

281
Wood Stork

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RELATION OF TEMPORAL VARIATION IN WATER LEVEL AND FISH AVAILABILITY
TO WOOD STORK REPRODUCTION IN THE
SOUTHERN EVERGLADES, FLORIDA

By

James A. Kushlan

Water Resources Division, U. S. Geological Survey, Miami, Florida

John C. Ogden

Office of Natural Science Studies, U. S. National Park Service,
Everglades National Park, Homestead, Florida

and

Aaron L. Higer

Water Resources Division, U. S. Geological Survey, Miami, Florida

Prepared by the
U. S. GEOLOGICAL SURVEY
in cooperation with the
U. S. NATIONAL PARK SERVICE

Tallahassee, Florida

1978
4

CONTENTS

Abstract.	
Introduction	
Study Area	
Methods	
Results	
Hydrology	
Wood Stork population	
Wood Storks and water ^{conditions} level	
Fish population	
Wood Storks and fish availability	
Discussion	
Requirements for successful nesting	
~~Relation of Wood Storks to water supplies~~	
~~Wood Storks and management of surface water~~	
Wood Storks as an indicator of ^{ecological} ~~environmental~~ stability	
Acknowledgements	
Literature cited	

ILLUSTRATIONS

Figure 1.--Physiographic and geographical locations in southern Florida. Imagery by Earth Resources Technology Satellite

2.--Location map of the southern Everglades.

3.--Plant communities of the southern Everglades

4.--Surface water flow into two sections of Shark River Slough and through the eastern Big Cypress Swamp

5.--Deviation from natural flow in the southern Everglades 1962-72 based upon water flow index (discharge central slough/discharge eastern Big Cypress Swamp). The average index 1953-61, (0.58) is indicated by a solid line and standard deviation (± 0.17) is indicated by a dashed line

6.--Month when wood stork colonies formed in the southern Everglades 1953-72. Years of successful nesting are stippled. No ^{wood stork} colonies formed in 1962.

7.--Water level ^{at P-32} in southern Everglades during formation of wood stork colonies.

8.--The relation between early drying rate (Nov-Jan)
in Shark River Slough and the months (1963-72)
in which wood stork nesting colonies were formed. . . .

9.--The relation between early and late drying rates
in the southern Everglades. The derivation of these
rates is explained in the text. Drying rates in
years of successful wood stork nesting are shown
as circles, years of unsuccessful nesting as
squares. Open symbols are those for the years
1953-61, prior to completion of levees. Closed
symbols are those for the years 1962-7³. The
averages for each group before 1962 are shown
in double symbols.

The shaded polygons represent the range of variation of

successful and unsuccessful years before 1962

.

10.--Relation between fish density in the marshes of
Shark River Slough and water level, October 1966
to April 1967. Numbers at data points indicate
month of datum.

11.--Fluctuations of water level^{AP-33} and density of fish
in Shark River Slough.

TABLES

Page

- Table 1.--Water conditions and nesting success of wood
storks in the southern Everglades, 1953-73
- 2.--Effect of short-term rises in water level on
wood stork nesting 1953-73
- 3.--Drying rates in years of successful and
unsuccessful wood stork nesting
- 4.--Water depth at peak fish density in
southern Everglades marshes
- 5.--Density of fish in southern Everglades
during summers of similar water depth.

CAP
Relation of temporal variation in water and fish availability
to wood stork reproduction in the southern Everglades, Florida

By
James A. Kushlan, John C.
Ogden, Aaron L. Hight

ABSTRACT

The wood stork is the wading bird species most sensitive to changes in the availability of food in the Everglades. Previous studies have shown that the initiation and success of wood stork nesting depends on high densities of fish concentrated ^{in ponds and other catchment basins} during the dry season. The extreme dependence of the wood stork on the cyclic hydrologic regime of the southern Florida wetlands makes it an indicator of the well-being and ecological stability of the Everglades.

The wood stork has declined in numbers over the last 25 years. An accelerated rate of decline from 1962 to 1972 coincided with the implementation of management of surface water flow in the Everglades. The reason for the storks decline involves loss of peripheral wetland feeding habitat, loss of food production in artificially dry marshland, and ^{changes in the hydrologic regime of the Everglades}.

The fish on which the wood stork feeds ^{increase} in density as water levels fall during the dry season. Highest densities in the Everglades marsh occurred in front of the drying edge of surface water ^{at} a depth of about 0.3m. Dry season densities were greatest when the previous year experienced a drought. Prolonged high water levels ^{over} extended over several years resulted in decreased fish abundance.

Historically Wood stork nesting success was associated with high summer water levels, ^{high rates of surface water discharge and} high rates of drying. Before the ^{closure of the south side of the water conservation} area in 1962, years of successful and unsuccessful nesting were characterized by different patterns of drying. These patterns ^{changed} ~~break down~~ after 1962 and generally ^{the predictability of} ~~failed to predict~~ successful nesting. ^{breaks down thereafter.} Only two successful ^{Nesting} years occurred after 1962 and in only one of these ^{was the} ~~were~~ drying rates similar to successful ^{Nesting before} years prior to 1962. Two other potentially successful years after 1962 failed. This suggests that changes in the hydrobiological relations occurred within the Everglades after 1962.

After 1962 lack of successful nesting can be attributed in large part to late colony ^{late} formation and the interruption of nesting by winter rainfall. In this period colonies formed earlier in years of high ^{early} drying rates. Delay of colony formation is ultimately the result of inability to attain a suitable nutritional state since food supply is the primary factor in the initiation of nesting. Many of the complex food associations of the wood stork remain to be elucidated.

The recent decline and reduced nesting success of the most sensitive of the dominant wading bird predators suggest that recent ^{hydrologic} changes within and near the Everglades have altered the historical ecological conditions. Management of the remnant Everglades is constrained by these recent changes and the future viability of the Everglades population of wood storks is ^{uncertain under current conditions.}

INTRODUCTION

The Florida Everglades is a vast, shallow marshland which in its natural state encompassed nearly 10,000 km² stretching from the south shore of Lake Okeechobee to the mangrove swamps of southwest Florida, 160 km to the south. A sheet of surface water generally less than 1 m deep flowed southward over a gradient averaging about 5 cm/km at a maximum rate of about 475 m/day (1550 ft/day) (Leach, Klein and Hampton 1971²). Near the latitude of Miami, the principal Everglades drainage, ^{called The Shark River Slough,} is constricted by a slightly higher marshland to the east and west and funnels into a series of dendritic streams which enter coastal mangrove swamps. These streams coalesce into the mangrove-lined rivers such as the Shark and Broad Rivers.

¶ The Everglades ^{can be} ~~is~~ now divided into three distinct regions (Fig. 1): agricultural lands directly south of Lake Okeechobee, three Water Conservation Areas established as water-management impoundments; and Everglades National Park including within its boundaries the southernmost part of the Everglades.

The present ^{reports on studies} paper made in 1965-72³ by the U. S. Geological Survey and the U. S. National Park Service. Its purpose is to relate variation in water supply to the production of aquatic animals and the reproductive success of ^{particularly the Wood Stork,} the wading birds that breed in Everglades National Park.

Water supply is critical to the colonial nesting wading birds (order Ciconiiformes: herons, ibises, storks) that breed during the dry season when ^{inundated Areas are reduced to isolated pools and fish become concentrated}

by falling water levels. The wood stork (Mycteria americana) is the species most sensitive to variations in food availability because, unlike visually hunting species of herons, the stork feeds exclusively by non-visual, tactile methods and its feeding efficiency is directly related to fish density (Kahl, 1964). Kahl ⁽¹⁹⁶⁴⁾ also found that in southern Florida this species requires the high densities of aquatic organisms concentrated by falling water level to

trigger and sustain nesting. Historically, when wood storks ~~experienced~~ ^{nested} successful ~~nesting~~ ^{nesting} so did other species of wading birds, although wood storks failed in some years when other wading birds were successful. Since wading birds ~~function as~~ ^{are the} dominant predators in the ecosystem and are adapted to the naturally

fluctuating water conditions of the Everglades, the wood stork is in many respects an indicator of the natural functioning and general well-being of the Everglades ecosystem. ~~It is~~ ^{For this}

reason ~~that~~ The biology of the wood stork has been emphasized in this paper.

STUDY AREA

The study area was the ^{South Terminus} of the Everglades drainage system south of U. S. Highway 41 (Fig. 2). The study was concentrated ⁱⁿ

the Shark River Slough ^{which} originates in the marshes north of U. S. Highway 41 in what is now Water Conservation Area 3 ^{and extends to the south west coast (Fig. 2).}
^{South of US 41, the slough covers 791 Km². However 214 Km², now known}

^{as the eastern slough, lies} east of Everglades National Park and ^{is} cut off from the rest of the southern Everglades by levee L-67 extension (Fig. 2).

Vegetation of the Everglades ^(Fig. 3) is dominated by four plant associations described in detail by Davis (1943), Loveless (1959) and Craighead (1971);

(Plant nomenclature is that of Long and Lakela, 1971). Sawgrass marsh, composed of almost pure stands of Cladium jamaicensis, is the predominant community.

At ^{an} slightly lower elevation than sawgrass marshes, mixed marshes or prairies consist of pure or mixed stands of

herbaceous plants, with Eleocharis cellulosa and Rynchospora tracyi dominating.

