Estimating Sighting Proportions of American Alligators During Night-light and Aerial Helicopter Surveys

Allan R. Woodward, *Florida Game and Fresh Water Fish Commission, 4005 South Main Street, Gainesville, FL 32601*

Kenneth G. Rice, *Florida Cooperative Fish and Wildlife Research Unit, 117 Newins-Ziegler Hall, University of Florida, Gainesville, FL 32611*

Stephen B. Linda, *Florida Game and Fresh Water Fish Commission, 4005 South Main Street, Gainesville, FL 32601*

Abstract: We used mark-resight methods to estimate sighting proportions of American alligators (*Alligator mississippiensis*) during night-light and aerial helicopter surveys. Alligators ≥122 cm were captured during 5- to 12-day periods on Orange Lake and Lake Woodruff National Wildlife Refuge, Florida, and marked with paint on the dorsal neck area. Replicate helicopter surveys were subsequently flown on each area to record marked and unmarked individuals. Population estimates were calculated and compared with night-light and aerial counts of alligators ≥122 cm. Estimated mean proportion of alligators ≥122 cm sighted during May–June night-light surveys was 0.189 for Orange Lake and 0.090 for Lake Woodruff NWR. Mean sighting proportions during May aerial surveys were 0.106 for Orange Lake and 0.172 for Lake Woodruff NWR. Night-light and aerial alligator counts can be corrected for visibility bias to estimate population size, but sighting proportions may vary depending on habitat type, environmental conditions, and season.

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Harvest levels for most game species can be controlled by manipulating season length, hunting hours, methods of take, daily bag limits, and sex ratios of harvests (Strickland et al. 1994). Such regulatory constraints may not be economically practical nor adequate for preventing over-harvest of commercially valuable species such as crocodilians. Consequently, harvest quotas have been widely employed to prevent overharvest by most crocodilian harvest programs, including American alligator harvests. (Hines and Abercrombie 1987, Joanen and McNease 1987.) Knowledge of population size and sustainable harvest rates are essential for establishing quotas if alligators are harvested at high rates. However, population estimates have typically been difficult to obtain (Bayliss 1987).

Louisiana bases alligator harvest quotas on population estimates extrapolated from nest counts (Chabreck 1966, McNease and Joanen 1978, Taylor and Neal 1984, Joanen and McNease 1987, McNease et al. 1994). However, population estimates from nest surveys rely upon an underlying but uncertain relationship between the number of harvestable alligators and the number of nests (Taylor and Neal 1984). Further, nest surveys are not suitable for estimating populations on wooded habitats common in Florida (Jennings et al. 1988). Mark-recapture has been used for estimating population size of crocodilians (Murphy 1977, Webb et al. 1983, Hutton and Woolhouse 1989). However, estimator assumptions are frequently violated, particularly homogeneity of capture probabilities (Bayliss 1987). Mark-resight methods tend to meet estimator assumptions and, therefore, provide more reliable population estimates (Bayliss et al. 1986, Brandt 1989, Rhodes and Wilkinson 1994).

Alligators, as with marine mammals such as manatees (Packard et al. 1985), spend a certain proportion of time submerged when they are unavailable for counting during surveys. The proportion of submerged alligators along a survey route is dependent on environmental conditions such as water temperature and wave action (Murphy 1977, Woodward and Marion 1978). Further, visibility of emersed alligators may be affected by vegetation density, survey craft speed, and observer skill. The product of the proportion of emersed alligators and their visibility is the sighting proportion. Harvest quotas in Florida have been based on night-light surveys adjusted for the estimated sighting proportion (Hines and Abercrombie 1987; A. Woodward, unpubl. rep., Fla. Game and Fresh Water Fish Comm., Tallahassee) derived from mark-recapture studies at Par Pond, South Carolina (Murphy 1977, Brandt 1989). However, these sighting proportions have not been verified for Florida alligator populations. Our objective was to determine the proportion of the alligator population observed during night-light and aerial helicopter surveys on representative habitat types in Florida.

