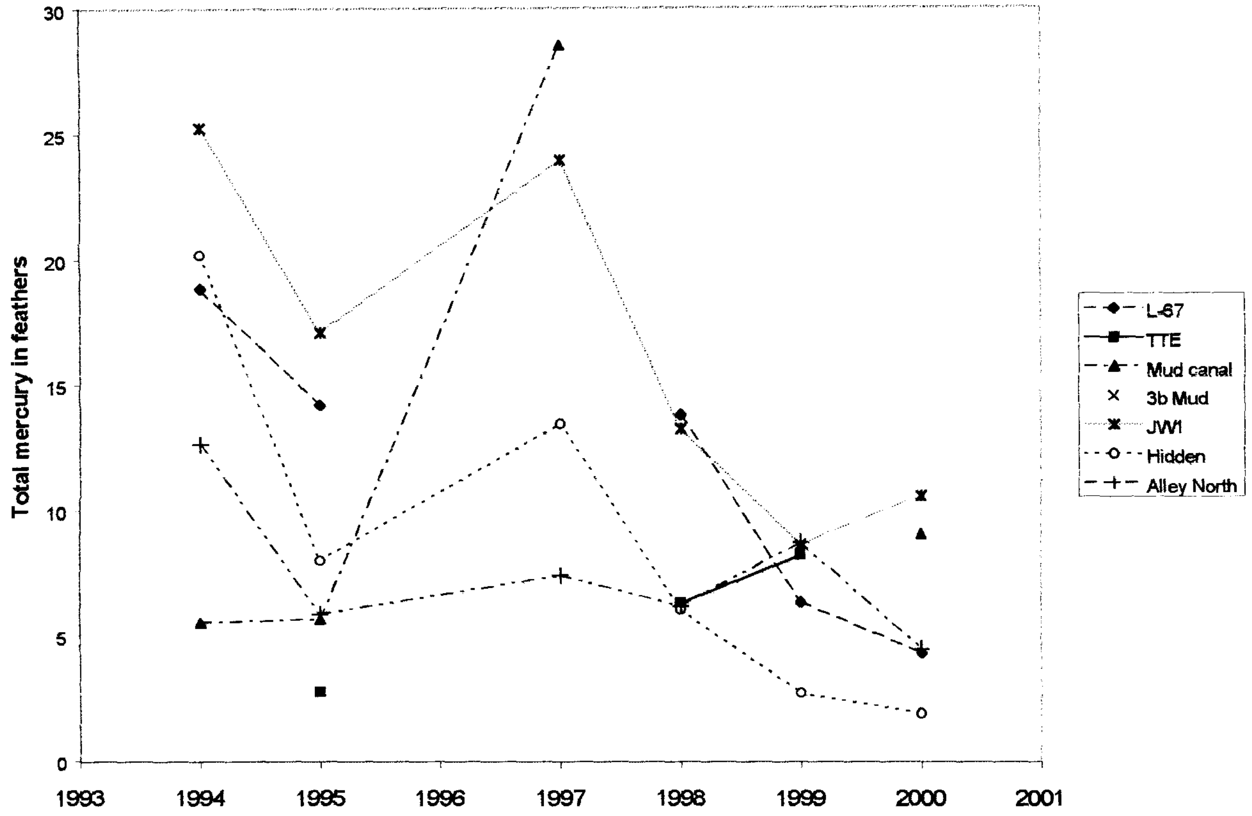


Figure 2.10. Graph of least-squared mean mercury concentrations in feathers taken from Great Egret nestlings at approximately 20 – 30 d of age, at various colonies in the central Everglades. LS means standardize mercury concentrations to an 8-cm bill length, thus standardizing mercury concentrations for age and cumulative exposure through food.

Refinement of counting accuracy.

For the past several years our research team has become increasingly aware of the possibility of individual bias as a source of counting error, especially when counting particularly large colonies. Individual bias is known to be a factor in counting error, both from studies of error in transect surveys and from studies of bias in counting pictures of known numbers of targets (Erwin 1982). This work has shown that observers tend to underestimate, though the amount by which they underestimate is thought to vary considerably with the specific conditions of study. For example, Rodgers et al. (1995) have shown that there is considerable error in estimation of Wood Stork nests in colonies, largely as a result of confusing Wood Stork with Great Egret nests. Similarly Dodd and Murphy (1995) found that a variety of techniques were necessary for accurately counting relatively small colonies of Great Blue Herons (*Ardea herodias*) in South Carolina. However, these studies used ground counts as the standard from which to compare aerial counts, and it is likely that ground counts themselves show considerable bias.

