
Set-Back Distances to Protect Nesting Bird Colonies from Human Disturbance in Florida

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Abstract: *Breeding colonial waterbirds are particularly susceptible to human disturbance because of their high-density nesting habits. Identified detriments to reproductive success include egg and nestling mortality, nest evacuation, reduced nestling body mass and slower growth, premature fledging, and modified adult behaviors. Fifteen species of colonial waterbirds nesting at 17 colonies in north and central Florida were exposed to three different human disturbance mechanisms (HDMs) in order to determine recommended set-back (RS) distances for protecting these mixed-species nesting assemblages. Both intraspecific and inter-specific variation were observed in flushing response distances to the same human disturbance mechanisms. In general, colonial waterbirds exhibited greater average flush distances in reaction to a walking approach than to approaching motor boats. Recommended set-back distances were estimated using a formula based on the mean plus 1.6495 standard deviations of the observed flushing distances plus 40 meters [$RS = \exp(\mu + 1.6495\sigma + 40)$]. In general, a recommended set-back distance of about 100 meters for wading bird colonies and 180 meters for mixed tern/skimmer colonies should be adequate to effectively buffer the sites we studied from human disturbance caused by approach of pedestrians and motor boats. We recommend follow-up studies to test our model at other breeding colonies.*

Distancia de alejamiento para proteger de las perturbaciones humanas a las colonias de aves nidificadoras en Florida

Resumen: *Las aves acuáticas que habitan en colonias durante el período de cría, son particularmente susceptibles a las perturbaciones humanas por sus hábitos conducentes a una alta densidad de nidos. Los factores que disminuyen el éxito reproductivo, incluyen la mortalidad del huevo y el pichón, la evacuación del nido, la reducción de la masa corporal del pichón o crecimiento lento, el abandono prematuro del nido por parte de los pichones y comportamientos adultos modificados. Quince especies de colonias de aves acuáticas que nidificaron en 17 colonias del norte y centro de Florida, fueron expuestas a 3 mecanismos de perturbación humana diferentes, a los efectos de determinar distancias de alejamiento recomendables para proteger las agregaciones mixtas de éstas especies. Variaciones intra-específicas e inter-específicas en las distancias de respuesta frente a los mismos mecanismos de perturbación humana. En general, las colonias de aves acuáticas exhibieron una mayor distancia promedio antes de volar en reacción a la cercanía de pasos que al acercamiento de una embarcación a motor. La distancia recomendada de alejamiento fue estimada utilizando una fórmula basada en la media más 1.6495 desviaciones standard de la distancias antes de volar observada, más 40 m [$RS = \exp(\mu + 1.6495\sigma + 40)$]. En general, una distancia de alejamiento de alrededor de 100 m para las colonias de aves zancudas y 180 m para las colonias mixtas ("tern/skimmer"), sería adecuada para amortiguar a los sitios que estudiamos de los impactos de las perturbaciones humanas causadas por la aproximación de caminantes y embarcaciones con motor. Recomendamos estudios de seguimiento para probar nuestro modelo en otras colonias de cría.*

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Introduction

Human disturbance can adversely affect wildlife, with colonial breeding birds being particularly susceptible because of their high-density nesting habits. Several studies have shown both qualitative (Johnson & Sloan 1976; Ellison & Cleary 1978; Anderson & Keith 1980) and quantitative (Jenni 1969; Tremblay & Ellison 1979; Parsons & Burger 1982; Kaiser & Fritzell 1984) human impacts on colonial waterbirds. Adverse effects include egg and nestling mortality (Teal 1965; Schreiber 1979; Jeffrey 1987), premature fledging or nest evacuation (Veen 1977), and reduced body mass or slower growth of nestlings (Kurry & Gochfeld 1975; Pierce & Simons 1986). Adult behavior also may be altered by disturbance, resulting in altered foraging patterns (Skagen et al. 1991) and other detrimental effects on reproduction (Gillet et al. 1975; Tremblay & Ellison 1979; Cairns 1980; Safina & Burger 1983). Responses of colonial waterbirds to disturbance may vary with habitat type, physiography of the colony, food supply, seasonality, and bird species (Manuwal 1978; Ollason & Dunnet 1980; Erwin 1989). Some researchers also have reported no significant effects in relation to frequency of disturbance on breeding success (Goering & Cherry 1971) or various degrees of habituation to disturbances (Robert & Ralph 1975; Burger 1981a; Burger & Gochfeld 1981).

