EVALUATING METHODS TO MEASURE NESTLING SURVIVAL IN TRICOLORED HERONS

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Abstract: Measurement of survival in nestling ciconiiforms is difficult due to dense vegetation, cryptically plumaged young, and unpredictable movements of mobile nestlings in treetops. Thus, we used posture-sensing radio transmitters to measure survival of nestling tricolored herons (*Egretta tricolor*) during the 40- to 50-day period when young are mobile in the colony but dependent upon parental feedings; we used the known survival of birds marked with radio transmitters to assess the use of other techniques to estimate survival. We found nestling mortality rates nearly 3 times as high in the post-mobile stage as during the pre-mobile stage. Nestling censuses that used unique color-band combinations along a marked nest transect became unreliable after 21 days of age. Similarly, censuses of young in congregation and loafing areas within the colony resulted in large underestimates of nestling survival. Poor detectability of carcasses on transect walks (33–50%) precluded use of carcass counts to estimate chick mortality directly. We conclude that telemetry is probably the only reliable method for the accurate measurement of nestling survival in most colony situations.

The reproductive success of long-legged wading birds is of considerable interest to wildlife and land managers because these species are useful as indicators of wetland productivity, trophic structure, human disturbance, and contamination of wetlands (Custer and Osborn 1977). Although wading birds are relatively convenient to survey and monitor in colonial nesting aggregations, the measurement of reproductive success is limited because young birds become mobile and difficult to count less than half way through their period of dependence upon parental feeding.

Most long-legged wading birds (Ciconiiformes) are considered semi-altricial, and have relatively long periods of parental care (Palmer 1962). Development in many species is characterized by rapid development of climbing limbs and skills and an early ability to ther-

moregulate and move about (7–15 days; McVaugh 1972, Werschkul 1979). A majority of the period up to independence is spent in loose flocks in treetops, where young roost and are fed by parents (Rudegeair 1975, Werschkul 1979, Kushlan 1977, McVaugh 1972). These pre-independent juveniles generally are referred to as nestlings, even though they spend little or no time in the nest. For example, little blue herons (*Egretta caerulea*) may spend only 36% of the entire pre-independence "nestling" period actually in or near the nest (Werschkul 1979). Young roseate spoonbills (*Ajaia ajaja*) leave their nests at 14–21 days of age, but remain in the colony an additional 24–37 days (R. Bjork, Natl. Audubon Soc., pers. commun.).

The most common and widely used technique for measuring nest success (production of ≥1 young to a given age) and nestling survival of colonially-nesting ciconiiforms is to visit nests repeatedly along a route or belt transect through the colony and count nest contents or banded nestlings (Jenni 1969, Maxwell and Kale 1977, Black et al. 1984, Frederick and Collopy 1989,

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Bancroft et al. 1990). However, as nestlings gradually leave the vicinity of the nest at between 12 and 23 days of age, they may no longer be reliably associated with their nest mates, despite complete dependence of the nestlings on parental feedings for at least 3 weeks afterwards. Both light- and dark-plumaged young in the tops of trees may be exceedingly difficult to see even if banded, and so may not be counted reliably. Survival of a cohort of nestlings from the same area might be inferred from the tally of young found dead in that area, but the proportion of carcasses found by observers, and whether the carcasses are even from the nests being counted, is usually unknown. Although these sources of error could obviously affect attempts to estimate reproductive success, they never have been measured directly, and the majority of studies have limited the estimation of nestling survival to the very early mobile stage. Because the early mobile stage is less than half of the period of dependence upon parents, methods for monitoring survival past this point would clearly be of value. Consequently, we monitored nestling survival in a colony of tricolored herons by placing radio transmitters on young, and compared survival measured in this way with results obtained using more traditional methods.

