Wildl. Soc. Bull. 13:262–273, 1985

NIGHT COUNTS AS AN INDEX OF AMERICAN ALLIGATOR POPULATION TRENDS[1]

JOHN M. WOOD,[2] *Florida Cooperative Fish and Wildlife Research Unit, and Department of Wildlife and Range Sciences, University of Florida, Gainesville, FL 32611*

ALLAN R. WOODWARD, *Wildlife Research Laboratory, Florida Game and Fresh Water Fish Commission, 4005 S. Main Street, Gainesville, FL 32601*

STEPHEN R. HUMPHREY, *Florida State Museum, and Department of Wildlife and Range Sciences, University of Florida, Gainesville, FL 32611*

TOMMY C. HINES, *Wildlife Research Laboratory, Florida Game and Fresh Water Fish Commission, 4005 S. Main Street, Gainesville, FL 32601*

American alligator (*Alligator mississipiensis*) populations in southeastern states have undergone a classical cycle of rangewide decline, protection, and increase (Hines 1979, Chabreck 1980). However, in Florida, knowledge of the cycle was based on indirect indicators of population status, such as hide sale volumes, nuisance alligator complaints, and rate of habitat loss (Hines 1979). In 1971, the Alligator Recovery Team proposed that night counts be used as an index of population trends in different parts of the alligator's range (Chabreck 1976) and to provide objective evidence

---

[1] Contribution No. 6353 of the Journal Series, Florida Agricultural Experiment Station, Gainesville 32611.

[2] Present address: Florida Game and Fresh Water Fish Commission, 3991 SE 27th Court, Okeechobee, FL 33474.

for federal or provincial status designations. The proposal called for southeastern wildlife agencies to establish transects throughout suitable alligator habitat, conduct 1 survey/year/transect, and inventory the broadest possible array of wetland types within the limits of personnel and budgets.

Based on the same principles as roadside counts, transects are frequently used because large areas may be quickly and easily traversed (Overton 1971:424). Although night counts are inferior to direct population estimates, the former are the simplest and most economical way of obtaining an index of the relative size of a population (Overton 1971: 424) in heterogeneous habitat. The accuracy of night-count indices is only 20–25% of true population means (Taylor and Neal 1984:316–317).

Several sources of variability associated with precision of the night-count index have been documented. Chabreck (1966) pointed out that route selection, time of year, and skill of observer may have affected the precision of indices on marsh refuges in southwestern Louisiana. Murphy (1977) demonstrated that indices were positively correlated with water temperature in a thermally altered reservoir in South Carolina. Woodward and Marion (1978) found that indices on a lake in north central Florida also were affected seasonally by water temperature, as well as by water levels and behavior patterns.

This research determined whether trends in alligator populations could be monitored statewide using night-count indices collected once a year, and suggested ways to increase precision of the indices by identifying sources of variation that should be controlled when monitoring trends in the future.

METHODS

Source of Data

Biologists with the Florida Game and Fresh Water Fish Commission conducted night counts of alligators in Florida from 1971 to 1982. Survey routes ranging from 1.3 to 52.5 km in length were established in several habitat types: 40 on lakes or ponds, 21 on rivers or creeks, 14 on canals, 2 on abandoned phosphate surface mines, and 1 on an estuary. Lengths of survey routes were estimated from maps traced onto U.S. Geological Survey (USGS) 7.5-min quadrangles and measured with a cartometer. Water levels in the lakes, rivers, and canals were obtained from readings at local or nearby gauging stations (U.S. Geol. Surv. 1971–1982). The indices of alligator population size were determined by dividing the number of alligators observed by the length (km) of the survey route. The quotient of alligators observed during the survey, including alligators of undetermined length and the survey route length, was defined as total alligators/km. Additionally, 4 subsets of the total count, excluding alligators of undetermined length, were used to analyze indices in 4 size-classes. These subsets were defined as <0.9-m alligators/km, 0.9–1.8-m alligators/km, >1.8-m alligators/km, and >0.9-m alligators/km, respectively.

Night counts were conducted from an airboat or outboard-motor boat along an unbounded transect, which normally skirted the open-water/shoreline vegetation interface (Woodward and Marion 1978). Barring personnel and mechanical failures, boat and observer were assigned the same survey routes each year. Generally, each survey route was sampled 1 night/year between May and October. Some survey routes were established in 1971, whereas others were first sampled in 1981. Consequently, the total number of samples collected for any 1 route varied from 1 to 13.