Tree islands are raised slightly above the surrounding marshes and vegetated by hardwood communities,

where inundated during high water, swamp hardwoods including Salix caroliniana, Chrysobalanus icaco, Persea borbonia, Myrica cerifera and Ilex cassine. Islands above high water level are covered by hardwood communities called hammocks which include Celtis laevigata, Ficus aurea, Eugenia axillaris, Bursera simaruba, and Lysiloma latisiliqua. In the lower ^{part of the} slough, dendritic streams are lined by river-bank

forest

composed of

Rhizophora mangle, Conocarpus

^{no?} erecta, Annona glabra, Salix caroliniana and Chrysobalanus icaco.

^{Farther inland}
Sawgrass replaces riverbank forest.

Shark River Slough is the southern part of the Kissimee-Okeechobee-Everglades drainage system. Through the years the drainage system has been modified by canal drainage, water control and

water management practices, and urban and agricultural growth. one of the important management works was the completion of a levee along the south side of Conservation area 3 which changed the pattern of southward flow to the Shark River slough.

The history and some of the consequences of these developments on the total system have been reviewed by Leach et al. (1971).

METHODS

Water level was recorded continuously at U. S. Geological Survey gaging station P-33 (Fig. 2). ^{Station} P-33 is located in sawgrass marsh in central Shark River Slough at ^{land elevation} ~~ground level~~ of 1.6 m (5.2 ft) above msl (mean sea level). Data from P-33, available from 1953 through 1972, were used to characterize the hydrology of the southern Everglades and serve as a general indicator of water conditions in southern Florida.

_____ High water
years _____ are those in which water level at P-33 ^{exceeded} ~~rose~~
2.0 m (6.7 ft.) above ^{MSL} ~~MSL~~ during January.

_____ The rate of water-level decline was quantified by calculating an early and late drying rate for Nesting Year ^{which runs from June through May.} The early drying rate is the net rate of change from the highest water level in November of the previous year to the highest level the following January. The late drying rate is the net rate of change from the highest water level in January to the highest level in March. Note that these rates were applied to the calendar year in which the dry season occurred ^{period and nesting} even though calculations were based in part on water level in the previous calendar year.

Surface-water flow was measured at culverts and water control structures along U.S. Highway 41. In this paper water flow through these structures was divided into three discharge segments as shown

in Fig. 2. To determining the relation between these flows, a water flow index was established, which is the ratio of ^{calendar year} discharge into Shark River Slough divided by discharge through the eastern part of the Big Cypress Swamp ^{which is not controlled} years of low discharge are

Those in which flow through the two sections across the Shark River Slough was less than $320 \times 10^6 \text{ m}^3$ (260,000 Acre-ft) during the June-May annual cycle in number per unit area

Density of aquatic organisms was determined by samples obtained with Higer pull-up traps. The traps consisted of a sheet of 3-mm mesh nylon netting on a 1.5 x 3.0 m frame which rests on the bottom of the marsh and is pulled up by two operators standing 15 m away. This device has been described and discussed by Higer and Kolipinski (1967) and Kushlan (1974). Specimens were fixed in 10 percent formalin in the field and later identified, counted, and weighed to 0.001 gm after being blotted dry. Computer programs were used to calculate the average density of organisms per square meter of surface area for each sample period.

In 1965 ten traps were installed in the central part of Shark River Slough, 5 in sawgrass marsh and 5 in Eleocharis-Rynchospora marsh (Fig. 2).

Samples were generally collected during a one-week period each month; each trap was sampled on two consecutive nights whenever possible. Because variation between samples from the two

communities was within the range of variation within each community, data from all trap sites

were averaged to find the mean density of all fish for the period.

Population, movements, and feeding areas of wood storks from 1965 to 1972 were determined by regular, generally monthly, aerial surveys. The total population within the southern Everglades was censused during the winter-spring breeding season. Nesting numbers and success were determined by aerial observation and photography. Information on colony formation and nesting success from 1953 to 1965 was obtained from

W. B. Robertson, Jr. (National

Park Service, Pers. Comm.)

A breeding season was considered successful if the number of young produced was great enough to sustain a

stable total population through the next breeding

season. R.P. Allen's estimates of annual mortality (in Palmer, 1962) were used in calculating population trends.

RESULTS

Hydrology

Variation in rainfall, evapotranspiration and overland ^{water} flow from the water conservation areas results in seasonal changes in the quantity of water in the southern Everglades: The general yearly pattern of water-level fluctuation is as follows: water levels ^{begin to rise in} May or June ^{to a peak} in October. Thereafter levels decline, slowly and irregularly at first, but ^{accelerate in the spring. Levels next} continue to decline until the rainy season starts.

This temporal pattern of water-level fluctuation causes a spatial variation in the distribution of surface water. As the dry season progresses, evapotranspiration causes a decline of water level throughout the southern Everglades, surface flow decreases and finally ceases, marsh bottom becomes ^{increasingly} exposed along the higher land to the east and west, and drying progresses inward from the lateral edge^s and longitudinally from both the north and the south.

Dry season discharge from Water Conservation Area 3 ^{SUSTAINS}

inundation southwest of L-67

longer

than would otherwise occur.

9) After completion of the levee on the south side of Conservation area 3 in 1962 water-level fluctuations in Shark River Slough were caused by variation in rainfall and variation in controlled surface-
water discharge ^{through the levee} into the slough. Graphs of surface flows through the eastern Big Cypress Swamp and flows into the eastern and central parts of the Shark River Slough for 1940-72 are shown in Fig 4. Until 1962, the Big Cypress and Shark River flows were comparable.

Thereafter, surface flow into the upper slough was eliminated, but low discharges continued by underseepage along the levees ^(Fig 2). Flow was also reduced in the central slough in low rainfall years ^{from} 1962 to 1965 but ^{was} increased in later years.

To determine the significance of these changes in surface flow patterns, a comparison was made between recent controlled Everglades flows and uncontrolled flows in the Big Cypress Swamp. This can be done because of the high correlation of annual flow through the eastern Big Cypress

Swamp with flow into the southern Everglades ($r=0.93$, $p<0.01$) For the interval
1940 to 1961 ^(uncontrolled) the ratio of Everglades to Big Cypress flow was
0.58 (SD=0.17) for the central slough and 1.07 (SD=0.88)
for the eastern slough.

The surface-water flow into the central slough expressed
in terms of this ratio ^{is shown in Fig. 5}. Although flow was reduced in 1962-65, these were
dry years, and the index of surface flow into the Everglades relative
to the Big Cypress Swamp was similar to values
before 1962. With the resumption of discharge in 1966, however, surface
flow into the central slough
natural flow ^{would have been} in five years, 1966, 68, 69, 70, ^{was greater than what the} (t-test, $p<0.05$).

The increased ^{surface flow, in 4 years after 1962 were}
due primarily to water control. Water that under natural conditions would have
flowed into the entire slough was directed into the central
slough while discharge into the upper slough consisted only of seepage.
The increased flow ^{diverted} into the central slough can maintain high levels ^{there for}
prolonged periods.

From this ambiguity and the vague ref to
"under-seepage" [as opposed to over-seepage?] on previous
page, I read that GS isn't about to jeopardize
any funding by letting the ins say plainly
that overland flow was cut off by the levee
in 1962-5. It's not worth battle at this late date,
just interesting.

Wood Stork Population

The southern Everglades wood stork population, referred to by Kahl (1964) as the "Everglades-mangrove population", consists of those birds breeding in colonies at the margin of the southern Everglades. Information on this population before Everglades National Park was formed in 1947 is scattered and incomplete, But Holt (1933) reported 50,000

storks in a single colony in 1933. By 1960, the population stood at 6200 and a further decline occurred during the 1960s. By 1965 the southern Everglades population had declined to 5,200, and by 1972 to 1,800.

Storks did not breed successfully in all years even prior to extensive habitat changes, being unsuccessful in ^{dry} years.

Storks bred successfully in 6 of 9 years from 1953 to 1961, but did so in only 2 of 12 years from 1962 to 1973 (Table 1). During the period of fish ^{monitoring} (1965-72), there was only 1 successful year (1967).

Wood storks disperse northward throughout the southeastern coastal plain in summer. They return to south Florida in fall, generally November (Palmer, 1962, Kahl, 1964). On returning, they feed in a predictable sequence of

locations. They first utilize drying ponds and marshes within the coastal mangrove zone, remaining there through December. Feeding storks then move to the drying lower part of Shark River Slough. Later, in early spring, storks feed along the drying lateral edges of the central slough, a residual central slough pool north of the ridge, and, in recent years, along the south side of Water Conservation Area 3^A.

Nesting in the southern Everglades takes place in the winter and spring. Before 1962, colonies formed in November and December, but after 1962, the time of colony formation became increasingly irregular ranging from December to as late as March (Fig. 6). Through 1973, no year in which colonies formed as late as January has been successful. Years when colonies formed in December were successful about half of the time (Fig. 6),

Wood Storks and Water Conditions

Since the nesting success of wood storks is apparently predicated on colonies forming ^{from} ~~in~~ November ^{through January} or ~~December~~ (Fig. 6), it is important to determine ^{whether hydrologic} ~~the environmental~~ parameters affecting ^{the timing of} colony formation.

In the Big Cypress Swamp, wood storks begin nesting when the water levels fall to a specific point (Kahl, 1964). Wood storks nesting in the Everglades show no such correlation. As demonstrated in Fig. 7, water level at the reference station ^{in the central slough} varied 0.7 m (2.29 m to 1.59 m) during the times of colony formation.

It is ^{reasonable to suspect} ~~possible~~ that the timing of colony formation may be related to the rate of water-level decline during the dry season.

Although ^{such} There is no correlation before 1962 since colonies formed in November or December irrespective of drying rate. After 1962, early drying rate was significantly higher in years when colonies formed in December than in years when colonies formed later ($r=0.64$, $P<0.05$) (Fig. 8).