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Methods

Mark-resight experiments were conducted on Orange Lake in northcentral Florida during 1990–1992 and the lakes, streams, and canals on Lake Woodruff National Wildlife Refuge (Lake Woodruff NWR) in central Florida during 1990–1991. Orange

Lake (5,254 ha) is a diverse wetland with a large deepwater area (2,754 ha) bordered by a broad emergent marsh (2,500 ha). The marsh is stratified into 2 zones, a shallow marsh primarily composed of cat-tail (*Typha sp.*), sawgrass (*Cladium jamaicense*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria lancifolia*), and a deep marsh characterized by floating islands (Reid 1952) and spatterdock (*Nuphar luteum*). Cat-tail coverage on Orange Lake expanded from 20 ha to 280 ha during a 1991 drought on Orange Lake (FDEP, unpubl. data). The Lake Woodruff NWR study area consisted of an aggregate of lakes, ponds, streams, and canals bordered by a deep emergent (spatterdock) littoral zone (1,387 ha). Open water areas were bordered by seasonally inundated hardwood swamp (1,200 ha) and shallow cordgrass (*Spartina bakeri*) marsh. Vegetation densities on Lake Woodruff NWR were relatively constant during the study. All captures and surveys were conducted only on habitat accessible by airboats, which included open water, deep emergent marsh, and some shallow emergent marsh.

We caught and marked alligators ≥122 cm total length (TL) during 5- to 12-day periods in late April and early May. We captured alligators with Murphy-Wilkinson trip-snare traps (S.C. Wildl. and Mar. Resour. Dep., unpubl. brochure) during 1990–1991, and with night-capture techniques [snare poles and detachable-tip harpoons (Woodward and David 1994)] during 1990–1992. We used 1 boat with a crew of 3 persons for all capture efforts. Captured alligators were measured for TL and snout-vent length, then tagged for future identification. Alligators were marked with 2, 4 × 16-cm strips of asphalt spray paint applied to the dorsal neck region, and were color-coded by alligator size class with combinations of orange, yellow, green, pink, and white paint so that aerial observers could periodically calibrate size judgements. Paint marks were sufficiently large to be readily identified from the air but small enough that the observer detected the alligator prior to observing the mark. Paint was applied in several thin coats and allowed to dry for approximately 15–20 min. prior to releasing alligators. Tests of painted alligators in holding pens demonstrated that markings were discernible for ≥25 days after painting but lost by the following year.

Two or 3 aerial helicopter surveys were conducted on consecutive days on each lake at an approximate speed of 40 km/hour and an altitude of 40 m within 20 days after initial markings. Aerial surveys within each year were conducted by different observers and covered the same route and survey area as night-light airboat surveys. Survey routes generally followed the open water-emergent marsh zone of each study area but deviated when alligators were observed off-shore. Observations of alligators and any paint color combinations on marked individuals were recorded in 30.5-cm size classes on a tape recorder. We conducted 2 complete night-light surveys by airboat on each area during 15 May–15 June (Woodward and Marion 1978). Surveys were conducted within 2–41 days of the final aerial survey and surveys were separated by >13 days. Water temperatures ranged from 27–30 C. Unknown-size alligators (<6% of total counts) were apportioned into general size classes based on the observed size structure of known-size alligators (see Woodward and Moore 1993).

For each lake, date, and size class, the Chapman version of the Lincoln-Petersen estimator (Seber 1982:60) of population size,

$$\hat{N}_c = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1,$$

with estimated sampling variance,

$$\hat{\text{var}}(\hat{N}_c) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)},$$

was computed, where n_1 = number of marked animals in the population, n_2 = total number of animals sighted during an aerial survey, and m_2 = number of marked animals sighted during that survey. Population estimates were compared to night-light and aerial counts of alligators ≥122 cm to estimate the proportion of alligators observed during each type of survey. For each lake, year, and survey method, the ratio of the mean count to the weighted average of the $\hat{N}_c$ values (sighting proportion) was computed [weights were $1/\hat{\text{var}}(\hat{N}_c)$]. Using the assumption that the counts followed a Poisson distribution and counts and $\hat{N}_c$ were independent, the variance of the sighting proportion was estimated by the delta method (Seber 1982). An overall estimate of the sighting proportion for a given lake was obtained as the weighted average of the yearly sighting proportion estimates. A *t*-test was used to compare average night-light and aerial survey sighting proportions between areas. For each lake, a Chi-square test of association between size-class (122–182, 183–243, 244–304, 305–365, 366–426 cm TL) and sampling method (capture, aerial, night-light) was performed. If the Chi-square test was significant, (1) a multinomial logit model (Agresti 1990) was fitted to test for pairwise differences in the size class distribution between sampling methods; and (2) for each pooled size class, a separate logistic model (Agresti 1990) was fitted to test for pairwise differences in the relative abundance of the given size class between sampling methods. An ANOVA was used to compare square root-transformed total counts of alligators ≥122 cm between aerial and night-light survey methods. All analyses were conducted with SAS System Software (SAS Inst. 1989).