Beyond this wisdom, the field is surprisingly poorly developed. For example, there are few studies that include vegetative occlusion as part of the testing scenarios, yet vegetative occlusion is one of the most common problems in surveying wading bird colonies worldwide. There is a software program currently available that allows random numbers of targets to be displayed on a computer screen; observers are then timed in their estimation. However, this program does not include any vegetative occlusion to enter into the views, and the largest number of targets displayed is 1,000. The largest number of targets ever used in estimating observer bias to date is 3,000 (Erwin 1982), yet in the Everglades observers have routinely attempted to estimate colonies of over 10,000 targets. Other than the study of photos, none of the studies of observer bias have been able to use true numbers for comparison – they have most often compared estimates between observers. Lastly, although there is a general sense that aerial photographs can be used to closely estimate numbers, aerial photography may in some circumstances be more susceptible to vegetative occlusion problems than are observers. This is because observers may be able to visually integrate information from multiple angles, whereas still photography cannot.

During 2000, we took aerial photos of the Alley North colony during April. The ibises there were particularly and unusually well suited to the use of aerial photos, since the majority were nesting in matted-over cattails, rather than in shrubs. This allowed an almost unique ability to compare aerial estimates by observers, with counts of the photos. At the time of the photos, two experienced observers estimated approximately 8,000 White Ibis nests in the colony. Subsequently, the photos were counted by projecting them on a papered wall, and individual targets were counted using a click-counter, and marked off with a pencil mark so they would not be double-counted. The estimate of nests using the photographic technique was over 20,000 pairs.

This enormous underestimate by the aerial observers immediately called into question the accuracy of counting large colonies, both now and in the past, and demanded an investigation of counting error. This required the development of a tool which would allow the standardized measurement of observer bias in counting.

We constructed a scale model of a wading bird colony, designed after the approximate dimensions of the Alley North colony. The scale used was 1:158, and the birds, grass and trees are all to scale. We used white alfalfa seeds to represent White Ibises to scale as seen from 800 ft above the colony during an aerial flight. The colony is represented by an 8'X8' section of plywood covered with artificial grass, and model lichen shrubs. The surface of the grass was reduced to nearly ground level in over a third of the colony through the use of a small propane torch, which mimics the flattened grass that the ibises used to nest on.

The advantage of this model is simply that the numbers of birds (seeds) used in any estimation run can be determined with a high degree of accuracy. The numbers of alfalfa seeds in an experimental run are predetermined randomly, and the correct numbers of seeds are counted using a commercial seed counter whose accuracy is measured at greater than 99%. Seeds are then typically spread on the surface of the colony at realistic densities, using a flour sifter and a monofilament overlay grid. Observers are then allowed realistic time periods to walk around the model and estimate through repeated "passes" the numbers of birds on the colony. Preliminary tests have demonstrated that this methodology works, and we are in the process of embarking on a more refined study of interobserver bias with this tool. At present we have tested 10 individuals with this tool over a range of 200 – 10,000 targets and will in the next weeks be testing an additional 8 people. All of the subjects will remain anonymous, but have between one and 15 years experience in estimating wading bird colonies.

This model will also be used to estimate the error of using aerial photos to count birds in colonies. We are taking 2 – 4 pictures of every trial run, and plan to count these photos in the near future. This will give a close approximation of the bias associated with using photos.

We believe that these data will allow us to either come up with a scaled correction factor for current and past records, or failing that, will produce guidance on the responsible interpretation of wading bird colony estimates.

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CHAPTER III. WHITE IBIS REPRODUCTIVE PHYSIOLOGY AND BEHAVIOR

Introduction

White Ibises (*Eudocimus albus*) are in biomass and abundance the dominant species in the wading bird community of the Everglades system. Ibises have unique tactile foraging styles and require shallow water to successfully catch prey (Surdick 1998). They are also similar to other wading birds in the Everglades in that they nest colonially on tree islands with other wading birds. In addition, their population decline over the past 40 years is representative of population declines of most wading bird species in the Everglades system. As a result of these features, we believe a detailed understanding of the environmental and physiological factors that affect ibis reproduction have larger implications for successfully managing wading bird populations in the Everglades system.

White Ibis breeding patterns in the Everglades (and elsewhere) are complex. There is tremendous temporal and spatial variation in breeding ibis colony formation. These differences in colony timing and location are probably related to variation in environmental factors, such as food availability and hydroperiod, and variation among ibis individuals, such as physical condition, contaminant loads, and location of wintering site (Kushlan and Bildstein 1992). Thus predicting the locations and conditions under which ibises will nest is currently a real challenge for scientists, particularly in the hypervariable Everglades ecosystem.