Statewide Trends

The effect of water level on indices had to be quantified in order to extend the considerations raised by Woodward and Marion (1978) to the statewide survey data and still examine year-to-year trends. These trends were examined by determining the relationship between change in alligators per kilometer and change in water level occurring between any 2 consecutive years (i.e., by comparing the alligators per kilometer observed in year $= i$ vs. alligators per kilometer observed in year $= i - 1$ with water level in year $= i$ vs. water level in year $= i - 1$). Chi-square contingency tests (PROC FREQ in SAS, Helwig and Council 1979) were used to evaluate trends statistically. Chi-square was chosen over a more robust method because we could not determine a direct way to compare numerically similar changes in water level on physically dissimilar water bodies. The Phi coefficient, ranging from 0 (complete independence) to ± 1 (complete association) for 2×2 contingency tables (Hays and Winkler 1970:206), was used to measure the strength of the relationship between trends in water levels and indices. Frequencies were summed for all i vs. $i - 1$ comparisons within each survey route and grouped into 4 categories:

Alligators/km	Water level
$i > i - 1$	$i > i - 1$
$i > i - 1$	$i < i - 1$
$i < i - 1$	$i > i - 1$
$i < i - 1$	$i < i - 1$

Summary statistics for the index were computed for total alligators per kilometer and the 4 size-classes. Pearson product-moment correlations (PROC CORR in SAS) between total alligators/km and water levels on individual survey routes were displayed graphically to substantiate or refute Chi-square results when at least 6 years of data were available at 1 site.

Sources of Variation

We characterized the relationship between environmental factors and indices by examining the effects of discrete variables, such as habitat type and physiography on indices, and the effects of continuous variables, such as the percentage of the survey route adjacent to wetland habitat and water quality parameters. Only lake indices were used in the latter analysis to reduce heterogeneity of error variance. Alligators-per-kilometer data were transformed ($Z = ln[X + 1]$) to further reduce heteroscedasticity and normalize the distribution of the indices.

Discrete Variables.—Survey routes were grouped according to habitat type (lake, river, canal, etc.), physiographic region (Canfield 1981:9–20), and surficial geology (Fla. Dep. Nat. Resour. 1978–1981). The Waller-Duncan k-ratio t test (PROC GLM in SAS) was used to test for significant differences among treatment means in a completely random design. A k-ratio of 100 was used, which corresponds approximately with the 5% probability level.

Continuous Variables.—One wetland system (Palustrine) and 3 classes within this system (Aquatic Bed, Emergent, and Forested/Scrub/Shrub) were identified on lake margins (Cowardin et al. 1979). Sections of survey routes with no wetland class between the open water and the shoreline were classified as "upland." The percentage of each survey route adjacent to these wetland classes was determined by tracing survey routes onto small-scale wetland maps of Florida (Natl. Wetlands Reconnaissance Surv. 1981–1982) with a cartometer.

Water quality parameters, measured from September 1979 to August 1980 by Canfield (1981), included total alkalinity (mg/l $CaCO_3$), specific conductance (μmhos/cm 25 C), total nitrogen (mg/m^3), total phosphorus (mg/m^3), chlorophyll a (mg/m^3), and color (mg/l Pt). All observations on a survey route were assigned the same value, the mean of the 1979–1980 sample values.

Shoreline development (SLD), an index of regularity of a shoreline, was calculated for all lakes as follows (Lind 1979):

$$\mathrm{SLD} = \frac{s}{2\sqrt{a\pi}}$$

where

s is the length of the shoreline

and

a is the area of the lake.

Measurements of lake areas were obtained from the Florida Board of Conservation (1969) and shoreline lengths were measured from USGS quadrangles with a cartometer.

Both the RSQUARE (see Mallows 1973) and STEPWISE (FORWARD option, SLENTRY = 0.05) procedures in SAS were used to evaluate multicollinearity and the significance of the independent variables. Either SAS variable-selection procedure by itself tends to be subjective, so subsequent multiple linear regression models (PROC GLM in SAS) included only those effects that contributed significantly ($P < 0.05$) to reductions in residual sums of squares. Regression coefficients indicated direction (positive or negative) of the relationship between dependent and independent

Table 1. Observed and (expected) number of surveys in year = i vs. year = $i - 1$ in which total indices and water levels either increased or decreased.[a]

Alligators/km	Water level: Increased	Water level: Decreased
Increased	32 (50.7)	74 (55.3)
Decreased	66 (47.3)	33 (51.7)

[a] $\chi^2 = 27.30$, $P < 0.01$, df = 1.

Table 2. Number of surveys sampled in year = i vs. year = $i - 1$ in which indices and water levels either increased or decreased.

Alligators/km		Water level: Increased	Water level: Decreased
Increased	1975 vs. 1974	2	1
	1976 vs. 1975	3	6
	1977 vs. 1976	0	21
	1978 vs. 1977	4	2
	1979 vs. 1978	8	7
	1980 vs. 1979	7	16
	1981 vs. 1980	1	21
	1982 vs. 1981	7	0
Decreased	1975 vs. 1974	0	1
	1976 vs. 1975	4	3
	1977 vs. 1976	0	3
	1978 vs. 1977	17	3
	1979 vs. 1978	12	4
	1980 vs. 1979	6	8
	1981 vs. 1980	2	11
	1982 vs. 1981	25	0