Results

Capture Success

Night-capture techniques were more efficient (9.0 alligators/day) than baited trip-snare traps (1.7 alligators/day) for capturing alligators. Success using trip-snare traps (0.112 alligators/trap-night) was comparable to the 0.05–0.15 rates reported by Brandt (1989), but not efficient enough for our constrained mark-resight period.

Size distributions depended on sampling method for both Orange Lake (χ^2 = 445.8, 8 df, $P < 0.001$) and Lake Woodruff NWR ($\chi^2 = 75.7$, 8 df, $P < 0.001$). However, the size distribution of captured alligators was not different ($P = 0.355$) from that of alligators observed during night-light surveys on Lake Woodruff NWR (Fig. 1). On Orange Lake, the size distribution of captured alligators differed from that of alligators observed during night-light surveys ($P < 0.001$). In particular, the relative abundance of alligators 244–304 cm observed during night-light surveys was greater ($P = 0.01$)

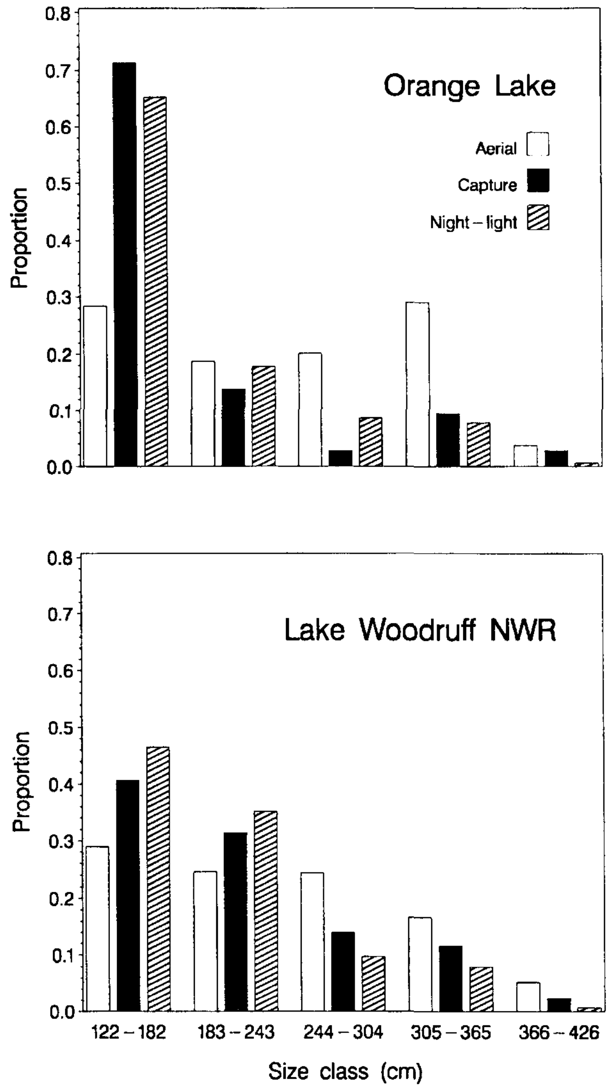

Figure 1. Size distributions in 61-cm increments of marked alligators during mark-resight experiments and alligators counted during night-light and aerial helicopter surveys on Orange Lake and Lake Woodruff NWR, Florida, during 1990–1992.

than that of captured alligators and the relative abundance of alligators 366–426 cm observed during night-light surveys was less ($P = 0.009$) than that of captured alligators (Fig. 1). The size distributions of alligators observed during aerial surveys was different ($P < 0.035$) than that of captured alligators and night-light counts for both study areas. Larger (≥244 cm) alligators tended to make up a greater ($P < 0.05$) proportion of total counts during aerial surveys than during night-light surveys (Fig. 1).