If this correlation between the rate of drying and ^{time of} colony formation is meaningful, it may be related to changes in ^{surface} the system after 1962.

Desertion of colonies by nesting wood storks is apparently also related to water conditions. This is important because of seven attempts at renesting after desertion, only one was successful. Desertion was, in all cases for which

information is adequate, correlated with rises in water level ~~greater~~ ^{of 3cm or more} than or equal to ~~3cm~~ (Table 2). ^{However} Desertion in response to such water

level rises occurred only within the first 2 months of nesting. ^{After 2 months, nesting storks apparently continue to nest for as long as they can locate food sources.}

The desertion of nesting colonies due to relatively small rises in water level suggests why colonies ^{that} formed after December have failed.

Wood storks require approximately 4 months to fledge young and

colonies formed late have insufficient time for development prior to

the onset of the rainy season which ^a rises water levels and inevitably

causes desertion. It seems possible that colonies formed as late as

late January could succeed prior to the rainy season, but until 197³

none has.

In that colony desertion and, after 1962, colony formation are correlated with hydrologic parameters, it seems probable that Wood Stork nesting success is also related to ^{in the southern Everglades} water conditions. In an attempt to discern such a relation, we used 3 parameters to describe the temporal variation in water level: discharge into Shark River Slough, winter water levels, and the rate of winter-spring drying. Table 1 shows the correlation of the first two parameters with Wood Stork nesting. Before 1962, this relation was straightforward: stork nesting failed in low water years but generally was successful ^{years of} in high winter water levels and high discharge. ^{The} latter relation

was first noted by Robertson (1964). After 1962, however, this relation broke down: storks failed in the three years ^{having} both high water level and high discharge and they successfully nested in two years of low water conditions. This strongly suggests that the hydro-biological system support^{ed} Everglades wood storks underwent changes after 1962.

Analysis of the third parameter describing water level fluctuations is more complex. The overall relation is that ^{successful} years generally had higher drying rates than did unsuccessful years (means different, t test, $P < 0.01$, Table 3). A more detailed analysis is shown in Fig. 9 where the late drying rate is plotted against the early drying rate for each year of record. Plots of successful and unsuccessful years before 1962 ^{form} 2 distinct clusters, shown as shaded polygons, which differ in mean late drying rate: (t test, $P < 0.05$). (The single exception to the pattern, 1959, is out of its proper cluster because of water level changes which took place after young storks had fledged.)

NOT
Clear

Comparison of later years to base line data from before 1962 shows that the drying rates of most unsuccessful years continued to fall within or close to the cluster for unsuccessful years before 1962. However four years are anomalous. The unsuccessful year of 1969 was considerably deviant from other years. Drying rates for 1962 and 1971 were similar to pre-1962 successful years, but in both these years wood storks failed.

Drying rates in 1967 were different from all other

successful years ¹ (t test, $P < 0.05$) ^{but} produced successful nesting only in 1963. ^{These drying rates similar to those of pre-1962 successful years associated with successful nesting.} However, as can be noted from Table 1, before 1962 such rates were produced in high water years whereas 1963 was a low water year.

These results show, first of all, that successful and unsuccessful years before 1962 can be characterized by how fast water levels dropped in the nesting season ^{in addition to water level and discharge}. However the non-conforming results of later years

further supports the idea that the hydrologic system has undergone profound changes in the interim.

Fish Population

The density of fish in Shark River Slough is related to water depth (Fig. 1⁰). As water levels ^afall, density of fish at the trap sites increased to a peak in January and then declined as water level declined further. The occurrence of peak fish densities during moderately low water levels is apparently caused by the movement of small fish to deeper areas well in advance of the drying edge of the marsh. Such peak densities occurred when water depth in the marshes reached about 0.3 m (Table 4). This wave of densely concentrated fish apparently moves across the southern part of the Everglades until fish finally become concentrated in localized depressions. Such movement of fish during periods of drying was shown previously ^{by Kushlan (1972)} for a pond in the Big Cypress Swamp, but these movements were more limited.

To analyze how water level correlates to changes in fish density, it is necessary to first examine the water level fluctuations at station P-33 (Fig. 1⁰). Droughts occurred in 1965 (prior to the study) 1967, 1971 and 1972. From the summer of 1968 through 1970 water levels were continuously high due to high surface water discharge discussed earlier (Fig. 4). ^{Both} The prolonged wet period and the drought affected fish populations during the study. Fluctuation of fish density is also shown in Fig. 1¹ which demonstrates how density increases when water levels drop.

Since fish density varied with both water level and time of year, density at different times can be compared directly only if the data are from the same time of year, at approximately the same water level, and at a time when water levels are changing at similar rates in the same direction. These criteria were met in August of several years

(Fig. 1¹). Fish densities during the summer of 1966 and 1968 (both following droughts) were relatively high, but during the continuously wet period from 1968 through 1970, summer fish density declined by 47 percent from the first (1966) to the third (1970) summer (Table 5).

Additional evidence of the decline in ^{the} fish population ^{during} extended high water is shown in the dry period of 1971. Samples taken near what should have been peak fish density showed a moderate rather than a high density (Fig. 1²). This may be contrasted with the high densities in

1972 which, following the 1971 drought, reflected the return of typical conditions. These data indicate that the abundance of fish decline during continuous high-water periods and increase after drought^s.

These results do not support previous hypothesis^es which predicted an increase in the density of fish during continuously elevated water level (e.g., Kolipinski and Higer 1969).

Wood Storks and Fish Availability

Of the several feeding areas used by wood storks, information on the fish populations^{is available} only in the Shark River Slough. This is however, the most critical area because storks feed there when securing food for young in the nest, the period of highest energy demand.

wood storks feed during periods of falling water levels when fish densities are increasing (Fig. 12). Storks usually feed at a water depth of about 0.3 m, the depth where fish are maximally concentrated (Table 4). Storks feed on this dense wave of fish while the slough dries and continue to do so as remnant fish stocks become concentrated within topographic depressions.

The result of this pattern of fish concentration is that highly concentrated food supplies are generally available to storks feeding in the slough throughout the mid-nesting period.

The prolonged wet period from 1968 to 1970 resulted in a 47 percent decrease in the standing crop of fish in central Shark River Slough (Table 5). Since the analysis of drying rates (Fig. 13)⁹ suggested that 1971 probably should have produced successful wood stork nesting, the failure may have been caused in part by lack of food. If so, it was probably due to the combined effects of high water from 1968 to 1971 and the reduced inflow of fish into Shark River Slough from the northern Everglades and previous tributary areas to the east.

DISCUSSION

Requirements for Successful Nesting

Wood stork colonies in Everglades National Park are fully protected and thus disturbance ^{is not} as a cause of nesting failure. Nor does the species' movements or residence during the nonbreeding season appear to be a source of high mortality because the population returns to south Florida each year in numbers which correspond to the previous seasons' reproductive output. It is possible, however, that the nutritional condition of returning storks may be lower than in previous years. Furthermore unlike storks nesting in the Big Cypress Swamp (Kahl, 1964), there is no evidence that Everglades colonies have failed due to high winds or cold weather (W. B. Robertson, Jr., NATIONAL PARK SERVICE, pers. comm. ¹⁹⁷³). We suggest that nesting success and failure in most cases are related to the abundance and availability of food in the supporting system, a view consistent with the proven sensitivity of wood storks to variation in food supplies (Kahl, 1964).

The well documented dependence of southern Florida wood storks on concentrated food supplies (Kahl, 1964) means that feeding success is determined by the interaction of two factors: a water depth shallow enough for wading and a high density of fish. Feeding sites are located where these two conditions are met. This explains the successive movement of wood storks to different feeding areas during the winter and spring. The storks use coastal feeding sites in early winter when water in the Everglades is too deep for feeding. Later

movements to the Everglades and within the Everglades also follow the pattern of drying.

Storks move into the Everglades during and immediately after colony formation and continue to feed there as the area progressively dries. In the Everglades marshes,

maximum ^{fish} density is reached near

the depth at which storks feed. Storks feed on these dense fish concentrations and move with the wave of migrating organisms as the Everglades dries.

— This pattern of food utilization suggests why drying rates might be important. ^{with regard to nesting success.} Fish in high densities must be available in Shark River

Slough over several months, it necessitates continual concentration along the drying edge and ultimate concentration in residual pools.

This requires a drying rate sufficient to maintain a wave of concentrated fish over a relatively long period of time. Water-level rises, whether

due to short-term rainfall (Table 2), beginning of the rainy season, or

increased overland flow due to surface water discharge, ^{Reduce fish density by dispersing} dispersing concentrated fish ~~and thus decrease fish density~~ and as a consequence ^{affect}

feeding efficiency of storks.

The drying rate in the Everglades and ^{probably through-} out south Florida was ^{more rapid} in years when wood storks bred successfully than in years when breeding was unsuccessful (Table 3). Before 1962,

Sentence
structure.

successful wood stork nesting was characterized by high drying rates late in the nesting season (Fig. ⁹ ~~8~~) which is the period of heaviest use of the Everglades by feeding storks. During this period, wood stork nesting was generally successful in high water years ~~(Table 1)~~ and unsuccessful in low water years (Table 1).

Changes in the manner and extent of surface water flow into the southern Everglades after 1961 (Fig. 4, 5), discussed in the next section, have affected wood stork nesting success. In the ² 11-year period after 1961, wood storks bred successfully in only 1963 and 1967. 1974?

Of the successful years, only 1963 had drying rates similar to successful years before 1962. The rates in 1967 were very different from other successful years. However, two unsuccessful years, 1962 and 1971, had drying rates which were similar to earlier successful years. Thus after 1962, the relationship between stork production and drying rates differed from the relationship that held prior to 1962.