A better understanding of patterns in ibis reproductive physiology and behavior would also lend insight into many theoretical and conservation/management questions. For example, variation in nest initiation dates suggests that ibises are an opportunistic breeder. Opportunistic species have unique hormonal and behavioral interactions that allow them to quickly come into reproductive condition in response to favorable environmental conditions. This strategy is often associated with fairly unpredictable environments. Alternatively, ibises may be rather strictly seasonal breeders and only appear to have a flexible timing schedule because individuals from different populations or locations routinely immigrate into the Everglades system; this process could result in high variation in nesting dates. In this example ibis *populations* may be some what flexible in their timing of reproduction, but *individual* birds show a predictable seasonal reproductive pattern. Thus detailed knowledg about the mechanisms involved in ibis reproduction may give us a better understanding of the interactions between wading bird breeding behavior and hydrology patterns in the Everglades system.

In addition to a flexible breeding schedule, we have recently observed that the number of ibises breeding has been in many years considerably lower than the number of ibis present within the Everglades system (see Chapter I). There are several alternative hypotheses that might explain this observation: 1) a large proportion of White Ibises never attempts to breed. Many species of birds skip years between breeding efforts because they are physiologically or energetically limited (Hector et al. 1985). Thus, if ibis reproduction is very costly if may a be natural part of ibis life history for the birds to skip years between nesting attempts. Alternatively, if the birds were adversely affected by a toxin (such as mercury) then they might be unable to reproduce. In both of these scenarios only a small proportion of the ibises present on the marsh would attempt to breed, and the explanations would be consistent with the above observation. Alternatively, a large proportion of ibises might attempt to breed but fail early. This hypothesis is different from the first hypothesis because in that most birds actually attempt to breed. In this situation birds may begin to reproduce but fail or abandon nests because environmental conditions are not conducive to breeding. If birds began to breed and subsequently fail before we have the opportunity to accurately survey the colony then we would see fewer birds at the colony than on the marsh.

There may also be a second kind of counting error associated with breeding asynchrony. Within a colony White Ibis reproduction may be sufficiently asynchronous that it is difficult to estimate the total number of breeding pairs by counting them at any one time. We estimate the number of breeding pairs by counting adults present at the nest when we survey the colony. If birds are asynchronous breeders, or if earlier breeding birds are present for one survey yet away from the nest on the next survey (chicks receive less constant attention than eggs, see below) and later breeding birds have begun to nest we might (incorrectly) assume that the some of the later birds continue to be the birds we counted in the previous months survey. In these cases we would miss the additional late breeders and the estimates of number of breeding birds would be low, creating an impression that many birds are not breeding.

Finally, the number of breeding pairs in large colonies may simply be underestimated, even in individual monthly counts. One might predict that as the number of breeding pairs increases, precision decreases. This is because estimating large numbers is difficult (see Chapter II), as the number of breeding birds increases they are often more concentrated and difficult to distinguish, and the nesting structure in the colonies is vertically stratified making difficult to see nests near the ground. Typically, large numbers are underestimated by most observers, and the value of the underestimation increases with number of targets.

Some combination of the above hypotheses may best explain the observed patterns of seemingly small proportions of breeding birds. The objective of this part of the project is to evaluate some of the above explanations by examining the reproductive behavior and physiology of White Ibises. By capturing ibises, following them with radio-tags and examining morphological changes during reproduction we can identify whether or not a bird is breeding, classify its stage of reproduction, determine where it is breeding, and look for correlates of both timing of breeding and breeding status.

In 1998 and 1999 we successfully developed methods for trapping adult ibises, and began to describe changes in body condition, external morphology and hormone levels during the reproductive cycle. This year our objectives were: 1) investigate White Ibis breeding dispersal, nest attendance and continuity of breeding attempts, 2) examine changes in gonad size and condition to allow for comparison with other opportunistic and seasonal bird species, and 3) improve our model of the morphological and hormonal changes during the breeding season. This report details the results from our research activities during January through July 2000.

Methods

Trapping Adult White Ibis .

We selected trap sites by surveying the Water Conservation Areas for ibis foraging flocks. Ibises were lured to the trap site on the marsh by white plastic flamingos supported by 1-m long steel legs. Typically, we placed approximately 40 decoys in an area near foraging ibises at least one day before we attempted to trap birds at that site. At all trap sites we recorded how many decoys we used, the number of decoys with their heads up versus head down, density of decoys, water depth, and vegetation type and height.

To capture the ibises we placed two 3 m x 12 m, 100 mm gauge mist nets in a V shape on two sides of the plastic decoys. The nets were support by three aluminum poles (height = 3.06 m). At the middle pole (crux of the V) the net tiers were interlaced. Each pole had two guy lines tied at its top (above the net) and was anchored to a piece of concrete weight (8 kg). Each pole was also inserted into a 1.5 m length of conduit placed into the muck for added support. The middle pole was placed at the edge of the decoys and the nets run along the edges of the decoy cluster. Although nets were placed the night before a trapping event they were not unraveled (or open) until the next morning when we arrived before light. After we retrieved birds from the mist net we collapsed the nets to ensure that no birds would be captured while we were processing birds on the boat. To reset the nets we simply extended the tier loops along the poles.