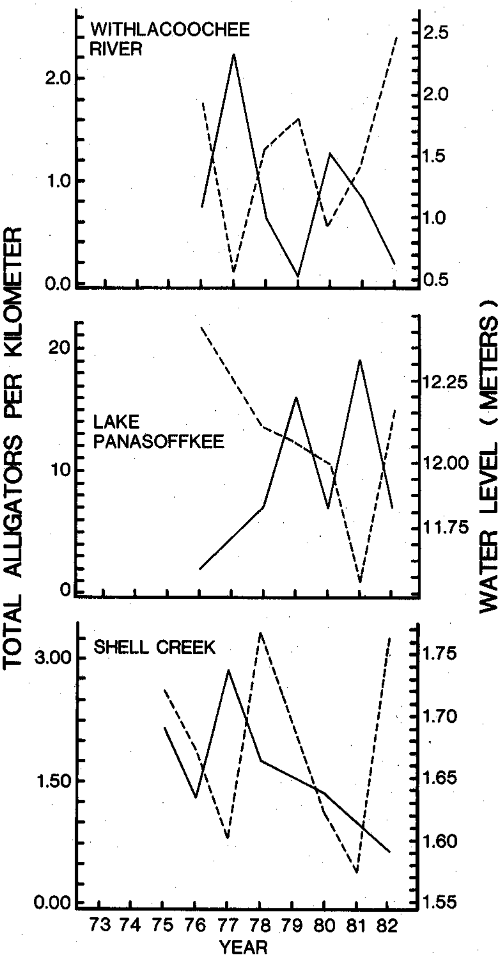

Fig. 1. Annual trends in total alligators per kilometer (solid line) and water level (dashed line) on the Withlacoochee River, Lake Panasoffkee, and Shell Creek.

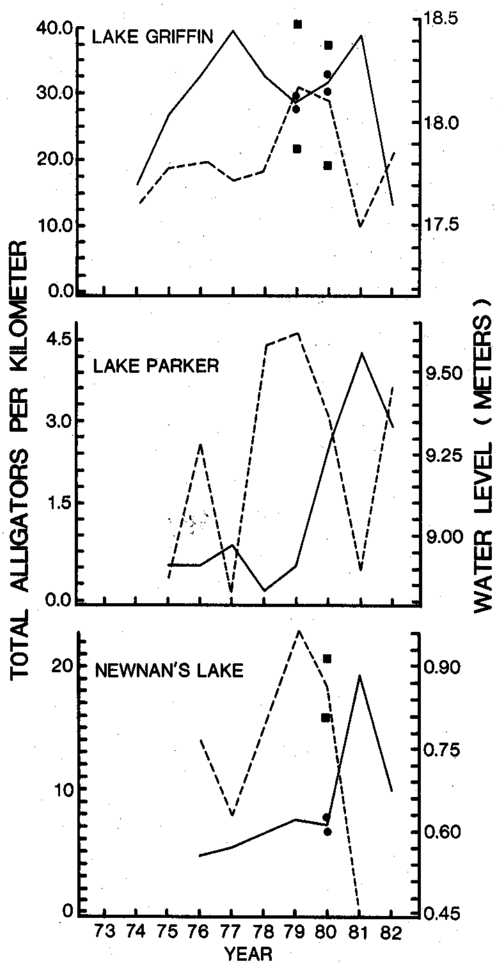

Fig. 2. Annual trends in total alligators per kilometer (solid line) and water level (dashed line) on Lake Griffin, Lake Parker, and Newnan's Lake. In the cases where alligators (circles) and water level (squares) were measured twice annually rather than once, the lines are drawn through the average values.

variables. The coefficient of determination (R^2) indicated the amount of variation in the dependent variable attributable to the independent variables in the model. Coefficients of partial determination (Neter and Wasserman 1974:265) were calculated to quantify the relative contribution of each independent variable to the reduction of residual sums of squares.

RESULTS AND DISCUSSION

Statewide Trends

Year-to-year changes in total alligators per kilometer were significantly ($P < 0.01$) affected by changes in water level (Table 1). Chi-square statistics also were significant ($P < 0.01$) for all 4 size-class indices. Phi coefficients indicated a negative relationship between indices and water level, and were -0.19, -0.28, -0.29, -0.29, and -0.37 for >1.8 m, >0.9 m, 0.9–1.8 m, <0.9 m, and total alligators per kilometer, respectively. Annual comparisons (Table 2) tended to support the overall results (Table 1). Total alligators per kilometer increased in 88% of the 1977 sur-

Table 3. Variation in alligators per kilometer among survey routes in Florida. Surveys were conducted annually, beginning in various years.