_____ . This implies that the entire system was changed after 1962, ^{this} can also be seen in the relationship between drying rates and month of nesting (Fig. ⁸ 9).

_____ After 1962, higher early drying rates were correlated with early nesting. Before 1962 this relationship did not hold.

Whereas water conditions which produced successful wood stork

nesting before 1962 were relatively straight-forward, (high water levels, and ^{high discharge} high late drying rate) conditions producing successful nesting after 1962 were not. After 1962, nesting was successful in low water years one of which had highly atypical drying rates.

It is apparent from Fig. 6 that nesting failure after 1962 was ^{in part} associated with late colony formation which did not allow sufficient time prior to the onset of the rainy season, ^{and therefore that} A major requirement for successful wood stork nesting is early colony formation. Historically no nesting ^{that} began after December has succeeded although, based on the length of the nesting period, colonies formed as late as the end of January could theoretically succeed. The factors affecting early nesting are not certain, ^{but} The correlation between high early drying rates in Shark River Slough and early nesting (Fig. 8) is compelling. However, this relation is meaningful only ^{insofar} ~~in as far~~ as the data from the slough reflects conditions throughout southern Florida, since storks are not utilizing the slough ^{during} ~~through~~ most of the period measured by early drying rates. It is not unreasonable to presume that hydrologic conditions throughout southern Florida are generally similar and can be approximated by conditions in the southern Everglades.

Delay in colony formation is undoubtedly due to failure to attain a suitable nutritional state because food serves as the proximate stimulus in initiating nesting (Kahl 1964). If colonies

are to form as early as November, storks must begin nesting soon after they arrive in southern Florida. Either a suboptimal nutritional state on arrival, failure to obtain enough food in November-January, or both, are the proximate causes of delayed nesting. More information on the food ecology of wood storks on their summering grounds and immediately after arrival in southern Florida is clearly ~~indicated~~ ^{needed}.

Relation of Wood Storks to Water Supplies

Water conditions and wood stork nesting success in the Everglades after 1962 are summarized as follows. From 1962 to 1965 surface water flow was low due to reduction of discharge. This occurred during dry years and consequently annual flows did not differ from similar drought years prior to the closure of the ^{southside of Conservation Area 3} ~~the~~ [^]. In fact wood storks bred successfully in one of these years (1963) in which drying rates were similar to pre closure years of successful breeding (Fig. 10). What was unusual is that these conditions occurred in a low water year.

Discharge to the Shark ^{River Slough increased} ~~^~~ after 1965. However the distribution of flow differed from past years because surface water was diverted into the central Shark River Slough (Fig 4).

In 1966, 1968, 1969, ^{and 1973} ~~and~~ 1970, this flow exceeded what would have occurred under natural conditions (Fig. 5), and in each of these years wood storks failed. Wood storks succeeded in 1967 and had low production in 1971 and 1972. The annual surface flow in each of these three years was similar to what would ^{have been} ~~be~~ expected under noncontrolled conditions (Fig. 5).

Water levels and drying rates are determined by the amount of surface water discharge and its timing. Decreased drying rates

can be caused by the continuation of excess flow into the dry season when water levels would otherwise be dropping. The correlation of high drying rates to wood stork production suggests the importance of the timing of discharge as well as the amount.

That the rate of water level recession and not absolute water level is important in the Everglades is somewhat unexpected in light of the findings of Kahl (1964) and Kushlan (1972) ~~in~~ that, in the Big Cypress Swamp, wood stork nesting and feeding of wading birds on concentrated fish stocks both occur at specific water levels when fish become accessible. The difference between the Everglades and Big Cypress Swamp is probably due to the nature of fish concentration in the two areas. In the Big Cypress Swamp fish become concentrated in highly localized and relatively small depressions where feeding is dependent upon the water becoming shallow enough for wading. In the Everglades, fish are concentrated along a drying edge in broad gently sloping marshes making a continual supply of food available along a gradient over a range of falling water levels.

If fish move long distances in front of the drying edge of the marshes, levees along the north edge of the upper slough and along the east boundary of the park (Fig 2) may have affected wading birds ^{by cutting off fish movement}. Under pre-levee conditions much of the Everglades north and east of Everglades National Park undoubtedly served as a tributary area for central Shark River Slough in that food organisms from these areas probably moved toward the

slough as water levels fell. The recent phenomenon of wood storks feeding in Water Conservation Area 3 is probably attributable to the levee artificially concentrating fish.

An additional aspect of water supply is its effect on the fish populations which are the important intermediate links in the Everglades food chain. The extended high water period from 1968 through 1970 (Fig. 1¹)

led to a 47 percent decline in Fish Abundance from the first to the third summer (Table 5). It is possible that the nesting failure of 1971 may have involved the low density of fish.

Wood Stork as an Indicator of Ecological Stability

Since the early 1960's, the population of wood storks breeding in the southern Everglades has experienced a drastic decline in nesting success and, as a result, a marked decrease in numbers

reaching an especially critical point by the early 1970's. By 1972

~~The population numbered~~
only 1,800 birds

down from tens of thousands ~~to~~ ^{from} its height.

It is necessary to understand the factors involved in successful reproduction of wood storks not only because the species is endangered in southern Florida but because its extreme dependence on concentrated fish and declining water levels makes it an indicator of the ecological stability and natural functioning of the southern Everglades. The stork's dependence on narrow water level and food relations is greater only by degree than that of several other once-abundant species of ciconiiforms (snowy egret, common egret, white ibis) ^{which} comprise an important segment of the dominant carnivore trophic level in the Everglades and are essential to the proper functioning of the unique wetland ecosystems of southern Florida.

Analysis of the factors leading to unsuccessful nesting of wood storks in the southern Everglades is complicated because the population decline coincided with

WATER CONTROL, URBAN EXPANSION INTO PERIPHERAL
WETLANDS AND WATER MANAGEMENT. Same?

There is little doubt that drainage and loss of habitat coincided with and impelled the decline of all southern

Florida wading bird populations after the 1930's when nesting colonies exceeded one million birds. It is this loss of habitat that also makes management of present wetlands difficult in terms of remnant populations of these dominant carnivores. Loss of peripheral, higher marshes, particularly along the developed Florida east coast (Fig. 1) decreased feeding areas utilizable when water levels in the Everglades are too high for effective feeding and also decreased ^{the} tributary area of regions such as Shark River Slough. If our hypothesis that fish move long distances during periods of lowering water level is correct, loss of tributary areas decreases the food available during the dry season in Shark River Slough.

The extremely sensitive food-water level-breeding relation of the wood stork makes it, a priori, the indicator species for the Everglades. However, its recent history suggests that under present conditions the species ^{MAY BE} ill-adapted for survival. Certainly loss of habitat has irrevocably altered the natural system to which it was adapted. Management, especially water management, in an attempt to supply habitat conditions for the most sensitive of the wading birds is ecologically sensible and recommended. It is possible, however, that present conditions may depart too greatly from the natural system to which the wood stork was adapted for the species to ~~be capable of~~ supporting a stable population. The resolution of this question must await more detailed study of whether supplying proper water conditions is sufficient to bring about successful nesting.

Sentinel
Struct.

ACKNOWLEDGMENTS

We wish to Acknowledge
The contributions of two colleagues who initiated this study and saw it through its early stages - Dr. W. B. Robertson, Jr. and Dr. M. C. Kolipinski. Dr. Robertson was responsible for beginning the study of wood storks in Everglades National Park and has contributed his hard-earned data, valuable suggestions and interest to the continuing study. Dr. Kolipinski was responsible for setting up the fish sampling program and establishing preliminary methods of data analysis. We thank G. Davis, R. Hermance, ^{H. Klein} B. F. McPherson, F. Nix, O. T. Owre, T. Schmidt, L. A. Purkerson and W. B. Robertson, Jr. for their most helpful and constructive criticism of earlier drafts of this paper. We also wish to thank the ranger division of Everglades National Park for supplying logistical support under various adverse circumstances.

Table 1. Water conditions and nesting success of wood storks
in the southern Everglades 1953-72.

Year of Nesting	Nesting Success ¹	General Water Conditions	
		Water Level	Discharge
1953	+	High	High
1954	+	High	High
1955	+	High	High
1956	-	Low	Low
1957	-	Low	Low
1958	-	High	High
1959	+	High	High
1960	+	High	High
1961	+	High	High
1962	-	Low	Low
1963	+	Low	Low
1964	-	Low	Low
1965	-	Low	Low
1966	-	Low	Low
1967	+	~~High~~ Low	High
1968	-	Low	Low
1969	-	High	High
1970	-	High	High
1971	-	Low	High
1972	-	Low	High
1973	-	High	High

1. + = successful nesting season,
- = unsuccessful nesting season

Table 2. Effect of short-term rises in water level on wood stork nesting 1953-73.

Magnitude of the short-term rise	Reaction of nesting storks	Number of short-term water-level rises occurring in the:			
		First month of nesting	Second month of nesting	Third month of nesting	Fourth month of nesting
Less than 3 cm	desertion	0	0	0	0
	no desertion	4	1	1	1
	desertion	1	13	0	0
Greater than or equal to 3 cm	desertion	0	0	0	0
	no desertion	0	0	3	0

Table 3. Drying rates in years of successful and unsuccessful

wood stork nesting

	Number of years	Average early drying rate Nov-Jan (cm/day)	Average late drying rate Jan-Mar (cm/day)	Overall Average* drying rate Nov-Mar (cm/day)
High water successful	7	.23	.20	.22)
Low water successful	1	.24	.15	.20)
Low water unsuccessful	9	.14	.14	.14)
High water unsuccessful	3	.15	.003	.08)
				.22**
				.12

* calculated by $\frac{(\text{Nov-Jan}) + (\text{Jan-Mar})}{2}$

** significantly different (t test, $P < 0.01$)

Table 4. Water depth at peak fish density in
Southern Everglades marshes

Date	Depth at Trap site (m)
11 Jan 1967	0.24
7 Dec 1967	0.28
6 Feb 1969	0.31
24 Feb 1971	0.27
22 Feb 1972	0.28
MEAN	0.28

Table 5. Density of fish in southern Everglades during summers ^{of} similar water depth.