Traps were set by sunrise and we stopped trapping by 1000 hrs. We trapped during the early morning hours to avoid heat stress to the birds and control for variation caused by diel hormone patterns. In addition, birds seemed to respond best to the decoys in low light conditions. We processed birds on an airboat parked on average 25 m from the trap area.

Measuring and sampling of birds

Once birds were trapped we immediately (mean time from bird touching the net to completion of blood collection: 9.3 ± 0.97 mins.) collected a 3 ml blood sample from the jugular vein with a 22-gauge needle and 5cc syringe. While birds were being processed we placed a leather hood on their head to cover their eyes. Birds typically responded by appearing to ‘sleep’ (i.e. droop head and become docile). We marked each bird with a U.S. Fish and Wildlife Service aluminum band placed on the left leg above the carpels. Ibises are sexually size dimorphic (males larger than females). Thus, we could usually estimate the gender of a bird from its bill and body size, though there is some overlap. Later we compared our subjective assessment to a more objective one using a discriminant function analyses (see below). We palpated female birds for presence of a shelled egg .

If a female did not have an egg or if the bird was male we proceeded to examine their gonads through a laproscopic procedure. Birds were anesthetized with isoflurane gas administered via a portable respirator and oxygen tank. Within 3-4 minutes ibises were unresponsive to touch. To view the gonads we made a small (5 mm) incision through the skin near the posterior-most rib on the left side of the bird. We slid the incision over the musculature between the ribs and made another incision into the abdominal cavity, so that the two incisions would not overlap when the skin was slid back into place. We then inserted an otoscope to view the gonads. Gonad length and width were estimated using a scale on the otoscope and we described color and, for ovaries, stage of oogenesis. Later, we used equations for calculating volumes of cylinders (testes) and spheres (ovary follicles) to estimate gonad size. Once the exam was complete, we discontinued isoflurane treatment and sealed the incision with veterinary quality super-glue. Ibises recovered quickly from the anesthesia, usually in less than 2 minutes.

We measured mass, straight and curved bill length, bill color, bill depth, wing chord, tarsus length and color, keel, and face color of the captured birds. Colors were measured by holding a paint swatch (Wal-Mart stores brand numbers 0071-1111) up to the body part and recording the color that most closely resembled the leg or face. We also visually scored fat stores and pectoralis size and examined birds for brood patches. Three mature scapular feathers were collected for mercury analysis. Mercury concentrations in feathers were determined by the Florida Department of Environmental Protection chemistry lab using cold vapor AA spectroscopy following acid digestion. Hormone levels in serum samples are still being analyzed at the time of this report.

Six birds received 6V radio-transmitters and 18 birds received 3V radio-transmitters (American Wildlife Enterprises, Tallahassee FL.). Radio-transmitters were attached using teflon ribbon figure-8 harnesses that looped around the top of each leg and across the back. This harness was fitted and then stitched together with cotton thread above the radio. The harnesses are made to come off the bird in 1 –3 years via deterioration of the cotton stitch. We did not mark female birds that were gravid with a late stage egg because our main goal in marking birds was to determine if they were breeding birds. We assumed gravid females were breeding. In addition to monitoring the radios attached during the 2000 field season, we also listened for signals from the 12 radios attached during the 1999 field season.

We attempted to locate the birds using radio telemetry on the ground and from fixed-wing aircraft. On each flight we visited all known ibis nesting colonies and flew transects (7 km apart; 300 m altitude) over Water Conservation Areas 1, 3A, 3B, 2A, and 2B. If we located a bird we recorded the coordinates and description of the location as seen from the air (e.g. in a colony, with a group of feeding birds, etc). We also made regular visits to known breeding colonies in an airboat. To listen for signals from the boat we elevated the yagi radio antenna at least 3 m above the airboat with a telescoping pole and scanned up to 5 hours for signals. If a bird was relocated in a colony at least twice it was considered a breeding bird.

Determining gender and stage of reproduction

As mentioned above White Ibises are sexually dimorphic, with males up to a third larger than females and relatively little overlap in other characters like bill length and curvature. However, there is overlap in size and morphometrics. We therefore verified our initial estimates of gender with statistical methods of classification.