Survey route	County	n	$\bar{x}$	SD	95% CI
Lakes					
Lake Jackson	Highlands	6	0.26	0.14	0.12–0.41
Ocean Pond	Baker	9	0.61	0.29	0.39–0.84
Lake Tarpon	Pinellas	8	0.77	0.37	0.46–1.08
Santa Fe Lake	Alachua	2	0.80	0.08	0.04–1.56
Palestine Lake	Union	9	1.08	0.51	0.68–1.47
Lake Dora S.	Lake	1	1.27		
Lake Okeechobee at Belle Glade	Palm Beach	1	1.40		
Station Pond	Levy	8	1.47	1.23	0.44–2.50
Lake Parker	Polk	8	1.75	1.62	0.39–3.11
Lake Harris W.	Lake	1	1.93		
Lake Dora N.	Lake	1	1.94		
Doctor's Lake	Clay	3	2.67	0.17	2.25–3.09
Lochloosa Lake	Alachua	3	3.24	1.89	0.00–7.94
Lake Eustis	Lake	1	3.26		
St. Vincent Island	Gulf	1	3.48		
Lake Harris E.	Lake	1	3.60		
Lake Okeechobee at Okeechobee	Okeechobee	1	4.25		
Lake Iamonia	Leon	6	4.36	1.55	2.72–5.99
Lake Arbuckle	Polk	11	4.69	2.66	2.90–6.48
Lake Miccosukee	Jefferson	6	5.42	1.34	4.00–6.83
Rodman Reservoir	Marion	1	5.82		
Lake Maggiore	Pinellas	7	7.15	3.74	3.66–10.65
Lake Woodruff National Wildlife Refuge	Volusia	2	7.45	4.84	0.00–50.96
Lake Okeechobee at Moore Haven	Glades	1	7.55		
Lake Jessup S.E.	Seminole	3	8.39	2.22	2.87–13.90
Newnan's Lake	Alachua	7	8.77	4.94	4.14–13.39
Lake Jessup N.W.	Seminole	3	9.08	4.44	0.00–20.12
Lake Okeechobee at Clewiston	Hendry	2	9.37	8.24	0.00–83.45
Lake Griffin N.	Lake	2	9.57	0.79	2.45–16.69
Lake Wauberg	Alachua	6	9.70	5.73	3.69–15.72
Lake Panasoffkee	Sumter	6	9.70	6.38	3.00–16.40
Lake Eaton	Marion	3	10.27	5.72	0.00–24.48
Lake Alice	Alachua	3	13.21	8.65	0.00–34.70
P. G. Run of Orange Lake	Alachua	8	15.62	6.75	9.97–21.26
Lake Griffin E.	Lake	9	17.12	3.93	14.10–20.15
Lake Apopka E.	Orange	5	17.12	8.90	6.07–28.18
Orange Lake	Alachua	5	21.24	7.37	12.08–30.39
Lake Apopka S.W.	Lake	5	21.48	9.44	9.76–33.20
Lake Apopka N.W.	Lake	5	23.63	14.42	5.73–41.53
Lake Griffin W.	Lake	11	29.06	8.11	23.61–34.51
Creeks and rivers					
Chipola River	Calhoun	6	0.15	0.07	0.08–0.22
Escambia River	Escambia	4	0.31	0.10	0.15–0.46
Prairie Creek	Charlotte	6	0.61	0.65	0.00–1.29
Ochlockonee River	Liberty	5	0.66	0.57	0.00–1.37
Withlacoochee River S.	Hernando	7	0.86	0.74	0.17–1.55
Wimico Waterway	Gulf	8	0.93	0.47	0.53–1.32
Julington Creek	Duval	9	1.29	0.26	1.09–1.49

Table 3. (Continued.)

Survey route	County	n	$\bar{x}$	SD	95% CI
Waccasassa River and Bay	Levy	6	1.37	1.09	0.23–2.51
Kissimmee River Pool B	Highlands	5	1.55	1.00	0.31–2.79
Shell Creek	Charlotte	7	1.58	0.75	0.88–2.28
Bear Creek	Bay	9	1.88	0.47	1.51–2.24
N. Lake George and Little Lake George	Putnam	1	1.92		
Kissimmee River Pool A	Polk	5	1.93	2.05	0.00–4.47
Kissimmee River Pool D	Highlands	5	2.22	1.65	0.17–4.26
Kissimmee River Pool C	Highlands	5	2.30	1.55	0.38–4.22
Crystal River	Citrus	6	2.55	1.01	1.48–3.61
Kissimmee River Pool E	Highlands	5	2.95	1.02	1.68–4.22
Arbuckle Creek Marsh	Highlands	5	3.35	2.11	0.73–5.96
Withlacoochee River N.	Citrus	8	4.06	2.86	1.67–6.46
Paradise Run	Okeechobee	3	8.05	7.24	0.00–26.05
Salt Springs Run	Marion	1	12.85		
Canals					
Cape Coral	Lee	9	0.10	0.11	0.02–0.19
Port Charlotte	Charlotte	8	0.72	0.28	0.49–0.96
C-18 Canal	Palm Beach	7	1.32	0.78	0.60–2.05
L-8 Canal	Palm Beach	9	1.37	0.79	0.76–1.97
Kissimmee River Pool B	Highlands	5	1.42	0.55	0.74–2.10
Kissimmee River Pool D	Highlands	5	1.58	0.44	1.04–2.13
L-35B Canal, area 2A	Broward	8	2.09	0.79	1.43–2.75
Kissimmee River Pool A	Polk	5	2.44	1.94	0.03–4.85
Kissimmee River Pool C	Highlands	5	2.54	1.03	1.27–3.82
Fort Kissimmee	Highlands	9	2.67	1.31	1.67–3.68
L-67 Canal, area 3	Broward	8	2.93	0.91	2.17–3.69
Kissimmee River Pool E	Highlands	5	3.41	0.74	2.48–4.33
Miami Canal	Broward	13	5.38	3.71	3.14–7.62
L-39 Canal	Palm Beach	6	6.97	3.56	3.24–10.71
Abandoned phosphate surface mines					
Saddle Creek E.	Polk	7	2.25	2.09	0.30–4.21
Saddle Creek N.W.	Polk	5	2.77	2.58	0.00–5.96
Estuary					
Apalachicola Bay–East Bay area	Franklin	1	3.31		