The increasing popularity of outdoor recreational activities in recent years has resulted in increased human disturbances of colonial waterbird breeding sites. This frequently has led to increased protection of these sites by placing them in public ownership and concomitantly, restricted recreational access to land and water around these breeding colonies. Conservation personnel are faced with the difficult task of effectively buffering important wildlife resources from disruptive human activities despite increasing demands for access to public lands. We define a set-back distance as a minimum distance of nonintrusion by humans measured from the perimeter of a colony that will preclude disturbances to nesting birds. Previous recommendations for set-backs around nesting colonial waterbirds as a strategy to alleviate disturbances have ranged from 50 to 200 meters for tern (Sterninae) species (Buckley & Buckley 1976; Erwin 1989) and 100 to 250 meters for wading bird (Ardeidae) species (Vos et al. 1985; Erwin 1989). Anderson (1988) suggested a "threshold" estimate of 600 meters to protect a Brown Pelican (*Pelecanus occidentalis*) colony in Mexico. Although Florida began protecting colonial waterbird nesting sites from human disturbance in 1976, the set-back distances currently used by a natural-resource personnel to protect avian colonies in Florida are not based on regional empirical data. Most set-back distances were derived from "best estimates" at the time of posting but were difficult

to defend on legal and biological grounds. Therefore, a multispecies study was conducted to determine the set-back distances necessary to protect nesting colonial wading birds and seabirds from human disturbance.

We were interested in determining if individual species members of the ground nesting guild (order Charadriiformes) and tree nesting guild (orders Pelecaniformes and Ciconiiformes) would exhibit similar flush distances to the same type of human disturbance. In Florida, the ground-nesting guild is represented by the gulls, terns, and skimmers (family Laridae), and the tree nesting guild is represented by wading birds (families Ardeidae, Threskiornithidae, and Ciconiidae) and other seabirds (families Pelecanidae, Anhingidae, Phalacrocoracidae). One proposed advantage of coloniality is its antipredator role (Lack 1968), and a primary advantage of increased vigilance is to allow the alerted birds to flee (Krebs 1978). Thus, colonial nesting may facilitate group vigilance, and similar species within each colonial nesting guild may exhibit similar flush distances. In addition, we wanted to identify the potential of various types of human activities for causing wildlife disturbance. Pedestrian and boat traffic are the most frequent forms of human disturbance to waterbird nesting in Florida, especially at colonies on islands and marine coastal sites.

Our primary goal in this study, however, was to recommend set-back distances to prevent human disturbance of single-species and mixed-species colonies. Herein, we develop a technique to calculate set-back distances around breeding-bird colonies and recommend this method as a general model that may be applied elsewhere for buffer zones specifically designed for each species and location.

Study Area

Data were collected at eight wading bird and nine seabird (collectively termed colonial waterbirds) nesting sites in Florida during the spring-summer of 1989–1991: Dee Dot Ranch (Duval Co.), a mixed-species wading-bird colony in a sparsely treed freshwater swamp, dominant nesting vegetation was cypress (*Taxodium distichum*); Matanzas Point (St. Johns Co.), two separate tern nesting sites in natural coastal dune habitat, sparsely vegetated with sea oats (*Untola paniculata*); Port Orange (Volusia Co.), a mixed-species wading-bird colony on a marine dredged-material island, dominant vegetation was black mangrove (*Avicennia germinans*); Oaks Mall (Alachua Co.), a mixed-species wading-bird colony in a freshwater swamp, dominant vegetation was southern willow (*Salix caroliniana*); Lake Yale (Lake Co.), a mixed-species wading-bird colony in a freshwater swamp, dominant vegetation was cypress; Haulover Canal (Brevard Co.), a mixed-species wading-