For these analyses of gender and stage of reproduction we pooled data collected in all years of this study (1998, 1999, and 2000). There were no significant differences in any morphological measurement among years (all MANOVA P's>0.05). To determine gender by classification with a discriminant function analysis we used birds whose sex was determined through laproscopy or genetic sexing (total n = 34; genetic sexing by Zoogen, see Frederick et al. 1998). Overall accuracy of the discriminant function model was 99.97% with 100% of males being correctly identified and 99.95% of females correctly identified. The following variables best discriminated between the males and females: bill length curved, bill length straight, bill depth, and wing length (Table 1). Keel length and tarsus length did not significantly contribute to the model. We did not use mass because we found that the inclusion of gravid females significantly affected this variable's ability to predict sex.

The color of White Ibis legs and bill changed significantly during the course of the breeding season. To analyze changes in soft tissue color we scanned the standard color swatches we had used in the field into the computer and scored them for red, blue and green content. All colors had the highest red score possible, but they did vary from light to dark and from blue tint to green tint. These scores were entered into a principal components analysis. The first (PC1) score accounted for variations from light to dark, the second score (PC2) accounted for variation from blue to green.

We created a second discriminate function analysis using 5 variables related to the color of ibis bills and legs to classify the stage of reproduction (Table 3.2). The model was created from scores of 52 known stage breeders. These birds were either trapped or sighted on the nest, or had a pronounced and extended gular sac when captured (indicates display and nest building), or had an egg in the oviduct (egg-laying). The model correctly identified known breeders (jackknife validation; Sokal and Rohlf 1995) 91% of the time. From this model we then predicted the stage of 32 birds which were captured at an unknown stage of nesting . Five of these birds received classifications we thought ambiguous or incorrect, and so we manually classified these birds as unknown stage, or into a stage that would seem more appropriate. For example, a bird classified in the display stage who had no gular sac and an active brooding patch, was classified as an incubating bird. Ten birds were missing one or more of the measurements used to determine reproductive stage. We estimated their stage based on examination of their scores on brood patch, gonad size, and gular sac.

Analyses

For analyses of trapping factors and seasonal changes we combined data collected in all years of this study (1998, 1999 and 2000). In addition, we summarized our trap success, radio telemetry, and laproscopic examination results for the 2000 field season. All descriptive statistics are reported as mean ± standard error. Statistical analyses were done on SAS software. All data were examined to make sure they the assumptions of the tests (e.g. normality).

Results

Trapping Summary:

We captured 50 White Ibises from 15 February through 9 June 2000 (Table 3). We trapped on 36 days and set a total of 86 mist net trap sets (trap success: 1.43 ± 0.23 bird/day). The average number of birds trapped per day decreased this season compared to last year, probably because the interval between successive sets was increased as we collected more data (gonad condition) from each captured bird. We set the trap more than once on 63% of trap days.

Radio Tracking:

Summary

Of the 36 birds marked with radio transmitters in either 1999 or 2000, we relocated 29 of the birds on at least one occasion during the 2000 field season (Table 4). Of the seven birds we never heard during 2000, five were marked in 1999 and two were marked in 2000. Six birds (20.6%) were relocated at least once, but never in a colony. Three of these birds were located frequently early in the season but could not be located after 8 March 2000. We suspect that these birds may have been wintering in the Everglades and did not attempt to breed in our study area. Indeed two of these birds that we suspect were migrants did not have any sign of gular pouch or brood patch development when they were captured early in 2000. These two birds represented 18% of the birds marked early in 2000 (n = 11). This may represent an estimate of the size of the over-wintering population in the Everglades, although sample sizes are small. The third bird that apparently migrated early was marked in 1999 so we do not know its morphological condition when we relocated it in 2000. Two other birds that we did not relocate in a colony were marked late in the 2000 season (5 April and 15 May) and we suspect that they may have not been spending much time in a colony or had already finished breeding.

Twenty-three of the relocated birds (79%) were found in a breeding colony. As in 1999, most of the birds located this year were in Alley North, a large colony in northern WCA 3A (see Appendix I for location and composition). Seventeen of the marked birds bred at Alley North, three birds bred at Heron Alley, two birds at a colony in Loxahatchee and one bird at Shark Valley in Everglades National Park.

Site Fidelity

During 2000, we relocated seven birds (50%) that we marked during the 1999 season (Table 5). Female birds were more likely to be relocated than male birds. Only one female (16%) marked in 1999 was not relocated in 2000, but four males (67%) marked in 1999 were not relocated in 2000 (Table 6). Six of the 1999 birds were located in colonies during the 2000 season and one was not (see above). Five of the breeding birds were located in the same colony where they bred in 1999 (83.3% Alley North). One female that had bred at Hidden colony in 1999 bred at Alley North in 2000.