veys when water levels were relatively low compared with 1976 (Table 2, 21 out of 24 surveys). All water level measurements obtained in 1982 were higher than in 1981, and 78% of the 1982 surveys had lower counts than did 1981 surveys. On the southern Withlacoochee River survey (Fig. 1), indices were correlated inversely ($r = -0.89$, $P < 0.01$, $n =$

7) with water levels. Conversely, alligators per kilometer and water levels on the Shell Creek survey (Fig. 1) were not correlated ($r = -0.18$, $P = 0.71$, $n = 7$). Indices followed a downward trend on Shell Creek from 1977 to 1982 despite variability in water levels among the surveys.

The negative correlation between indices and water levels suggests that alligators may have dispersed into adjacent wetland areas during periods of high water. However, dispersal may be related to accessibility and availability of wetlands. At Shell Creek, where there was no correlation, there is a narrow floodplain with little adjacent wetland (26% forested). There was a correlation on the Withlacoochee River surveys, where 70% of the survey route is bordered by a forested floodplain. Water level was not correlated with indices on the Newnan's Lake ($r = -0.65$, $P = 0.16$, $n = 6$), western Lake Griffin ($r = -0.01$, $P = 0.99$, $n = 11$), and Lake Parker ($r = -0.21$, $P = 0.62$, $n = 8$) survey routes; where replicated (i.e., measured twice annually), indices were similar even though water levels varied (Fig. 2). These 3 lakes occupy bowl-shaped depressions and have less extensive areas of wetlands on their borders than do some other lakes. More specifically, 75% of Newnan's Lake is surrounded by a narrow band of common baldcypress (*Taxodium distichum*) swamp between open water and upland; the western Lake Griffin survey route lacks wetland vegetation along 65% of its length; and <10% of the shoreline on the Lake Parker survey route is composed of wetlands. In contrast, Lake Panasoffkee occupies a saucer-shaped basin and has extensive emergent and wooded wetlands along 54 and 15%, respectively, of its shoreline. Total indices and water levels at this site (Fig. 1) were negatively correlated ($r = -0.84$, $P < 0.04$, $n = 6$), although this relationship did not hold in 1980, when high-wave action during the survey appeared to reduce observability of alligators.

Placement of transects relative to the adjacent shoreline or wetlands may thus influence the way water-level changes affect alligator indices. Alligators have access to more habitat and are less likely to be observed along a survey line when water levels rise above the shore of a saucer-shaped lake basin. In contrast, bowl-shaped lakes, such as Newnan's, Griffin, and Parker, have less adjacent wetland habitat into which alligators can disperse during periods of high water. However, we speculate that unusually high or low water levels (e.g., the low water levels during the summer of 1981) may affect alligator dispersal even on bowl-shaped lakes, where the area inundated increases abruptly when the water level exceeds a critical, but undetermined, elevation.

Variation among Survey Routes

Discrete Variables.—Means of total indices for each survey route (Table 3) indicate that there was considerable variation in indices among survey routes and between years on the same route. Lake surveys ($\bar{x} = 9.02$, SD = 9.57, $n = 181$) had higher indices than either canal or river surveys ($F = 50.88$, df = 396, LSD = 1.48, k-ratio = 100). Indices on rivers ($\bar{x} = 2.56$, SD = 2.30, $n = 116$) did not differ from those on canals ($\bar{x} = 1.97$, SD = 2.49, $n = 102$). These trends also were seen in all 4 size-classes.

Of the 15 lakes with the highest mean indices (Table 3), 11 were in the Central Valley physiographic region. However, this effect is not ubiquitous suggesting that other factors may affect indices within physiographic regions. For example, lakes Dora, Harris, and Lochloosa, also in the Central Valley, had lower-than-average indices, whereas many lakes from other physiographic regions had high indices.

The primary productivity of lakes in Florida is influenced by underlying geologic formations (Canfield 1981). Indices were rela-

Table 4. Factors significantly associated with variation in alligator population indices on 23 Florida lakes, 1974–1982 (n = 159). The coefficient of partial determination (r^2) measures the percentage reduction of residual error (SSE) in the full model attributable to that independent variable.