STUDY AREA

We purposely selected a difficult, though common situation, by studying a cryptically-colored species nesting in dense understory vegetation on an island containing predators that may remove young. We studied tricolored herons during April–July 1990 on Frank Key, a marine island approximately 3 km south of the mainland at the southern tip of the Florida peninsula (25°6.5′N, 80°54.6′W) in Everglades National Park. Much of the island is low-lying and occasionally inundated by tides, and the margins are dominated by red mangroves (*Rhizophora mangle*), black mangroves (*Avicennia*

germinans), and white mangroves (*Laguncularia racemosa*) of various ages; the center contains a mixture of open pans, tropical hardwoods, and cacti. Tricolored herons have been recorded nesting on Frank Key since the early 1960's. Seven other ciconiiform species, 2 pelecaniform species, several passerine species (Kushlan and White 1977; G. V. N. Powell and P. C. Frederick, unpubl. data), ospreys (*Pandion haliaetus*) and 1 resident pair of bald eagles (*Haliaeetus leucocephalus*) also nested there during our study. Over 150 turkey vultures (*Cathartes aura*) roosted on the island throughout the spring and early summer of 1990.

Between 600 and 750 pairs of tricolored herons nested on Frank Key during the period 1985–89. The majority of the tricolored herons nested in a margin of young red mangroves and mature white mangroves approximately 50 × 300 m along the eastern edge of the island. The majority of nests were in dense trees 4–6 m in height. Nests were placed 2–5 m above ground.

METHODS

Nest Sampling Transect

Approximately 300 tricolored heron pairs established breeding territories in the study colony between 15 and 25 April, and we began monitoring a belt-transect approximately 200 m long through the nesting area on 30 April. Most nests had completed clutches at this time. We marked all nests within 2 m of the transect by placing an individually numbered red tag (2 × 15 cm) on branches under each nest, and we marked eggs individually on their ends with small indelible numbers. We also handled nestlings briefly during our visits to habituate them to researcher disturbance (Parsons and Burger 1982).

Nesting Success

During 26 ensuing visits to the transect spaced approximately 3 days apart ($\bar{x} = 3.36$, SE = 0.15) we followed the fates of 107 nests until all radio-marked young had left the colony permanently. Of these nests, 2 were little blue herons and the rest tricolored herons, illustrating the largely single-species composition within the transect. The transect was visited only during early morning hours (0500–0830 EST). During visits after young had become mobile, we carefully searched the vicinity of all nests and the entire transect for nestlings in trees or on the ground, but did not leave the path during these visual censuses.

We back-dated the initiation of nests from hatch dates by using a mean incubation period of 22 days (Bent 1926, Bjork 1986, Frederick and Collopy 1988). When calculating nest initiation dates, we only used nests for which we had recorded increases in clutch size, or those with accurate hatch dates. Nesting success (the probability of a nesting effort producing ≥ 1 fledgling) was calculated using Mayfield's (1961, 1975) method of prorating survival for the period of observation.

Colorbanding

We marked 69 nestlings in 39 nests with colored leg bands and 56 nestlings in 32 nests with colored bands and radio transmitters. Young were marked as close to 14 days of age as our visitation schedule allowed. Young within nests were marked in the same manner. We left nestlings unmarked in 32 monitored nests. We alternated marking treatments for consecutive elegible-aged nests on any given visit, in an effort to randomize treatment effects. We used combinations of white, blue, and red plastic coil-type colored bands ("bandettes," Natl. Band and Tax Co., Lexington, Ky.) and silver aluminum U.S. Fish and Wildlife Service numbered bands, all placed below the tarsometatarsal joint, to individually mark young. Banding and measuring required approximately 3 minutes/individual, and nestlings were released back into the nest. We assessed the usefulness of color marks by comparing fledgling counts using only visual methods with those using telemetry.