Nest attendance:

We opportunistically observed nest attendance exchanges between unmarked breeding adults whenever possible while listening at colonies. On 14 occasions we were able to quantify the time a previously attending bird spent in the colony after its mate arrived at the nest. In all of these cases we saw the arrival of the mate from outside the colony, watched the adult birds exchange nest care positions, and the relieved bird depart from the colony. Males on average spent 35.5 seconds (± 7.4 sec, n = 4) in the colony before departing. Females spent a little over a minute before departing (64.6 sec ± 13.6, n = 10). These departure times were not affected by whether or not the pair had eggs or chicks, though we would assume that early in the season (during egg-production) males may remain at the nest to guard their mate from extra-pair copulations (Frederick 1985). Thus, we are confident that later stage breeding birds leave the colony promptly upon the return of their mates. This indicates that through radio signals alone, we can reliably measure the amount of time birds are tending to their nests.

On 28 days we scanned colonies for presence of radio-marked birds (Table 7). Because most of our radio-marked birds were relocated at Alley North, we were best able to track changes in nest attendance at this colony. From mid-March through early-April most of our marked birds were at the colony upon our arrival (Figure 3.1). In this time period birds were most likely incubating and the eggs require constant attention. During this time birds would remain on the nest for approximately 2.5 hours (Figure 3.2). Indeed nest attendance switches (the loss or gain of a signal within our scan time) were rare (Figure 3.2). As eggs began to hatch and birds were tending chicks they spent less time at the nest and attendance switches were more common (Figure 3.2).

Morphological Changes:

White Ibises responded well to anesthesia with isoflurane. On average birds were exposed to high flow anesthesia for 4-6 minutes, after which we decreased flow of isoflurane to keep birds anesthetized. The procedure of anesthetizing the bird, making an incision, examining the gonads and resealing the skin took 16 minutes on average. After completion of other morphology measures we placed birds in a recovery box for approximately 10 minutes. All birds flew well upon release.

We attempted to visually examine the gonad condition of 12 female and 11 male White Ibises. We successfully scored the largest ovarian follicle on 90% of the female birds. Early in the season we realized that if a bird had an egg in the oviduct it was difficult to view the ovaries. Subsequently, if we felt the presence of an egg through physical exam then we did not attempt to perform a laproscopy on the birds. We successfully viewed the testes of 95% of male birds we laproscopied.

Gonad size and condition showed a seasonal pattern (Figure 3.3). Both ovary and testis volume increased during the display period, peaked during copulation and egg-lay and then decreased during incubation. We also examined the testes of 2 juvenile birds to compare relative size and color. The juvenile bird's testes were small and gray (Figure 3.3). Adult testes were larger during the breeding season and a light yellow color. Most males had small testes during chick rearing (mean of 159 mm^3 versus 821 mm^3 during copulation), but one male classified as a chick rearing bird had the largest testes measured (1308 mm^3). This bird may have been mis-classified, although other characteristics such as lack of a gular sac, and a down covered brood patch area suggested this bird would be chick rearing. Alternatively, this bird may have been undergoing a second nesting attempt, although we never relocated it via telemetry at a colony.

External Changes of breeding birds:

To evaluate changes in body condition we calculated a condition score that corrected for size variation. The first factor of a principal components analysis accounted for variation in size of various morphological measurements such as bill and wing length;

we used this principal component as a size factor score. We then created an expected relationship (linear regression) between mass and the size factor for each sex. The residual from each individual was then treated as its' body condition 'score'. In other words, a negative score means that a bird had a much lower mass/size ratio than expected (poor condition). Male and females went through significant body condition changes over the course of the breeding season (Figure 3.4). Both sexes gained mass before the display and nest building stage, and lost a considerable amount of mass through the egg production and incubation stage. Both sexes developed fat stores during the display and nest building stage. However, this energy store was more prominent in male birds (Figure 3.5). We did not detect a change in pectoral mass during the season, indicating that it is unlikely birds are storing protein energy ($P > 0.05$).

We found that bill color and leg color changed significantly in darkness and hue between breeding stages (all P's ≤ 0.007). These results are consistent with what we found last year. This year we did not detect a change in cloacal protuberance size ($F_{4,67} = 0.93$; $P = 0.4403$).

Birds began to develop brood patches during the copulation and egg-laying stage (Figure 3.6). During incubation the area posterior to the keel was completely bare of feathers and highly vascularized. After incubation brood patches were less vascularized and birds tended to groom feathers over the bare area. Finally during the chick stage down began to grow over the area.

As our ability to classify stage of reproduction based on morphological traits and gonad condition has become refined, we recognized that breeding ibises may molt body feathers (Table 8).

Mercury:

Total mercury concentrations in scapular feathers did not differ significantly between sexes (males 7.34 ± 1.11 mg/kg, females 7.13 ± 0.67 mg/kg; $F_{16,30} = 1.48$ $P = 0.3428$). Also, birds breeding at different colonies did not have different levels of mercury ($F_{3,9} = 1.88$, $P = 0.2034$).