Summer	Water Depth at traps (m)	Density (fish/m ²)
Aug 1966	0.68	8.9
Aug 1968	0.78	7.6
Aug 1969	0.73	5.9
Aug 1970	0.63	4.0

LAKE OKEECHOBEE

AGRICULTURAL LAND

WATER CONSERVATION AREA

BIG CYPRESS SWAMP

URBANIZED
FLORIDA
EAST
COAST

SHARK RIVER SCOUR

EVERGLADES
NATIONAL
PARK

Intake Manway
21/21

BROWARD RIVER

SHARK RIVER

22 March 1973

NASA ERTS E-1242
15240

Figure 1.--Physiographic and geographical locations in southern
Florida. Imagery
Technology Satellite.
by Earth Resources

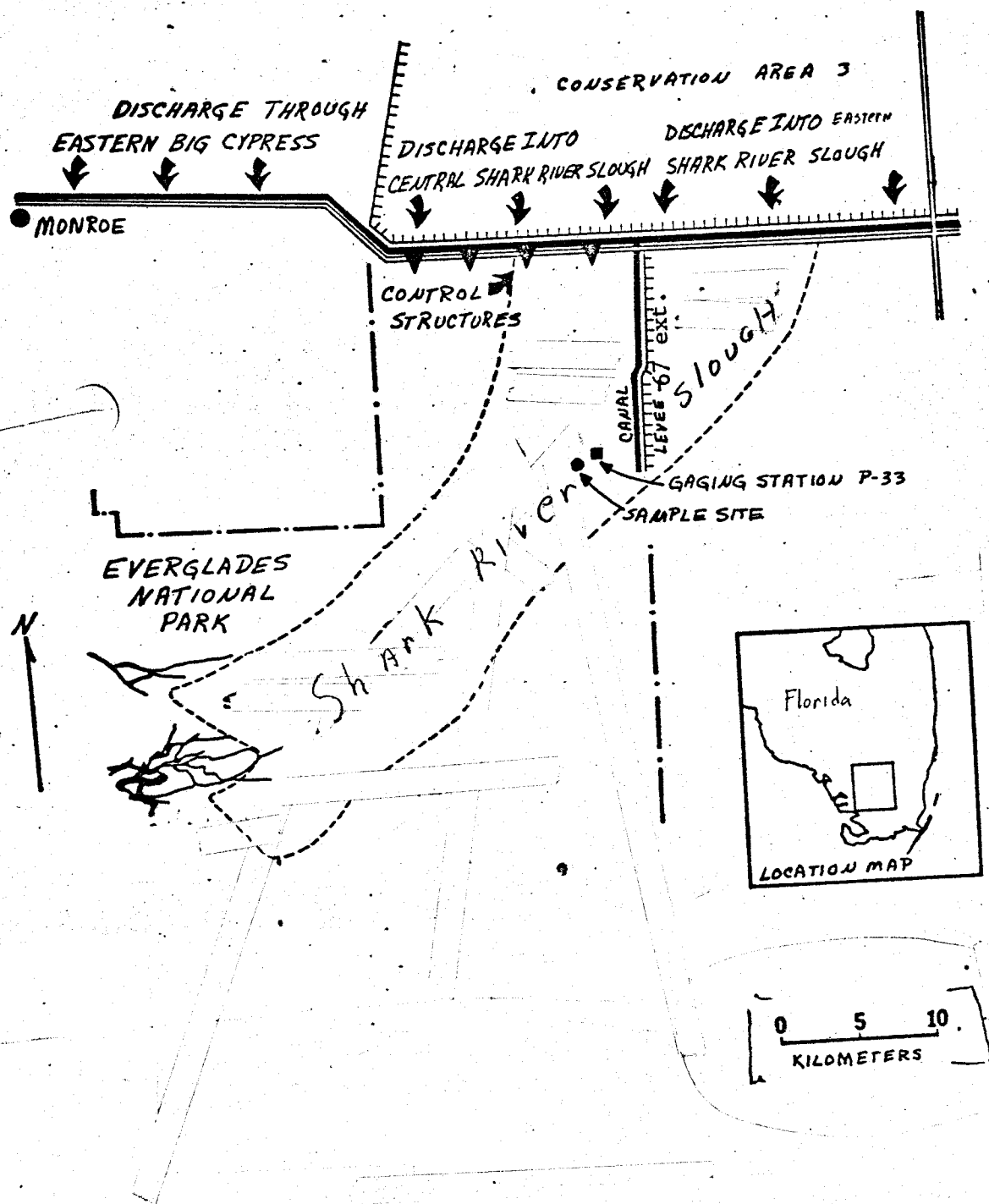


Figure 2.--Location map of the southern Everglades

- ① TREE ISLAND
- ② MIXED MARSH
- ③ SAWGRASS
- ④ RIVER-BANK FOREST

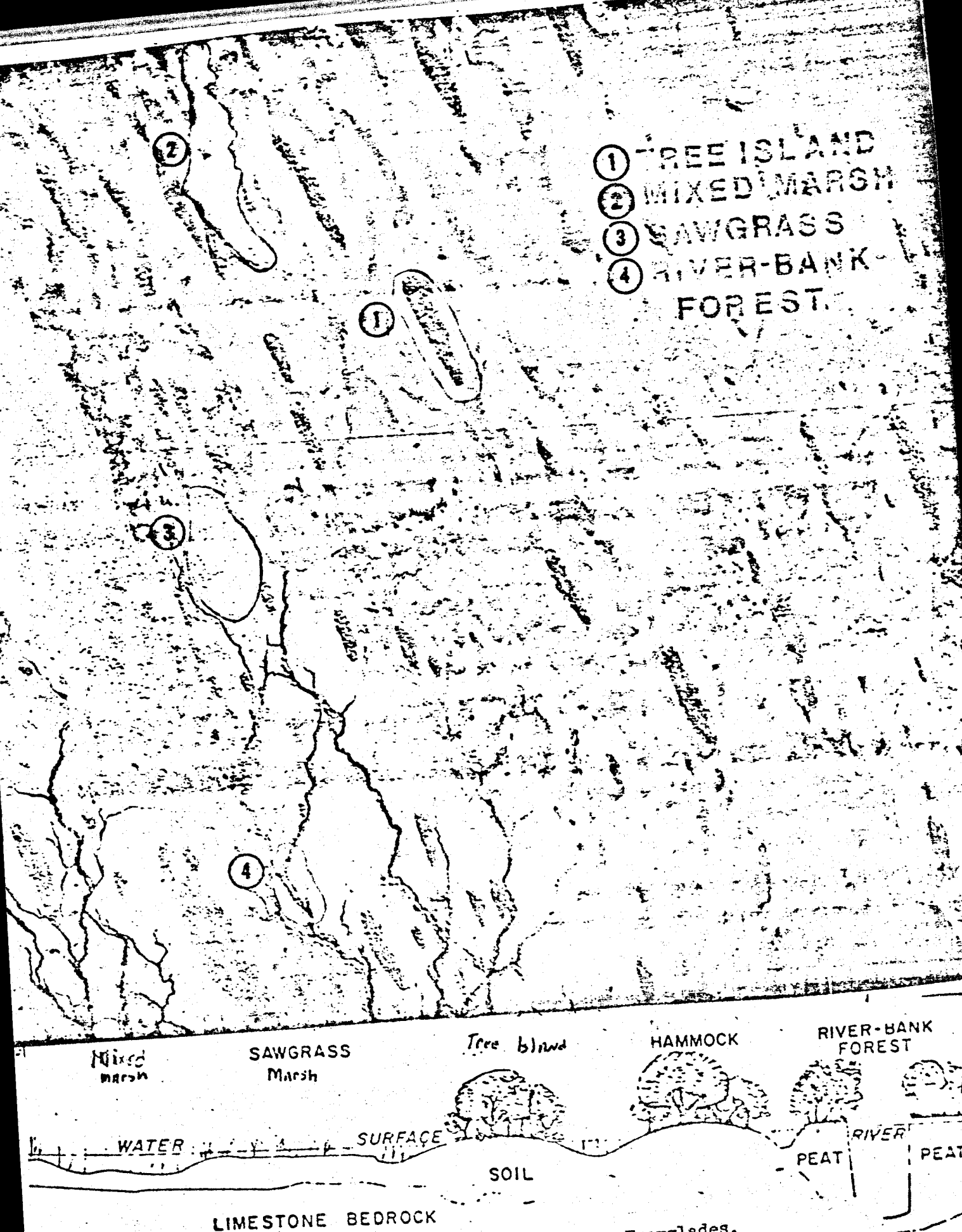


Figure 3.--Plant communities of the southern Everglades.