bird colony on a coastal dredged-material island, vegetation mostly coastal red cedar (*Juniperus virginiana*) and youpon holly (*Ilex vomitoria*); Pelican Island (Indian River Co.), a mixed-species wading-bird colony on a natural estuarine island, dominant vegetation was black and red (*Rhizophora mangle*) mangrove; St. Lucie Inlet State Park (St. Lucie Co.), a tern colony in coastal dune habitat; Island DS-3D (Hillsborough Co.), a tern and gull colony on a marine dredged-material island, little vegetation; Wakulla Springs State Park (Wakulla Co.), a cormorant colony in a freshwater riparian site along the banks of Wakulla Springs, primarily cypress trees; Holiday Island (Okaloosa Co.), a tern and skimmer colony in disturbed coastal dune habitat near Destin; Navarre Beach causeway (Santa Rosa Co.), a tern and skimmer colony nesting along the sparsely vegetated road right-of-way; St. George Island causeway (Franklin Co.), a tern and skimmer colony nesting along the sparsely vegetated road right-of-way; St. George Island State Park (Franklin Co.), a tern colony in natural coastal-dune habitat; Tern Island (Franklin Co.), a tern colony on an oyster-bar island in Alligator Harbor; and Phipps Point (Franklin Co.), a tern and skimmer colony on a sandy peninsula extending into Alligator Harbor. Further information for these sites are available in Portnoy et al. (1981) or Nesbitt et al. (1982).

Methods

This study was conducted under the Florida Administrative Code, General Purpose Wildlife Code 39-9.002, subsection 2, that permits personnel of the Florida Game and Fresh Water Fish Commission and their designated cooperating investigators to disturb birds for specific purposes of approved research. Our field work also followed the American Ornithologists' Union guidelines for scientists conducting research on wild birds (Oring et al. 1988). The time spent in each colony was less than or equal to the time required for normal nest-monitoring activities, thereby minimizing disturbance by researchers while still allowing data collection.

Three types of human disturbance mechanisms (HDMs) were used to elicit initial flushing responses: (1) walking (continuous, 1 step/sec, direct approach by 1-5 people on foot); (2) canoe (continuous, 0.5 m/sec, direct approach by 2 people in a 5.2 meter [17 foot] aluminum canoe); and (3) motorboat (continuous, 0.5 m/sec, direct approach by 2 people in a 4.3 meter [14 foot] aluminum jon-boat with a 30 hp motor of noise level 80-85 dBA). Our walking approach toward nesting birds essentially replicated Erwin's (1989) rate, which we considered a medium approach speed.

Experimental procedures were applied similarly among HDMs. Although the amount and types of vegetative cover varied among sites, all experimental nests were directly approached to allow an unobstructed cor-

ridor (≥ 5 m wide) of sight of the HDM by the nesting birds. The distance between the HDM and the nest was measured in meters using an optical range finder (Ranging, Inc., East Bloomfield, New York, U.S.A. models 120 and 620) with calibrated accuracies of ± 0.5 m (≤ 30 m) to ± 2.0 m (> 30 m). Each experimental bird and nest was at the edge of the breeding birds under observation and flushed in advance of other birds rising off their nests. Each test bird was classified as either an incubating adult (with eggs) or brooding adult (with nestlings) based on either direct observations or known colony breeding chronology. Response to a HDM usually involved alert or agonistic behavior, followed by rising off the nest and subsequent flight. Because it was difficult to quantify the initial alert/agonistic response distance due to concurrent breeding activity, we used the more readily detected and easily measured "flush distance" as an index of disturbance. It was defined as the distance from the HDM to the nest at the moment when the bird actually began movement away from the nest.

Nesting terns and skimmers may be more sensitive to human disturbance than other colonial waterbirds because they usually exhibit an "initial panic" or "initial mass upflight" (hereafter upflight) response when first disturbed (Palmer 1941; Erwin 1989). An initial upflight-response distance for terns was measured from the HDM to the colony edge. At some colonies, distances for individual flushed birds also were collected after the terns returned to their nests from an upflight during annual surveys. In these situations, the method varied from the initial upflight data collection in that 2-5 biologists were generally moving through a colony, with one person measuring the distance about 1 meter in front of the others. These individual flushing distances were analyzed for various trends separately from initial upflight distances because the birds already had been disturbed, but were not used in calculating the set-back distances (see below).