Alligators per kilometer	Source of variation[a]	df	F[b]	r^2
Total	SLD	1	50.13[c]	0.25
	N	1	147.92[c]	0.49
	PEM	1	24.58[c]	0.14
	Color	1	15.34[c]	0.09
<0.9 m	SLD	1	53.21[c]	0.26
	N	1	152.14[c]	0.50
	PEM	1	2.74	0.02
	Color	1	4.71[d]	0.03
0.9–1.8 m	SLD	1	18.63[c]	0.11
	N	1	51.88[c]	0.25
	PEM	1	42.39[c]	0.22
	Color	1	15.21[c]	0.09
>1.8 m	SLD	1	28.04[c]	0.15
	N	1	14.51[c]	0.09
	PEM	1	16.07[c]	0.09
	Color	1	2.27	0.01
>0.9 m	SLD	1	29.30[c]	0.16
	N	1	56.20[c]	0.28
	PEM	1	43.72[c]	0.22
	Color	1	14.23[c]	0.08

[a] SLD = shoreline development; N = total nitrogen (mg/m^3); PEM = percentage of Palustrine-Emergent wetland adjacent to the survey route; Color = (mg/l Pt).
[b] F-tests based on adjusted (Type IV) sums of squares.
[c] P < 0.01.
[d] P < 0.05.

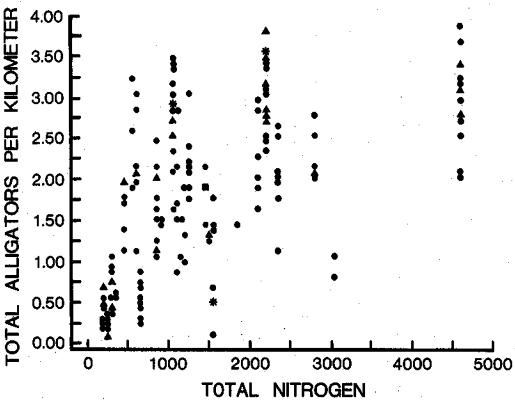

Fig. 3. Relationship between total alligator indices (transformed values, $Z = ln[X + 1]$) and total nitrogen concentration (mg/m^3) on 23 Florida lakes, 1974–1982. Circles = 1 observation, triangles = 2, asterisks = 3, and squares = 4.

tively high on Orange and Newnan's lakes (Table 3), which are naturally eutrophic because of the presence of underlying limestone deposits (Canfield 1981). Nearby Santa Fe Lake, which lies over sandy clays, had relatively low indices. However, indices were relatively high on Griffin and Apopka lakes, which occur over peat or sandy clay deposits. These latter lakes also are highly productive (Canfield 1981) due to cultural eutrophication (sewage, agricultural, and mining runoff). Any correlation that may exist between surficial geology and alligator productivity was masked by cultural activities.

Continuous Variables.—Analysis of variance for lake surveys (Table 4) showed that indices (total and all 4 size-classes) were positively correlated with SLD, total nitrogen (N), percentage of Palustrine-Emergent wetland, and lake color. These 4 factors collectively accounted for 36, 49, 53, 60, and 63% of the variation in >1.8-m, 0.9–1.8-m, >0.9-m, <0.9-m, and total indices, respectively. Lake color was not correlated with >1.8-m indices, but 34% of the variation among lake surveys in this size class was attributable to SLD, total N, and percentage of Palustrine-Emergent wetland. Shoreline development, total N, and color accounted for 59% of the variation in <0.9-m indices. Lake color accounted for <5% of the variation in total alligators/km and in the smaller (<0.9-m and 0.9–1.8-m) size-classes.

Total N was most indicative of the variability in indices among the 23 lakes studied. In a simple linear regression, total N accounted for 32% of the variation in total indices (Fig. 3), which was half of the 63% reduction of residual error in the full model (Table 4). Total N is 1 of several parameters that can be used to estimate the primary productivity of aquatic ecosystems (Baker et al. 1981). Thus, the survey data suggest that more productive lakes may have a higher abundance of alligators.

NIGHT COUNT RECOMMENDATIONS

We have shown that monitoring population trends of alligators in Florida is extremely complex. However, as more accurate (i.e., direct population estimation) techniques are tested and refined, management personnel should seek to implement monitoring efforts that measure indices with sufficient precision to be sensitive to temporal changes. Therefore, we recommend the following refinements to the current sampling design and execution of night counts.