Population Estimates and Sighting Proportions

We marked 36–76 alligators ≥122 cm on Orange Lake during 1990–1992 and 32–54 alligators ≥122 cm on Lake Woodruff NWR during 1990–1991 (Table 1). Mean (weighted) annual population estimates of alligators ≥122 cm ranged from 1,174–1,859 on Orange Lake and from 956–981 on Lake Woodruff NWR (Table 2). Estimated mean sighting proportions of alligators ≥122 cm during night-light surveys was 0.189 ($CI_{0.95}$ = 0.05, 0.33) on Orange Lake and 0.090 ($CI_{0.95}$ = 0.00, 0.34) on Lake Woodruff NWR (Table 2). We observed some evidence of a difference ($P = 0.104$) in night-light sightings proportion between areas, but note that the test was based on only 2 or 3 years/site and, thus, had low power. Estimated mean sighting proportion of ≥122-cm alligators during aerial surveys was 0.106 ($CI_{0.95}$ = 0.00, 0.22) on Orange Lake and 0.172 ($CI_{0.95}$ = 0.00, 0.74) on Lake Woodruff NWR (Table 2). We consistently counted a greater number ($P < 0.01$) of alligators ≥122 cm during night-light surveys than during aerial surveys on Orange Lake. However, on Lake Woodruff NWR, we saw no clear relationship ($P = 0.818$) between aerial and night-light counts (Table 2). We were unable to detect a difference ($P = 0.263$) in aerial sighting proportions between areas.

Discussion

We observed a substantially lower sighting proportion of alligators during night-light surveys (0.09–0.19) than did Murphy (1977) and Brandt (1989) in their work on Par Pond, South Carolina (0.30–0.35), under similar water temperatures (27–30 C) and survey methods (Brandt 1989). However, their sighting proportion estimates included alligators <122 cm, which appear to be less wary and more easily detected at night. Further, denser emergent vegetation on our study areas relative to Par Pond may have contributed to lower sighting proportions, but we were unable to make quantified comparisons. The sighting proportion of alligators on Lake Woodruff NWR (0.09) was comparable to that reported for alligators ≥183 cm for impounded wetlands in South Carolina (0.09) (Rhodes and Wilkinson 1994).

Annual population estimates varied, possibly because of the low sample size of resighted marked animals, changes in observability due to varying densities of emergent vegetation (Orange Lake), and movement of marked alligators out of the survey area (Lake Woodruff NWR). A low number of marked animals relative to the total population causes highly variable estimates in mark-recapture experiments because of low probability of re-sighting (Seber 1982). Although this can be offset to some degree by capturing a high percentage of animals on the second sampling, we were not able to resight sufficient numbers to compensate for the low number of marked animals.

Alligator sighting proportions can be affected by the proportion of submerged alligators and the proportion of emersed alligators visible during a survey. Although we were not able to isolate these components, lower sighting proportions on Orange Lake during 1991 and 1992 than in 1990 may have resulted from reduced visibility

Table 1. Values for mark-resight parameters in the Chapman estimator (Seber 1982) for alligator populations on Orange Lake and Lake Woodruff NWR during 1990–92 aerial re-sight surveys; n_1 = number marked, n_2 = number sighted from air, m_2 = number of n_2 that were marked, $\hat{N}_c$ = population estimate.

Study area/Year	Date	n_1	n_2	m_2	$\hat{N}_c$	SE_N	95% C.I. Lower	95% C.I. Upper	Water level (m)
Orange Lake									
1990	21 May	36	213	5	1,319	450	436	2,201	16.58
	22 May	36	174	5	1,078	367	359	1,798	16.58
1991	7 May	69	127	3	2,239	957	362	4,116	16.12
	8 May	69	87	4	1,231	471	308	2,154	16.12
	9 May	69	77	4	1,091	416	276	1,906	16.12
1992	18 May	76	173	5	2,232	796	671	3,793	16.58
	19 May	76	177	4	2,740	1,067	649	4,832	16.57
	20 May	76	160	7	1,549	477	614	2,483	16.57
Lake Woodruff									
1990	8 May	32	149	4	989	366	271	1,707	0.09
	9 May	32	236	7	977	279	430	1,524	0.08
1991	14 May	54	112	5	1,035	360	330	1,740	0.27
	15 May	54	54	3	755	314	140	1,370	0.27
	16 May	54	131	5	1,209	422	382	2,036	0.28

Table 2. Mark-resight population estimates ($\hat{N}_c$), number of replicate surveys (N), mean number counted and sighting proportions of alligators ≥122 cm during night-light and aerial helicopter surveys on 2 Florida lakes during 1990–1992.