All data were collected between 0700 and 1600 hours on clear to partly cloudy days, with wind conditions less than 15 km/hour. Statistical analyses were conducted with PRODAS (Conceptual Software, Inc., Houston, Texas, U.S.A.). Observer bias in measurements of flush distances was minimized by having one or two observers take most of the measurements.

To reduce the effect of autocorrelation between the first disturbance and subsequent flushing events and to minimize our disturbance of avian breeding activities, we purposely limited the number of disturbances to one or two events per species or site at small, compact nesting colonies. Variances of statistics from autocorrelated observations would be biased because the observations were not independent. A negative (or inverse) relationship between successive approaches and flush distances would suggest that birds acclimated to our repeated

approaches. Because of these restrictions, our data were unbalanced (not all combinations of species, HDMs, sites, and years were represented). In these situations ($n < 5$), we were unable to analyze site-year classifications; therefore, this source of variability was untested. A greater number of disturbances were possible at some large waterbird colonies; multiple trials were conducted out of view of the preceding disturbance because the nesting habitat provided a physical barrier to direct visual and auditory contact with us and between successive, individually disturbed birds. For three species, we were able to collect data to compare the flush distances between breeding adults and older nestlings capable of movement from their nests. For nestlings, the approach distance also was measured as described above for adults. For large samples we plotted normal probability values and histograms for untransformed flushing dis-

tances. These histograms and scatter plots frequently yielded right-skewed distributions. With a threshold phenomenon such as minimum flush distance, this result was anticipated. Natural log transformation appeared to normalize distribution of the data; thus, all further analyses were performed on log-transformed data using parametric statistical procedures. Variances and standard deviation values in the text, Figures 1 and 2, and calculations recommending set-back distances from back-transformed data were estimated by application of the delta method to obtain the asymptotic distribution as described by Agresti (1984).

Because most colonies were visited only once a year, we could not test for seasonal variation or habituation. But for some species and colonies, we were able to examine the effect of successive approaches on flushing distance. For species with a sufficient sample size ($n \geq$