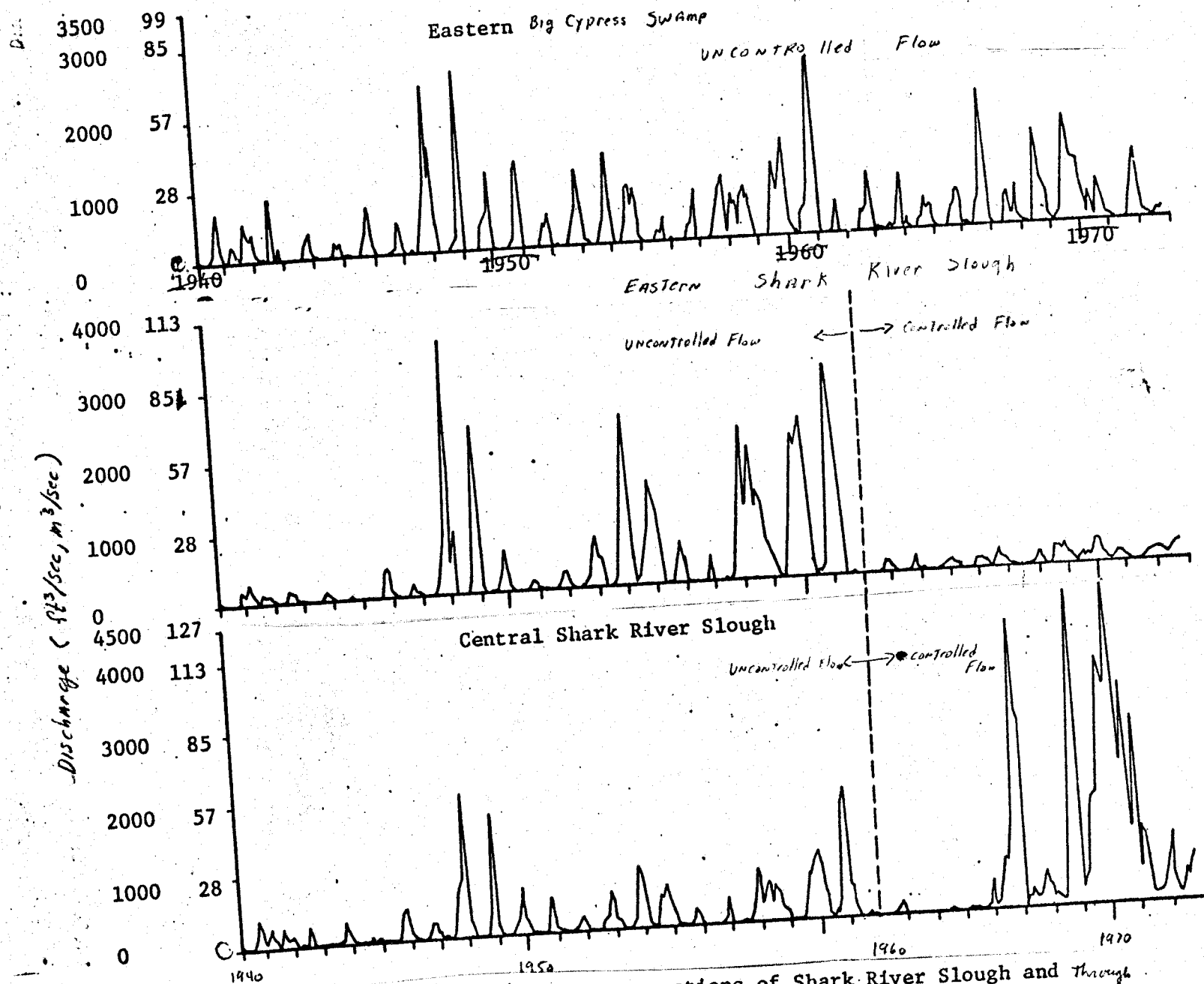


Figure 4.--Surface-water flow into two sections of Shark River Slough and through from the eastern Big Cypress Swamp.

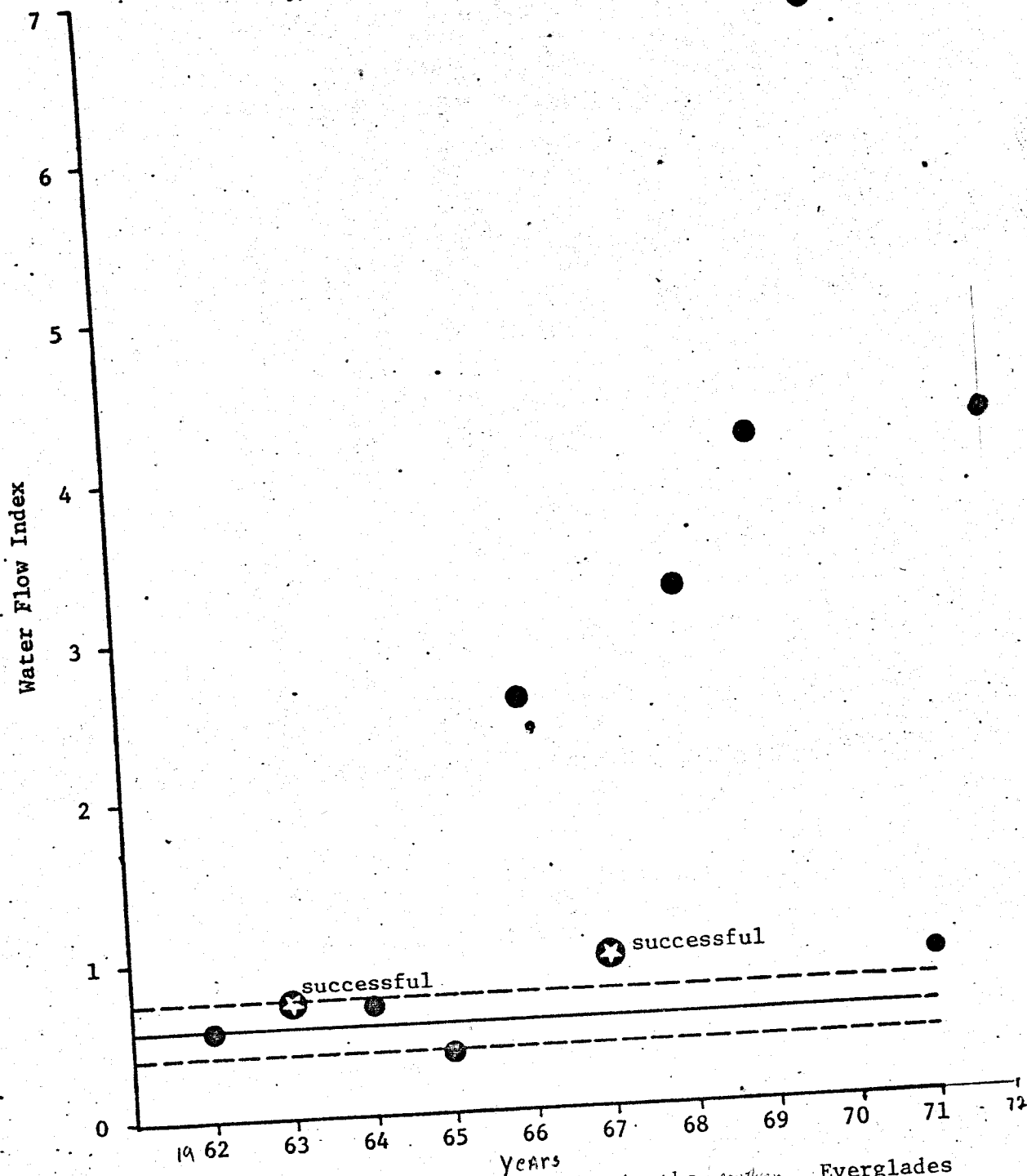


Figure 5.--Deviation from natural flow in the *southern* Everglades 1962-72 based upon water flow index (discharge central slough/discharge eastern Big Cypress Swamp). The average index for 1953-61 (0.58) is indicated by a solid line and the standard deviation (± 0.17) is indicated by dashed lines.

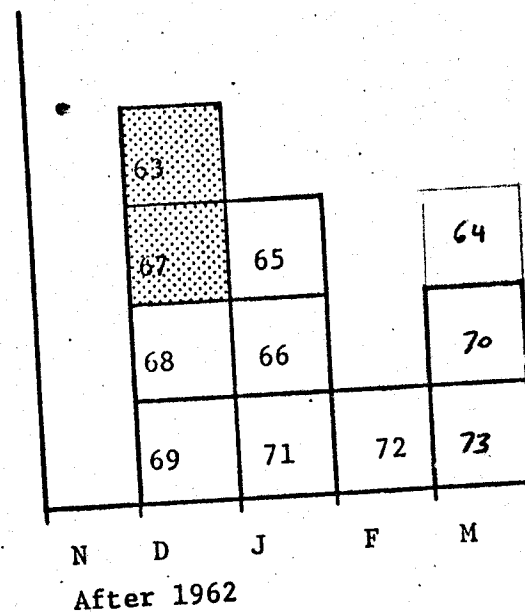
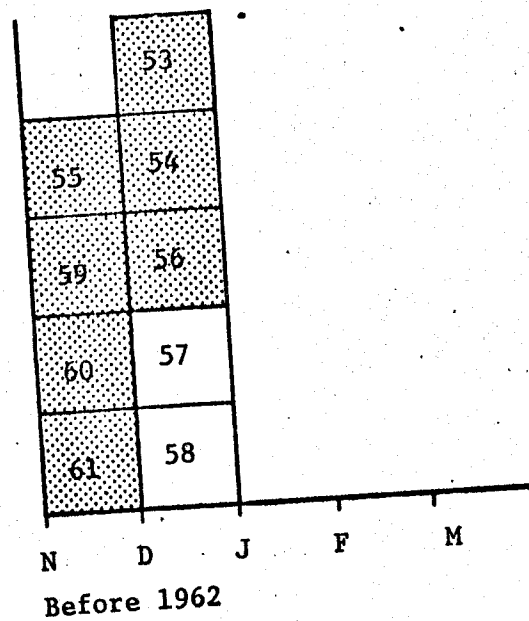


Figure 6.--Month when wood stork colonies formed in the southern Everglades 1953-197³.
 Years of successful nesting are stippled. No wood stork colonies formed in 1962.