Radio Telemetry

We used single-stage transmitters outfitted with mercury-activated posture-sensing switches (Kenward 1987) and with an expected life of approximately 90 days (Biotrack Ltd., Storborough Croft, U.K.) to track large-scale movements of the 56 young, and to identify and locate young that died. Posture switches were mounted at 45° to the plane of the base of the transmitter (and the plane of the back of the bird) with the long axis of the sensor and the antenna pointing posterior along the axis of the bird's body. The transmitters thus signalled changes in the posture of the bird (anterior-posterior, or "pitch") through a distinct change in pulse rate. Transmitters had a mass of approximately 1.8% of near-fledging mass of tricolored herons ($\bar{x} = 5.46$ g, SE = 0.02 g, $n = 30$) and were attached to the back of the bird by glueing the transmitter onto the scapular and central upper back feathers (F. Shaffner, U.S. Fish and Wildlife Service; and H. Haffner, Tour du Valat, France, pers. commun.). Radios were epoxied onto 2.5- × 4-cm ovals of black fiberglass window screen prior to attachment, and positioned on the bird's back feathers using dots of fast-bonding cyanoacrylate adhesive. We then adhered the screen more permanently to the feathers by painting it with rapidly-curing epoxy (Devcon Co.). Each nestling then was colorbanded, measured, and released back into the nest when the epoxy had cured. Attaching the bands and radios took 8–12 minutes/bird.

Radio-marked nestlings then were monitored with a receiver and 2-element H antenna from a hidden location approximately 100 m from the nesting area. Radio checks were performed between 0500 and 1100 for all marked nestlings 1 day prior to transect censuses, and on the morning of transect censuses, prior to entering the colony. We noted changes in best-gain frequency, general strength, approximate location, and latency to pulse-rate changes for all radios during each check.

We assumed radios with changing pulse-rates represented active, living birds; those that did not change during a continuous 5-minute listening session, and that also did not change during at least 4 other monitorings during the approximately 0.75- to 1.5-hour telemetry session were considered dead. All nestlings in the latter category then were checked by tracking the signal within the colony until the bird (or radio) was found. Because the measured life of this model radio was over 90 days, and because we were able to repeatedly locate radios on the island that had fallen into the water or mud, we assumed the inability to obtain a signal from a bird >50 days of age indicated that it had left the colony. Repeated searches in the colony well after 50 days of age for most of the nestlings did not result in the discovery of any remains of radio-marked birds thought to have fledged.

Observations in Loafing Area

Young ciconiiforms commonly congregate in open loafing and feeding areas located within or on the edges of colonies (Rudegeair 1975, Rodgers and Nesbitt 1979, Frederick and Collopy 1988). At Frank Key, mobile young congregated in an unvegetated and often shallowly inundated (<5 cm) mud flat in the center of the island during early morning hours. We could

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see this area from our radio monitoring position, and we repeatedly scanned it for color-banded birds with 10 × 42 power binoculars during every telemetry monitoring session. Each scanning session involved a minimum of 8 detailed examinations of the entire group of birds, spaced evenly over between 0.75 and 1.5 hours. Birds not seen during any of these observation periods were tallied as having died prior to independence.

Nestlings Found Dead

We collected all dead nestlings found on transect walks and performed complete necropsies on them. Extra time was spent searching for nestlings known to be missing. Age at time of death was calculated from nest history information for birds that were banded, and estimated for unmarked birds using culmen length (data from McVaugh 1972; Black et al. 1984; T. Custer, U.S. Fish and Wildl. Serv., unpubl. data). We assessed the utility of using carcasses to measure mortality by comparing the number of radio-marked carcasses found with the number that actually died (including those found dead only with the aid of telemetry). We also compared the detectability of carcasses in the pre-mobile nestling phase (when carcass findings can be compared with known disappearances) with that in the post-mobile phase (deaths known through telemetry, carcass counts from transect walks).

Statistical Analyses

We used Chi-square and binomial tests to identify differences between mortality rates, and ability to find carcasses. T-tests were used to identify differences in mean ages of chicks in broods receiving different marking protocols. Mann-Whitney U-tests were used to determine if differences existed among brood sizes in nests receiving different marking protocols; in those cases, the data were not continuous, or normally distributed.