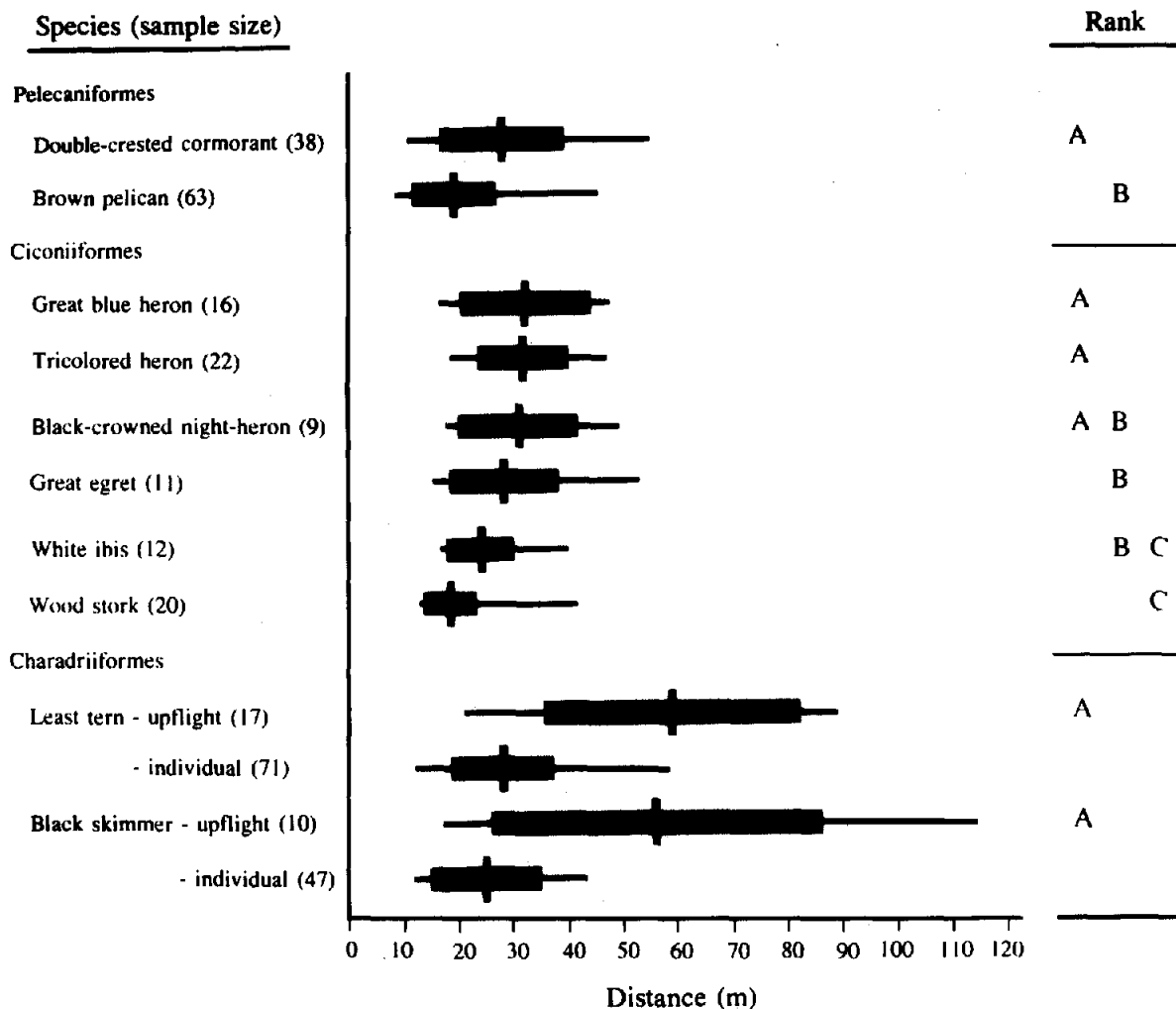


Figure 1. Distances at which colonial waterbirds flushed from nests in response to a walking approach directly toward their nest (vertical bar = mean; horizontal bar = range; solid horizontal box = ± 1 SD). Species within each order with the same letter under rank are not significantly ($p > 0.05$) different (ANOVA/Tukey's Multiple Range Test).