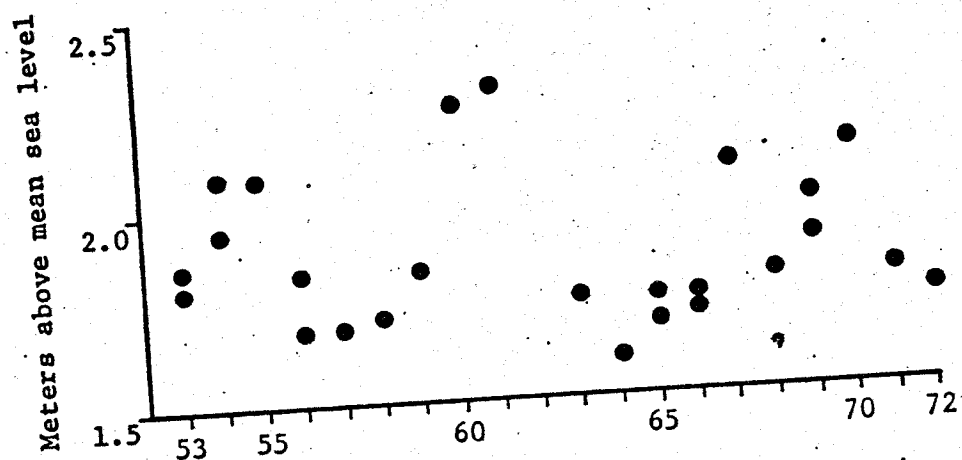


Figure 7.--Water level at P-33 in southern Everglades during formation of wood stork colonies.

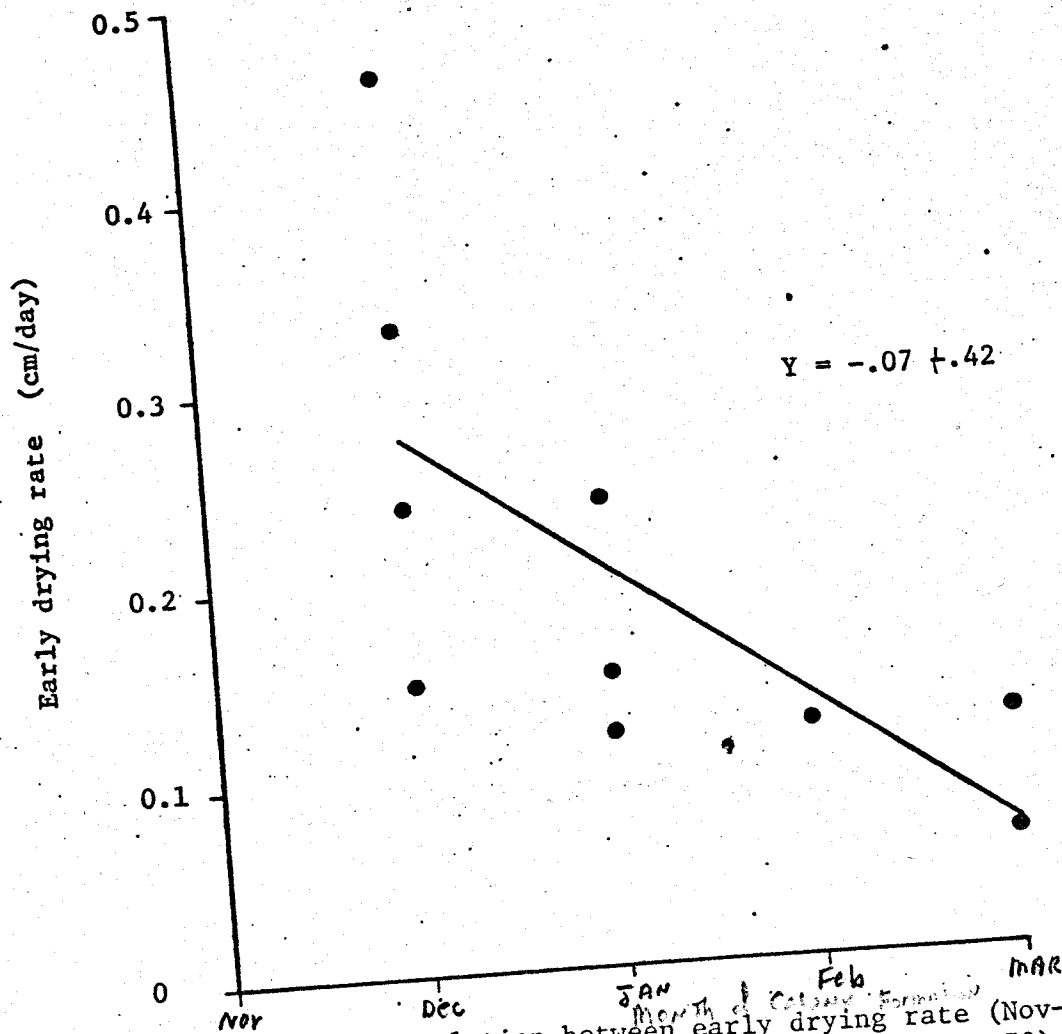


Figure 8.-- The relation between early drying rate (Nov-Jan) in Shark River Slough and the months (1963-72) in which wood storks nesting colonies were formed.

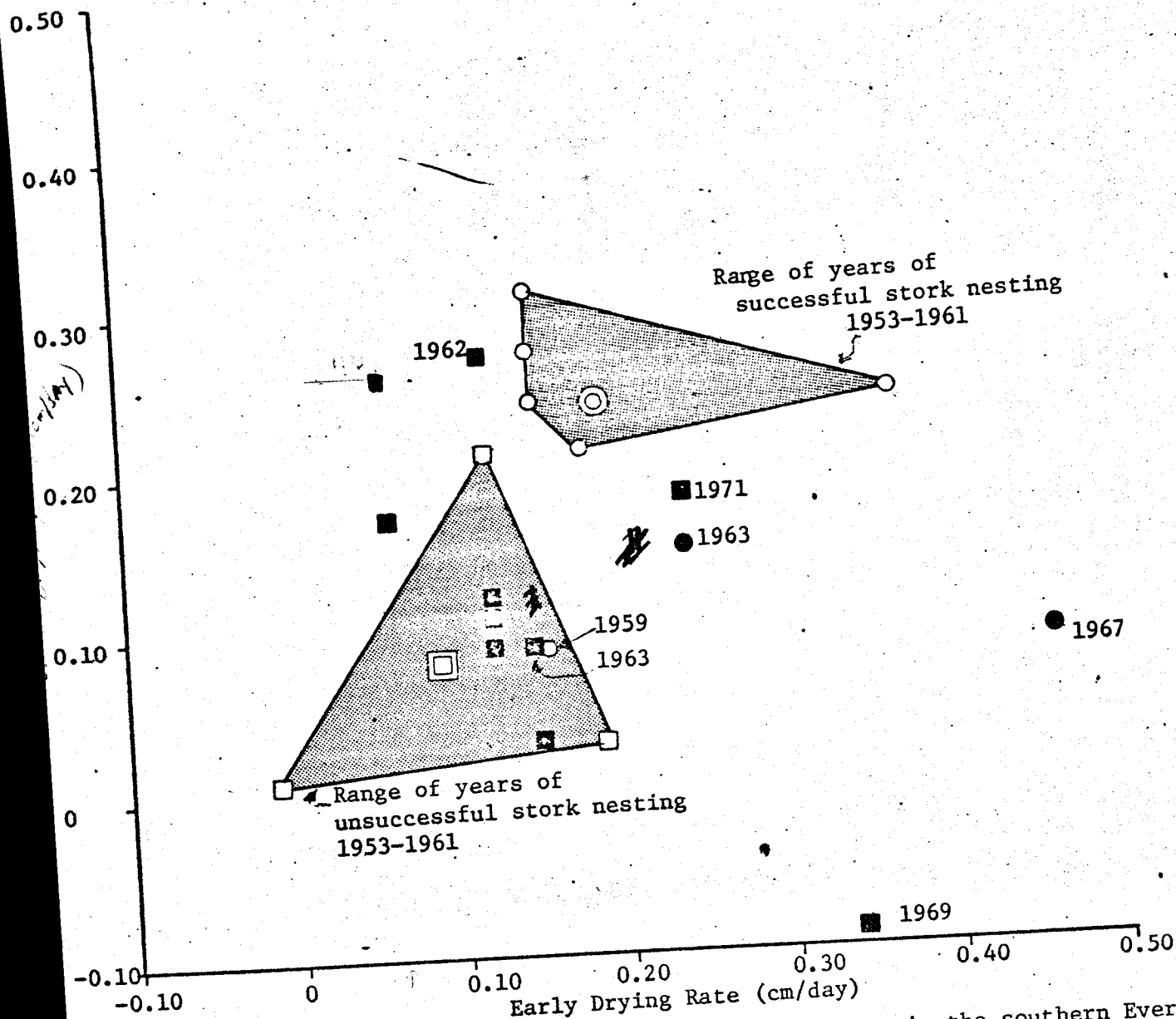


Figure 9. —The relation between early and late drying rates in the southern Everglades. The derivation of these rates is explained in the text. Drying rates in years of successful wood stork nesting are shown in circles, years of unsuccessful nesting as squares. Open symbols are those for the years 1953-61, prior to completion of levees. Closed symbols are those for the years 1962-72. The averages for each group before 1962 are shown in double symbols. The shaded polygons represent the range of variation of successful and unsuccessful years before 1962.