1. Because of the overwhelming effect of water level fluctuations on some indices, discretion is advised when selecting survey routes. Year-to-year comparisons of trends are best made between observations and among survey routes that have minimal fluctuations in water level during the survey period. If water fluctuations cannot be avoided, then the effect of changes in water levels on changes in habitat availability must be quantified.
2. If comparisons are to be made among different survey routes or types of water bodies, select the total array of survey routes at the beginning of the monitoring effort, avoiding the addition of routes after the first year. In view of the effects of water temperature (Goodwin 1977) and alligator behavior (Chabreck 1965, Joanen and McNease 1970, 1972, Goodwin 1977, Deitz 1979) on spatial distribution, all survey routes should be sampled during the same month. If trend analysis is to be confined to changes at individual survey routes, each should be sampled in the same month every year, but the counting of all routes could span several months.
3. Experimental error should be standardized by using the same well-trained observers every year (Chabreck 1966) and the same spotlight intensity, cruising speed, and starting time for surveys (Woodward and Marion 1978). Inclement weather (high wave action, rainfall, etc.) that reduces visibility should be avoided (Chabreck 1966, Woodward and Marion 1978).
4. Before surveys are run, the wetland classes (Cowardin et al. 1979) associated with transect routes should be divided into homogeneous segments. Observations should be recorded by segment to determine the effect of habitat on indices and spatial distribution. Water quality, particularly total N, also should be monitored to further quantify the relationship between system productivity and indices.
5. Preliminary tests should be conducted on the types of survey routes of interest to determine the sample size necessary (see Steel and Torrie 1960:87, Green 1979:41) to obtain an *a priori* level of precision in the index. For example, biologists should select several high-relief lakes of about the same size and shoreline development index and run several surveys within the same month, testing the enlarging data set to measure the effect on precision of the indices. Such tests should be conducted for each major type of survey route of interest, because some will require more replications than others to produce the same degree of confidence in the estimate of mean number of alligators per kilometer. Testing may have to be repeated in years with divergent hydrological conditions (e.g., comparing a drought year with a wet year) before adequate sample size guidelines emerge.
6. Given a standardized, annual sampling period and an adequate sample size, indices and water levels should be measured at several water bodies with similar physical characteristics over several years. Trends can be examined with a multiple regression

or with an analysis of covariance for a completely randomized design (Neter and Wasserman 1974:685–703) using year, water level, total N, and other independent variables. A set of water bodies should be selected to characterize the region of interest. The results of individual regression tests within the region then can be analyzed with sign tests, rank tests, or tests of percentage data.

CONCLUSIONS

Indices of American alligator population trends in Florida cannot be evaluated statistically from the available data, which lack the replication and blocking factors needed to account for several confounding variables. Major sources of variation in these indices were water level, visibility factors (e.g., waves, rain), shoreline relief and morphology, wetland habitat availability, water quality, and water color. Timing of surveys (month, time of initiation after sunset, and length of time from start to finish) probably contributed to variation among these indices, but was not examined because our analyses were established *a posteriori*. The data were used for descriptive examination of annual indices at individual water bodies. Among the 6 water bodies having the most complete data sets (counts for at least 6 years plus on-site water level measurements), indices appeared to increase at 3 lakes and decrease at 1 creek. However, year-to-year changes in indices were negatively correlated with changes in water levels at the 2 remaining sites (Lake Panasoffkee and the Withlacoochee River), thus no interpretation of trend was possible.

On the average, lake indices were higher than those on rivers and canals, but variability (i.e., standard deviations) among indices within each habitat type was as high or higher than the mean values. Productivity (total N), morphology (shoreline development), and wetland class (percentage of survey route traversing Palustrine-Emergent wetland) were positively associated with the variability in indices among lakes. Sampling alligator indices haphazardly, without regard for the effects of these and other environmental factors, will diminish the precision of indices. The sample design should be carefully worked out prior to collecting data.

Future sampling should control the confounding effects of water temperature, alligator behavior, and visibility by replicating samples within short periods with similar weather conditions. Sampling should measure the effects of water level, system productivity, wetland habitat availability, and other environmental variables using several water bodies that have similar physical characteristics (e.g., n samples for 2 or more lakes with high SLD and a deep basin, or low SLD and a shallow basin). After an experimental design is established (either multiple regression or analysis of covariance for completely randomized design), short-term tests should be run to determine the sample size needed to obtain mean indices within acceptable confidence limits. Trends should be determined for each group of water bodies (i.e., each treatment) with similar physical characteristics, because some types of water bodies are more sensitive than others to the environmental variables affecting indices. Statewide trends should be evaluated with a nonparametric analysis of these individual trends.

Acknowledgments.—We are grateful to the many technical personnel of the Florida Game and Fresh Water Fish Commission (FGFWFC) who established transects and collected the data presented here. A review of the applicability of this survey technique in Florida was requested and funded by FGFWFC and the U.S. Fish and Wildlife Service. H. F. Percival effectively promoted this cooperative effort of the University of Florida and the FGFWFC. The Florida Cooperative

Fish and Wildlife Research Unit provided essential services. Data were analyzed with the facilities of the Northeast Regional Data Center of the State University System of Florida in Gainesville. C. L. Abercrombie performed preliminary analyses and contributed stimulating discussions on analytical philosophies. A. V. Zale and M. W. Binford furnished ideas and sources of data regarding water quality. P. G. Bohall critically reviewed several early drafts of the manuscript and contributed many valuable suggestions. We are grateful to all these people and institutions for their help.