RESULTS
Effect of Marking on Survival

Mean age of chicks at marking did not differ ($t = 1.03$, 120 df, $P = 0.327$) between banded ($\bar{x} = 14.87$ days, SD = 2.83) and radio-marked ($\bar{x} = 15.33$ days, SD = 2.14) broods. We also found no differences ($P > 0.05$) in numbers of chicks in broods that were banded, those banded

Table 1. Survival (no. alive) of nestling tricolored herons in nests receiving different marking protocols, Frank Key, Florida, 1990.

Nestling age (days post-hatching)	Marking treatment[a]					
	None		Color bands		Transmitters and color bands	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
14	1.55	0.14	1.89	0.05	1.82	0.08
21	1.35	0.16	1.47	0.12	1.53	0.13

[a] Means did not differ ($P > 0.10$) among marking treatments within age-categories; Mann-Whitney U-tests.

and radio-marked, and those unmarked, either at the time of marking, or a week later (Table 1). These results suggest that the 3 groups of nests began the nestling period of interest (14 days through independence) with roughly equal numbers of young, and that neither marking protocol strongly biased survival.

Movements of Young

All young were observed within 1 m of their nests prior to 14 days of age. Young began spending time in branches and eventually in the tops of trees at between 14 and 21 days of age. Between the ages of 17 and 40 days, we found radio-marked chicks relatively close to their nests (up to 20 m distant) during our transect walks. Chicks began flying short distances at between 25 and 30 days of age, and we first began noting color-banded and radio-marked birds in the loafing area (>50 m from any nest) at about this age. Our observations of the colony from the telemetry monitoring site suggest that most volant young spent a portion of the early morning hours on or near the central mudflat area interacting with conspecifics and practicing foraging skills, and later being fed and roosting in the tops of nearby trees. Between 45 and 60 days of age, young expanded their activities to the most distant locations on the island (approx. 300 m from nest sites).

Evaluation of Methods

Using the survival of radio-marked birds as a benchmark, we evaluated the effectiveness of 5 other methods used to measure survival of young between the time they left the nest and independence from parents. These included sightings of unmarked young from marked nests on repeated transect walks, the use of colored bands to make nestlings more visible during transect walks, the use of pre-mobile nestling survival rates to estimate post-mobile survival, using

counts of nestlings actually found dead during transect walks as indices of mortality, and using counts of volant nestlings in loafing and congregation areas immediately adjacent to nesting areas as measures of survival.

Radio Telemetry

Fourteen of the 56 transmitters (25%) either failed electronically (5.2% of total) or came off the birds (19.6% of total). Elapsed time between deployment and radio-tag loss was variable, ($\bar{x}$ = 25.0 days, SE = 3.81 days). Four of the transmitters seen on free-ranging birds were hanging sideways and were even inverted, particularly on individuals with long scapular and back feathers. The greater range of motion of the transmitters attached to these longer feathers probably allowed the transmitters to catch on branches and pull off.

The mean time elapsed between first radio contact with a bird and a change in pulse rate (i.e., latency) was 1.90 minutes (SD = 1.94, n = 797). Seventeen percent of latencies were >5 minutes. Mean latency did not appear to change with age of chick. Posture sensing switches gave only 1 false positive (chick dead, but pulse rate changing). Evidence at this nest suggested that a predator had been eating the carcass during the time we were monitoring the chick's frequency, thereby causing the switch to fluctuate; this represents a 4.3% error (n = 23 dead chicks). Posture sensing switches gave 6 false negatives (chick alive, but pulse rate not changing during 5 minutes of continuous monitoring, and at least 4 other monitorings over a 0.75- to 1.50-hour period) out of 797 total monitoring sessions (0.75%); all of these false negatives eventually changed pulse rate as the birds started to move upon our approach. The total cost of equipment for radio-marking per bird was $62.25, and each bird required an average of 1.9 minutes to check/visit.