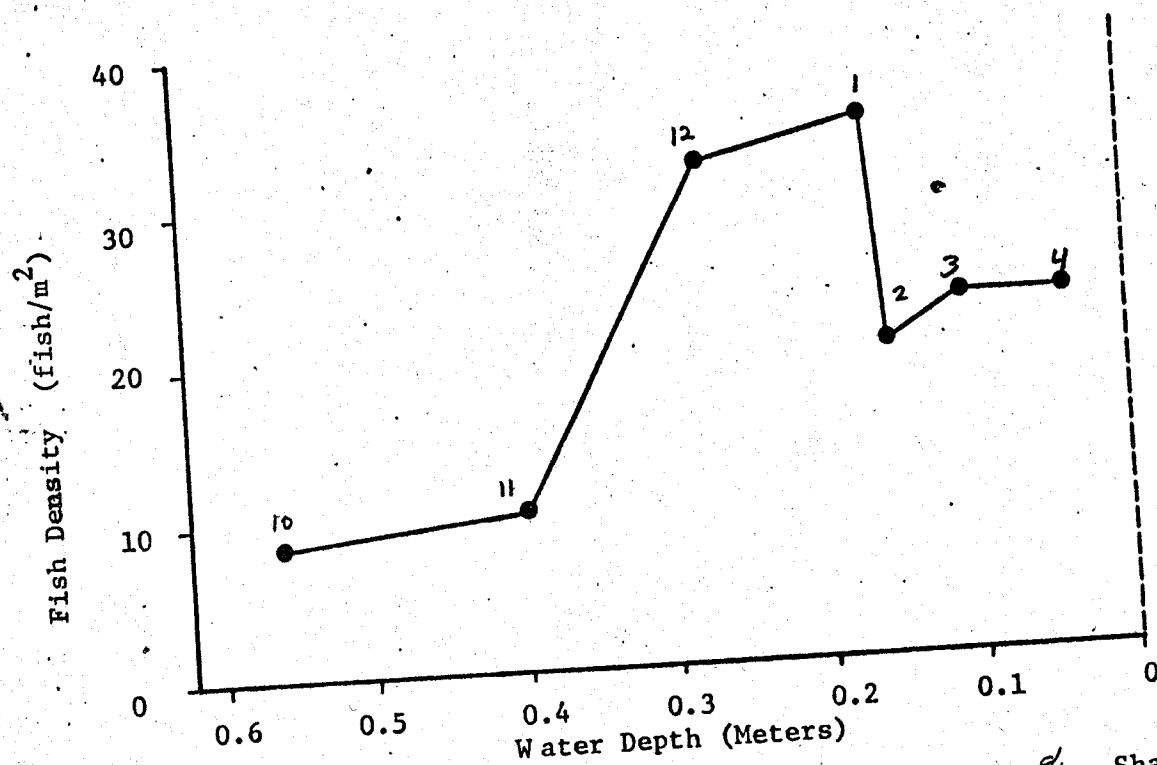


Figure 10. --Relation between fish density in the marshes ² Shark River Slough and water level, October 1966 to April 1967. Numbers at data points indicate month of datum.

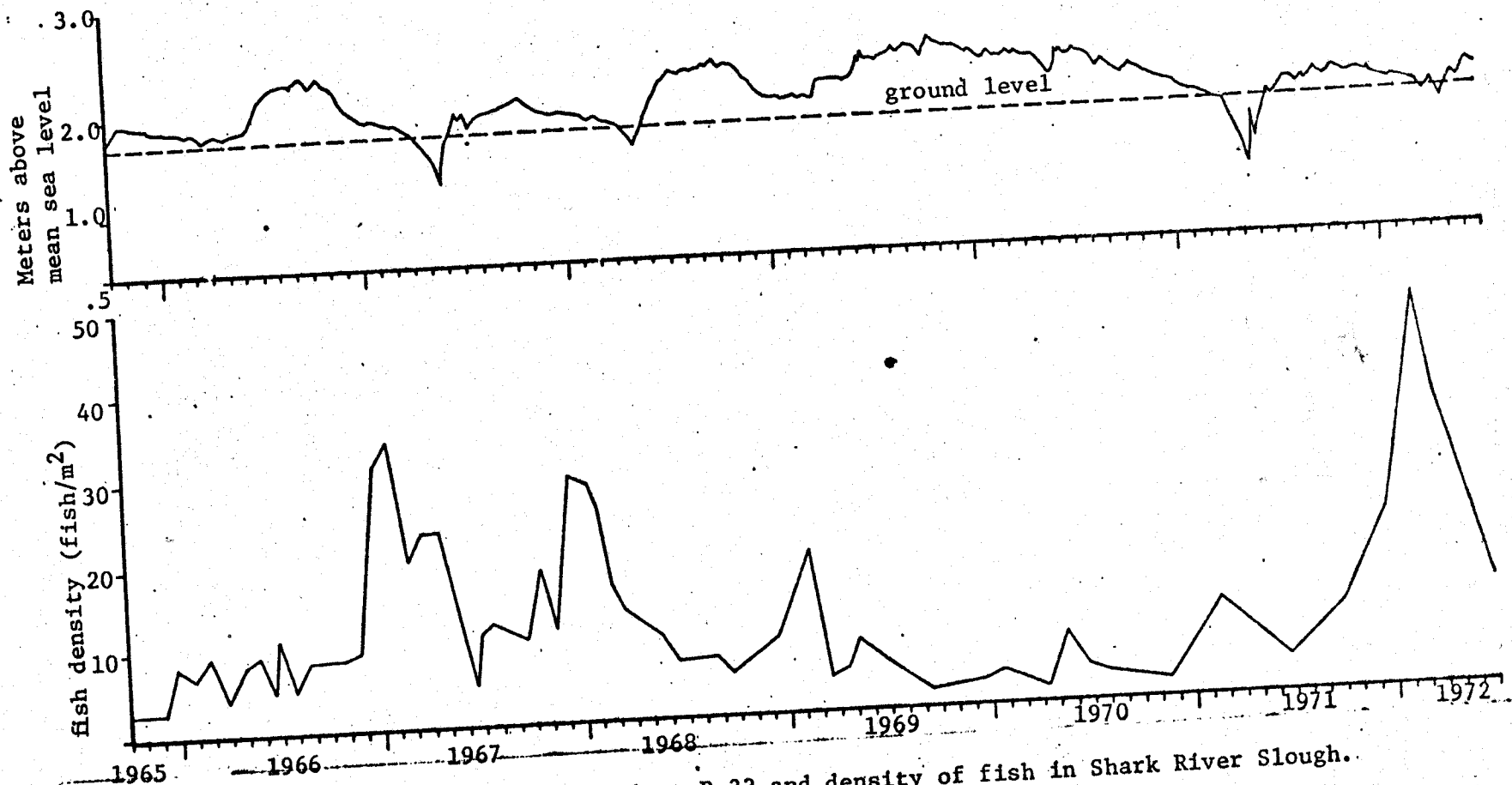


Figure 11.--Fluctuations of water level at P-33 and density of fish in Shark River Slough.

LITERATURE CITED

- Craighead, F. C. Sr., 1971. The trees of south Florida, Vol. 1
The natural environments and their succession. Univ. Miami
Press, Coral Gables, Fla.
- Davis, J. H. Jr., 1943. The natural features of southern Florida
Fla. Geological Survey Bulletin 25.
- Higer, A. L., and M. C. Kolipinski 1967. Pull-up Trap: A
quantitative device for sampling shallow-water animals. Ecology
48: 1008-1009.
- Holt, E. G. 1933. Report of Ernest G. Holt, Director of Sanctuaries.
Bird Lore 35: 371.
- Kahl, M. P., 1964. Food ecology of the wood stork (Mycteria americana)
in Florida. Ecol. Monogr 34: 97-117.
- Klein, H., W. J. Schneider, B. F. McPherson, and T. J. Buchanan, 1970.
Some hydrologic and biologic aspects of the Big Cypress Swamp
drainage area, southern Florida. U. S. Geological Survey. Open
file report. Tallahassee, Fla.
- Kolipinski, M. C. and A. L. Higer, 1969. Some aspects of the quantity
and quality of water on biological communities in Everglades
National Park. U. S. Geological Survey Open-file report.
Tallahassee, Fla.
- Kushlan, J. A., 1972. An ecological study of an alligator pond in
the Big Cypress Swamp of southern Florida. M.S. thesis,
University of Miami, Coral Gables, Fla.

1974. Quantitative sampling of fish populations in shallow, freshwater environments. Trans. Am. Fish. Soc. 103:348-352.

Leach, S. D., H. Klein and E. R. Hampton 197². Hydrologic effects of water control and management of southeastern Florida. U. S. Florida Geol. Survey, Rept. Inv. 60.

Long, R. W. and O. Lakela, 1971. A flora of tropical Florida. Univ. of Miami Press, Coral Gables, Fla.

Loveless, C. M., 1959. A study of the vegetation of the Florida Everglades. Ecology 40: 1-9.

Palmer, R. S., 1962. Handbook of North American birds. Yale Univ. Press, New Haven, Conn.

Robertson, V. B. Jr. 1964. Freshwater supply and the nesting of Wood Ibis in the southern Everglades. U.S. Natl. Park Service Rpt. 2 p. mimeo.