Discussion

Breeding behavior

Our ability to track birds over consecutive years has allowed insight into their philopatric behavior. During 2000, we were able to relocate over half the birds that were marked with transmitters in 1999. The majority of these birds returned to the same colony to breed in 2000. This suggests that ibises can be philopatric, at least in some years. This impression of philopatry is, however, inconsistent with data we have collected over the past 15 years, that suggest that colony size can be extremely dynamic (Kushlan and Bildstein 1992). However, as is the case with many other bird species, ibises probably use a mixed strategy for deciding where to breed. Perhaps birds visit and evaluate areas where they have been successful before but do not always choose to nest at that site (i.e. if conditions seem unfavorable). It is interesting that we were able to relocate considerably more marked females than males. This may indicate a sex-biased philopatry, or sex-biased mortality.

Nesting by adult ibises in the Everglades in consecutive years indicates that these birds are not energetically or physiologically limited from breeding every year. One of the objectives of our study is to address this phenomenon. Many species that skip years between reproductive efforts do so because they are limited energetically (Hector et al. 1985). For example, biennially breeding Wandering Albatross (*Diomedea exulans*) have a prolonged period of fledgling dependence. In theory the adults are energetically taxed by this prolonged dependency period and therefore can not successfully reproduce every year (Hector et al. 1985). The demonstrated ability of ibises to breed in sequential years suggests that if a proportion or all birds are not breeding it is unlikely that it is a natural part of ibis life history.

Radio-tracking data also lent insight into nest attendance. During incubation birds constantly tended the nest and switched attendance (approximately every 2.5 hrs., Figure 3.2). As the eggs hatched parents made frequent trips to and from the nest. We have demonstrated that we are able to track these changes, and might be able to detect differences between colonies. For example, nest switches occurred most frequently during early April at Alley North (Figure 3.1). These data are useful for understanding the degree of temporal variation within a colony and potentially, between colonies. It would be interesting to compare length of nest attendance and frequency of nest switches among colonies that had variable distances to food sources.

Morphology changes

During reproduction ibis testes enlarged and developed and then receded. Although we only examined one male during the display phase, this animal provided evidence that ibis testes are already enlarged before the actual fertilization phase. This would also follow the general pattern in other species of birds. Testes may be producing testosterone which would facilitate courtship displays and aid in nest site selection. After the fertilization and egg-laying stage testes decrease in size. A decrease in testes size may indicate that male are not producing large amounts of testosterone during incubation and brood rearing. This is consistent with the hypothesis the testosterone may interfere with nest attendance (Wingfield et al. 1990). This is also interesting because ibises are colonial nesters and one might predict the males would benefit from high testosterone levels, either to facilitate extra-pair copulations or because they are faced with constant antagonistic conspecific interactions with neighboring birds. In both of these situations sexual and aggressive male behavior is usually maintained by testosterone (Wingfield et al. 1990). However, the cost of decreased nest attendance probably outweighs the benefits of maintaining high testosterone levels because ibis nesting attempts are not successful unless both adults incubate and brood the young (Frederick 1985).

Female gonads also showed a seasonal growth pattern. Ovaries did not develop large follicles until the birds were producing eggs. As with testes, ovaries decreased during incubation and chick rearing. Results from last year indicated that female birds maintained high circulating levels of estradiol throughout the breeding season. Ibises may produce estradiol from an extra-gonadal source. Thus, it will be interesting to continue investigating the relationship between ovary size, estrogen level and breeding behavior in these birds.

Also interesting is the dramatic change in body condition over the course of the breeding season. Birds put on mass quickly before they began to tend a nest. Indeed 90% of male birds caught during the display phase had a fat store. While male and female birds have a similar body condition pattern the mechanism of change probably differs between genders. Males gain mass during the display stage and then may remain at the nest site for up to 10 days during the copulation and egg-laying stages. During this time males may take short trips away from the colony but for the most part appear to fast. We saw similar behavior in previous research we and G. Babbitt conducted of captive Scarlet Ibises and wild White Ibises (Frederick 1985, Frederick et al. 1999). This is also evident from our trapping results. We have caught 20 female birds during the egg production stage but only 3 males, suggesting that males are not often foraging and available to be trapped during this stage. Female birds also gain energy stores during the display period but those stores are depleted during egg production. Neither sex seems able to make up the lost mass during incubation. There is a trend for male birds to gain mass during the chick rearing stage, but female birds seem to remain at a deficit, at least by comparison with the courtship phase.

Non-breeding birds?