Pre-mobile Nestling Survival as an Estimator of Post-mobile Survival

As estimated with the Mayfield method, 78.5% of the 107 nest starts on the transect produced ≥1 14-day-old nestling. Of 164 nestlings that hatched, 3 were found dead and 6 disappeared and were assumed dead by 14 days of age (5.5% mortality). After 14 days, we could classify 44 of the radio-marked young as either having survived to independence (72.7%) or as having died (27.3%; as above, final status of some of the birds

was in question due to radio failure). The nestling mortality rate per day of exposure after mobility (0.0075) was therefore nearly 3 times that measured in nestlings prior to mobility (0.0026). Surviving birds left the island (dispersed) at a mean age of 59.2 days (SE = 1.20 days), with a small difference in dispersal age between first-hatched ($\bar{x}$ = 58.70 days, SE = 1.51 days, n = 21) and last-hatched ($\bar{x}$ = 60.60 days, SE = 20.74 days, n = 6) chicks.

Use of Carcass Counts to Estimate Mortality

Of 21 carcasses that were necropsied, the major cause of mortality was predation (57%), followed by malnutrition (29%) and disease (9.5%). Bald eagles or turkey vultures were the most likely predators because most bones remained intact with tendons attached; teeth marks were not evident on any bones; and carcasses were characteristically eviscerated and eaten on or near the nest (P. C. Frederick et al., pers. observ. at other colonies in Florida Bay).

On transect walks, we found 23 dead young that were >14 days of age, not counting those located with the aid of telemetry. Based solely on these carcasses, nestling mortality between 14 days and independence was 15.4%. The difference between this estimate and that derived from the radio-marked birds (27.3%), approached significance (χ^2 = 3.60, P = 0.06).

Detectability of carcasses did not appear t change between pre- and post-mobility nestlin phases. Of the radio-marked birds older than 1 days, 6 were found dead during normal transe walks, and 6 were found only with the aid o telemetry. In the absence of telemetry, thes latter birds would have been classified as mis ing. The resulting detectability (6 found out 12 total dead or missing) of birds >14 days age did not differ (binomial test, P = 0.89) fro the detectability (3 chicks found of 9 missin at <14 days of age.

Colormarking

We compared censuses of radio-marked chi with censuses using only sightings of chicks w color bands on the transect walks. The prop tion of nests classified correctly through sig ings alone became unreliable following 20 d of age, and decreased to essentially zero by days of age (Fig. 1). In our use of sighting: color bands on the transect walks, we made mistakes in assessment of nest production a

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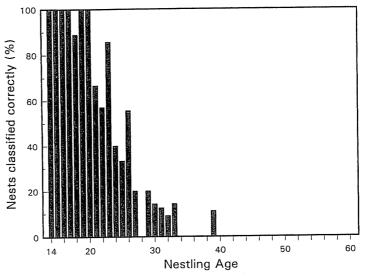sect walks, we made 46
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Fig. 1. Proportion of broods censused correctly during visual transect censuses, as a function of age of oldest nestling in each brood, Frank Key, Florida, 1990.

nests (30.5% of the total number of nests followed after 14 days) between 14 and 50 days of age. The mean age of chicks at last sighting on the transect was 27.30 days (SE = 0.99 days, n = 63 chicks) for all birds with color bands (including radio-marked birds), and 25.40 days (SE = 1.40 days, n = 8 chicks) for unbanded birds (Mann-Whitney U, Z = 2.42, P = 0.02).

Sightings of Banded Birds in Loafing Areas

We noted 28 individuals from 26 nests (22% of 127 banded birds) out of 40 sightings of banded, identifiable birds on the mud flats. The mean age of first sighting on the mud flat was 48.0 days, and varied from 28 to 50 days. Of 32 radio-marked birds known to have lived to this age, we sighted 13 (40.6%), indicating at best a 41% efficiency with this method. The survival rate of nestlings as determined from telemetry was higher (72.7%) than would have been predicted (22%) from sightings of banded birds alone (χ^2 = 15.4, 1 df, P < 0.001).

DISCUSSION

The lack of obvious differences in survival of young among the marked nestling treatment groups between 14 and 21 days of age suggests that they had similar survival rates. We doubt that this is a result of temporal sampling error because the 14- to 21-day period was not one of particularly low mortality. During this pe-

riod, chicks began spending large amounts of time in branches, and their behavior seemed representative of the rest of the mobile period. The lack of differences in survival rate also was not likely due to differences in brood size, because both groups started the 14- to 21-day period with similar brood sizes. Thus, we found no evidence to suggest that the reproductive measures gathered from radio-marked or color-banded birds were markedly different from unmarked birds.