LITERATURE CITED

BAKER, L. A., P. L. BREZONIK, AND C. R. KRATZER. 1981. Nutrient loading—trophic state relationships in Florida lakes. Fla. Water Resour. Cent. Publ. No. 56. Univ. Florida, Gainesville. 126pp.

CANFIELD, D. E., JR. 1981. Chemical and trophic state characteristics of Florida lakes in relation to regional geology. Final Rep., Fla. Coop. Fish and Wildl. Res. Unit, U.S. Dep. Inter., Fish and Wildl. Serv., Univ. Florida, Gainesville. 444pp. (Mimeo.)

CHABRECK, R. H. 1965. The movement of alligators in Louisiana. Proc. Southeastern Assoc. Game and Fish Comm. 19:102–110.

———. 1966. Methods of determining the size and composition of alligator populations in Louisiana. Proc. Southeastern Assoc. Game and Fish Comm. 20:105–112.

———. 1976. Cooperative surveys of population trends in the American alligator, 1971–75. Third working meeting of the Crocodile Specialist Group, IUCN/SSC, Maningrida, Northern Territory, Australia, 5–12 April. 8pp. (Mimeo.)

———. 1980. Status of the American alligator in Louisiana and in Baldwin and Mobile counties, Alabama. U.S. Dep. Inter., Fish and Wildl. Serv., Jackson, Miss. 72pp. (Mimeo.)

COWARDIN, L. M., V. CARTER, F. C. GOLET, AND E. T. LAROE. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dep. Inter., Fish and Wildl. Serv., Washington, D.C. 103pp.

DEITZ, D. C. 1979. Behavioral ecology of young American alligators. Ph.D. Diss. Univ. Florida, Gainesville. 151pp.

FLORIDA BOARD OF CONSERVATION. 1969. Florida lakes: part 3: gazetteer. Div. Water Resour., Tallahassee, Fla. 145pp.

FLORIDA DEPARTMENT OF NATURAL RESOURCES. 1978–1981. Environmental geology series. Florida Bur. Geol., Tallahassee. Map series 78–80, 84, 85, 88–90, 93, 97, 99, 100.

GOODWIN, T. M. 1977. Seasonal movements of adult alligators in a large freshwater lake in north-central Florida. M.S. Thesis. Univ. Florida, Gainesville. 56pp.

GREEN, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons, New York. 257pp.

HAYS, W. L. AND R. L. WINKLER. 1970. Statistics: probability, inference, and decision; volume II. Holt, Rinehart, and Winston, Inc., New York. 320pp.

HELWIG, J. T. AND K. A. COUNCIL, EDITORS. 1979. SAS user's guide: 1979 ed. SAS Inst., Inc., Cary, N.C. 494pp.

HINES, T. C. 1979. The past and present status of the alligator in Florida. Proc. Southeastern Assoc. Fish and Wildl. Agencies. 33:224–232.

JOANEN, T. AND L. MCNEASE. 1970. A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. Proc. Southeastern Assoc. Game and Fish Comm. 24:175–193.

——— AND ———. 1972. A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. Proc. Southeastern Assoc. Game and Fish Comm. 26:252–275.

LIND, O. T. 1979. Handbook of common methods in limnology. The C.V. Mosby Co., St. Louis, Mo. 199pp.

MALLOWS, C. L. 1973. Some comments on *Cp*. Technometrics 15:661–675.

MURPHY, T. M., JR. 1977. Movements, distribution, and population dynamics of the American alligator (*Alligator mississipiensis*) in a nuclear reactor cooling reservoir. M.S. Thesis. Univ. Georgia, Athens. 64pp.

NATIONAL WETLANDS RECONNAISSANCE SURVEY. 1981–1982. 1:250,000-scale wetland maps of Florida. U.S. Dep. Inter., Fish and Wildl. Serv., Washington, D.C. (15 maps.)

NETER, J. AND W. WASSERMAN. 1974. Applied linear statistical models: regression, analysis of variance, and experimental designs. Richard D. Irwin, Inc., Homewood, Ill. 842pp.

OVERTON, W. S. 1971. Estimating the numbers of animals in wildlife populations. Pages 403–455 *in* R. H. Giles, Jr., ed. Wildlife management techniques. The Wildl. Soc., Washington, D.C. 633pp.

STEEL, R. G. D. AND J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., New York. 481pp.

TAYLOR, D. AND W. NEAL. 1984. Management implications of size-class frequency distributions in Louisiana alligator populations. Wildl. Soc. Bull. 12:312–319.

U.S. GEOLOGICAL SURVEY. 1971–1982. Water resources data for Florida: Volumes 1, 2A, 3A, and 4. Florida Geol. Surv., Tallahassee.

WOODWARD, A. R. AND W. R. MARION. 1978. An evaluation of factors affecting night-light counts of alligators. Proc. Southeastern Assoc. Fish and Wildl. Agencies. 32:291–302.

Received 24 October 1983.
Accepted 28 January 1985.