This year our understanding of White Ibis reproduction in the Everglades has greatly increased. Over the past three years we have gathered information to describe and quantify ibis reproductive behavior, such as nest attendance and colony fidelity, and physiological changes such as brood patch development, gonadal changes, and hormone levels. Our original objective in gathering these data was to evaluate hypotheses that may explain why estimates of total wading birds on the marsh are orders of magnitudes larger than estimates of breeding birds in colonies. Here we discuss the hypothesis that a significant proportion of the birds present is not attempting to breed.

One important and beneficial tool that has developed from our work with ibis is a model that can be used to predict stage of reproduction from bill and leg color. By increasing our sample of marked birds and directly examining gonads we were more confident in assigning reproductive stage to birds captured away from their nest. The classification model has a relatively low rate of error (9%), that should decrease as we add more information to the model (capture more birds). Our confidence in assigning reproductive stage allows us to understand that ibises have the ability to molt their body feathers during almost any stage of reproduction (Table 8). Thus, our assumption last year that a molting bird was a non-breeding bird was probably incorrect. It is extremely unusual for birds to molt while reproducing because it is thought that both activities require high amounts of energy. In fact, the hormones associated with molting may inhibit breeding and visa versa (Dawson 1997). That is evidently not the case for ibis. While we never observed birds molting flight feathers, we did see considerable body molt (up to 75% on some birds) along their backs. It will be interesting to explore the endocrinological and energetic factors that allow molting and breeding to occur at the same time.

Another criteria we use to determine if a bird is a breeding is relocation of radio-marked birds in colonies. In any given year only a low proportion of marked birds is never relocated (1999: 7%; 2000: 8%). Other birds that are not found in colonies are birds that are marked very early in the season and may migrate away from the area, or birds marked very late in the season that may not spend much time at the nest or colony. Two birds that we captured this year that had many reproductively active traits, such as dark red bill and legs, brood patch, and egg present, we found only once in a colony. These birds may have been unsuccessful breeders. Further, we have never marked a White Ibis and then relocated it throughout the season away from colonies, as you might expect from a non-breeding bird. Except for very early in the season (mid-February), we have never captured an ibis that does not show any sign of breeding activity. Thus the observations we have made in 1999 and 2000 are inconsistent with the hypothesis that a large proportion of White Ibis did not attempt to breed in those years. However, in both 1999 and 2000, the proportion of birds breeding (as calculated from SRF and breeding survey results) was at or above 100%.

We are continuing to investigate alternative explanations to the hypothesis that large proportions of ibises remain in the Everglades during the breeding season, but do not breed. For example, we may be underestimating total breeding effort, either through errors associated with observer bias (see Chapter II) or through error associated with counting birds in a colony at a single point in time. The latter error comes about because ibises may nest asynchronously in a colony, and estimating a colony with a single count may underestimate the number of nests at the colony because early season breeding birds may be away from the nest, while late season breeding birds may just be arriving.

The past two breeding seasons have been remarkable years in the context of the past 30, in that large numbers of adult ibises bred. However, in other years we have seen fairly unambiguous evidence of low proportion of birds breeding. During 1998, for example, there were only 1,408 pairs of White Ibises attempting to nest in the Water Conservation Areas. This was a small proportion of the number counted on the marsh (estimated 22%). In this year there was not very much temporal variation in nest initiation dates and we estimated our counting error to be much lower for smaller colonies than it might be for larger, more asynchronous colonies, such as those encountered in 1999 and 2000. It seems unlikely that breeding asynchrony and counting error would best explain the disparities in counts in 1998. It may be that in years of poor environmental conditions many birds do not attempt to breed, or abandonment rates increase.

We are suggesting that there may be more than one explanation for why there are differences between the SRF counts and the breeding bird estimates. In years of excellent breeding conditions, when birds may constantly be immigrating into the area we may underestimate numbers of breeding birds because of breeding asynchrony and observer error at large colony sizes. In years of poor breeding conditions, our counts are probably much more precise. In these situations interactions among prey abundance, hydrology, and toxicological factors may prevent birds from coming into reproductive condition, or may cause high abandonment rates.

We are also currently investigating the effects of mercury on parental care. Mercury is a widespread and potent toxin in the Everglades system (Frederick 2000). Last year we detected a significant positive relationship between mercury levels and progesterone levels (Frederick et al. 1999). This sort of relationship could be the result of either mercury increasing the synthesis of progesterone or, alternatively, mercury blocking progesterone receptors. Previous work has shown that high levels of mercury do block progesterone receptors in female chickens (Lundholm 1991). This is an interesting relationship in light of the fact that progesterone is the primary hormone associated with male parental care (Askew et al. 1997). Mercury may be affecting parental care through blocking of progesterone receptors. If low-level exposure to mercury inhibits progesterone signaling then birds may abandon more readily in response to poor conditions.

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