Survival of chicks was age-dependent, and our results demonstrate that pre-mobility survival rates could not have been used to estimate survival during the mobility period. Our results also demonstrate that the use of brightly colored leg bands does not allow accurate censusing of nestlings >21 days of age in densely vegetated colonies. We conclude that the visual transect method is inaccurate and misleading thereafter. We repeatedly found banded birds on the transect through 45 days of age, and without the telemetry information would have assumed these birds were the only ones surviving. Visual censuses, even with the aid of color marks, underestimate nestling survival.

We suspect a large proportion of nestlings used the mudflats in the colony for feeding and loafing at 1 time or another, yet our estimates of survival based on resightings of birds with color bands on the flats were low. This did not appear due to band loss; all of the 24 individuals

observed with transmitters also wore their full complement of bands. We also do not think that expanding the time spent observing the flats would have increased the accuracy of estimates because nestlings generally did not use the flats prior to 0900 EST. This method also underestimates nestling survival.

Carcass counts were a poor estimator of true mortality, both before and after 14 days of age. The inability to find carcasses was partly due to removal by predators, but the radio-marked carcasses illustrated that carcasses often were present, albeit difficult to find, even in the immediate vicinity of the nest. Our data also suggest that carcasses do not become more (or less) obvious with age of nestling, so that counts of carcasses are not well suited to estimating mortality at any age. Carcass counts also underestimate mortality.

Our results have identified major difficulties with the other methods used to measure survival of mobile nestling tricolored herons. These problems will apply to varying degrees to other species. Large ciconiiforms are not likely to nest in dense or low vegetation (Burger 1978) and so may be censused with some accuracy even during the mobile phase, depending largely upon colony characteristics (Pratt and Winkler 1985). Although white-plumaged young may be more visible than dark-colored species, we suspect that mobile young of any color will be inaccurately censused by most methods when nests are in dense vegetation. Young may be accurately censused in several circumstances; where the colony size is small and the entire area may be censused completely, where cliffs or towers afford an unobstructed view of all nests (Pratt and Winckler 1985), or, in the case of some white ibis (*Eudocimus albus*) colonies, where the entire substrate is flat and affords an unobstructed view of all nests (Kushlan 1973, Frederick 1987). These situations are relatively uncommon (McCrimmon 1978, Osborn and Custer 1978, Nesbitt et al. 1982), and the majority of colonies containing smaller species of ibises, herons, and egrets are likely to display many features of vegetative density, and the lack of vantage point shown at Frank Key.

RESEARCH AND MANAGEMENT IMPLICATIONS

Following the fates of a sample of nestlings equipped with posture-sensing transmitters appears to offer an accurate way to estimate survival of cryptic, mobile nestlings in heavily vegetated habitat. Our transmitters had a low failure rate, were lightweight and rapidly deployed, efficient in identifying mortalities or transmitter losses, had adequate life span, and proved to be an extremely rapid method of checking chick status; as fast or faster, in fact than the transect walks. The major drawbacks were cost ($62.25/bird) and the high rate of tag loss. Cost can be reduced by buying partly assembled transmitters in an unfinished state (without antenna or potting). We suspect tag loss was due to exaggerated motion and increased probability of "hangup" because of their position on long feathers. All lost radios had large numbers of feather ends still attached, so we suspect that glue failure was not a problem. To limit the range of motion of radios, we suggest that the tips of scapular feathers be trimmed as short as possible at the time of glueing to allow attachment directly to the shorter feather shafts.

For those wishing to measure nest success or reproductive variables of small mobile ciconiiform birds, we suggest that the assessment of reproductive success should include the measurement of post-mobile phase nestling survival, and that telemetry currently is the best option for measuring late nestling survival.

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