	$\hat{N}_c$			Night-light surveys				Aerial surveys			
						Sighting proportion				Sighting proportion	
Study area/Year	N	$\bar{x}$[a]	SE	N	$\bar{x}$ count	$\bar{x}$	95% CI	N	$\bar{x}$ count	$\bar{x}$	95% CI
Orange Lk.											
1990	2	1174	118	1	300.0	0.256	0.20–0.31	2	198	0.169	0.13–0.21
1991	3	1256	231	2	194.5	0.155	0.10–0.21	3	98	0.078	0.05–0.11
1992	3	1859	311	2	299.5	0.161	0.11–0.22	3	171	0.092	0.06–0.12
1990–1992 $\bar{x}$						0.189[a]	0.05–0.33			0.106[a]	0.00–0.22
Lk. Woodruff											
1990	2	981	6	2	83.5	0.085	0.07–0.10	2	198	0.201	0.18–0.22
1991	3	956	132	2	157.0	0.164	0.12–0.21	3	99	0.104	0.07–0.13
1990–1991 $\bar{x}$						0.090[a]	0.00–0.34			0.172[a]	0.00–0.74

[a]Weighted mean.

caused by the drought-induced expansion of cat-tails. Lower sighting proportions of alligators on Lake Woodruff NWR in 1990 may have resulted from alligators leaving the survey area with rising water levels during the 28- and 41-day periods between aerial surveys and the night-light surveys. Because delta method results hold asymptotically (i.e., the approximation improves with increasing sample size), and our samples were not large, the confidence intervals for sighting proportions should be considered as approximate, at best.

Assumptions of the Chapman Estimator

The Chapman estimator (less-biased version of the Lincoln-Petersen estimator) is based on the following assumptions (Pollock et al. 1990): (1) the population is closed (no births, deaths, immigrants, or emigrants), (2) all animals are equally likely to be captured in each sample, and (3) marks are not lost and are not overlooked by observers. We believe that we met the above assumptions.

Closed population. Although some movement of animals in and out of Orange Lake was possible between the capture period and aerial resight surveys, we believe that this was negligible. Significant emigration of marked alligators to adjacent impoundments, canals, wooded swamps, and waterways may have occurred on Lake Woodruff NWR in 1990 due to rising water levels between aerial surveys and night-light surveys. Otherwise, we believe the amount of migration was minimal. Recruitment of alligators into the ≥122 cm size class and natural mortality would have been negligible during this short time span.

Homogeneity of capture probabilities. Capture and aerial sighting probabilities of alligators may vary among size classes of alligators and, possibly, among individual alligators within size classes. We believe that heterogeneous capture probabilities for the initial capture were inconsequential. Although larger alligators were more visible than smaller alligators during aerial surveys, the size distribution of marked alligators roughly corresponded to the size distribution of alligators observed during night-light surveys (Fig. 1). This minimized biases in population estimates relating to unequal visibility of different size alligators. We re-sighted alligators with an independent technique (helicopter) and observed <1% of either marked or unmarked alligators exhibiting avoidance of the helicopter.

Marking. Our marking system was temporary, but all evidence (captive studies and observations of marking on wild alligators) indicated that the time frame of our experiment was brief enough to discount loss of markings. Applying paint in several thin coats and allowing it to dry completely before release reduced the rate of mark loss. Furthermore, marks were sufficiently small to ensure that marked alligators were not more readily observed than unmarked alligators.

Management Considerations

Harvest quotas can provide an effective means of limiting harvest levels. Other traditional methods that reduce harvest efficiency often fail to prevent overharvest. Quotas rely upon knowledge of population size and sustainable harvest rate. A knowledge of sighting proportions can provide a basis for estimating populations from night-light or aerial surveys.

We saw some evidence of differences between areas in sighting proportions during night-light surveys, and we suspect that sighting proportions may be area-specific. Therefore, caution should be used in broadly applying sighting proportions for all alligator habitat types. For establishing alligator harvest quotas on lakes in Florida, we recommend using the more conservative (greater) sighting proportion of 0.189 estimated for Orange Lake. It should also be noted that this sighting proportion is only valid for night-light surveys conducted at similar speeds, intensity of coverage, and water temperatures.

We sighted a lesser proportion of alligators ≥122 cm with aerial helicopter surveys than with night-light surveys on Orange Lake. However, aerial sighting proportions are dependent on alligator thermoregulatory behavior which can vary by season and time of day (Lang 1987, Brandt 1989, Woodward and Linda 1993). Aerial counts also may vary by helicopter speed, weather conditions, intensity of coverage, and density of tree canopy in occupied habitat. Aerial surveys appear to have some potential for providing more accurate counts of larger (≥244) alligators and should be examined further.

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