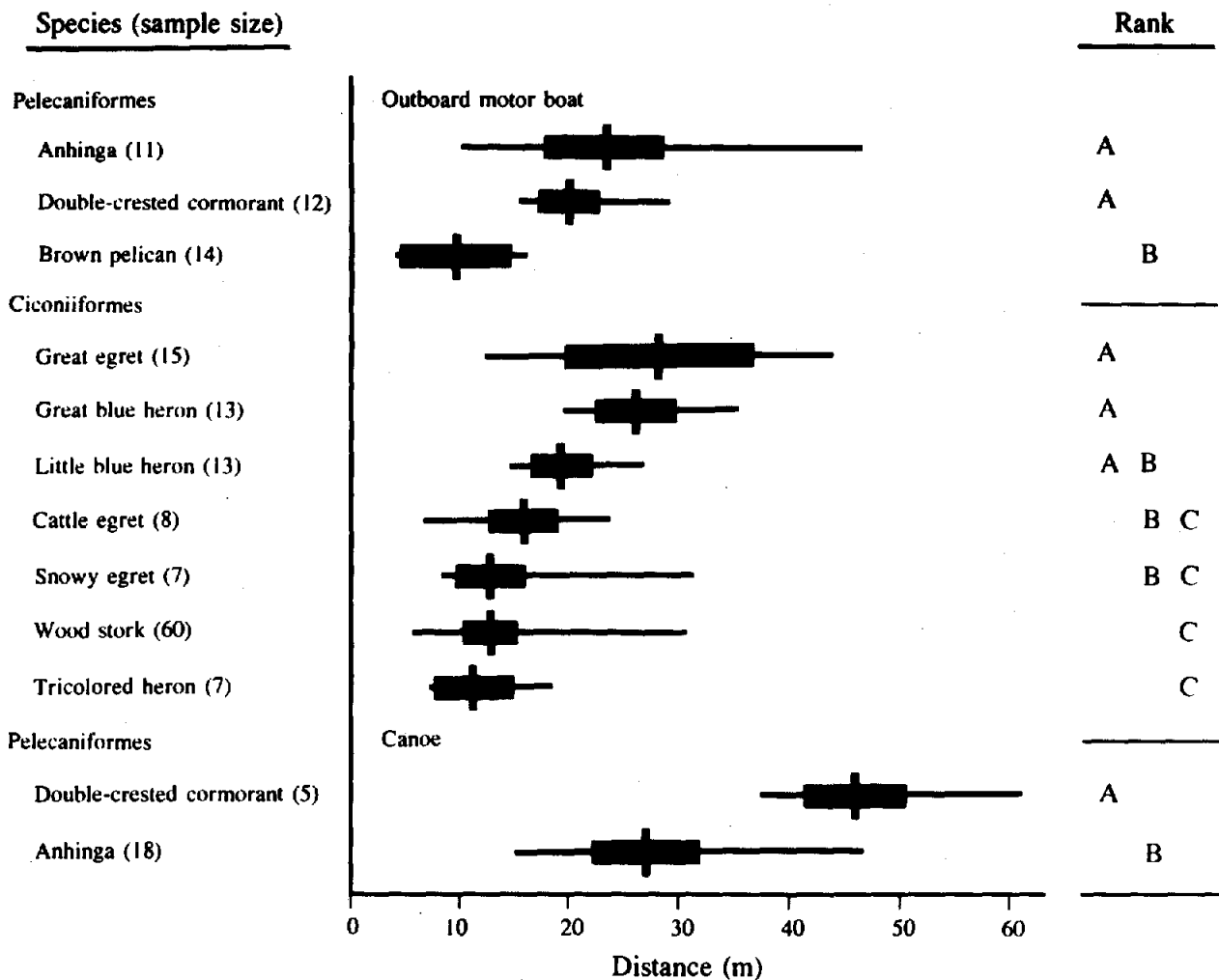


Figure 2. Distances at which colonial waterbirds flushed from nests in response to motor boat or canoe approach directly toward their nest (vertical bar = mean; horizontal bar = range; solid horizontal box = ± 1 SD). Species within each order with the same letter under rank are not significantly ($p > 0.05$) different (ANOVA/Tukey's Multiple Range Test).

5) collected on the same day, we tested for a trend in successive flushing distances and residual autocorrelation.

After eliminating data that exhibited trends or autocorrelation, the data were considered independent of one another. We combined a species' flush distances for some years and sites with small sample sizes ($n < 5$) for some colony-days (data collected on the same day at the same colony). We recognize that this may confound the effects of HDMs on flush distances for some species. To test for differences among species within the same HDM, we first tested for homogeneity of variances using Bartlett's X^2 statistic for sample sizes of at least 5, followed by a t -test or ANOVA/Tukey's Multiple Range Test on the subsets (species \times HDM, species \times species \times HDM). Where colony-days did not differ in variance of flush distances, we concluded that the individual ap-

proaches could be treated as the experimental unit and that each flushing response was a single datum.

Results

Data were collected on the flushing distances of 15 species of breeding colonial waterbirds in reaction to the three HDMs at 17 sites in Florida during 1989-1991.

Walking Approach

Wood Storks (*Mycteria americana*) exhibited the smallest mean flush distance (18.4 ± 5.5 m), whereas Great Blue Herons (*Ardea herodias*) possessed the largest mean flush distance (32.0 ± 12.3 m) to a walking approach (Fig. 1). There were significant (ANOVA/Tukey's M.R.T., $p < 0.05$) differences among some spe-

cies of colonial waterbirds to a walking approach that precluded further pooling of the data for the tree-nesting guild into taxonomic groups, such as family and order, higher than the species level. Mean upflight distances for Least Terns (*Sterna antillarum*, 59.0 ± 23.6 m) and Black Skimmers (*Rynchops niger*, 56.2 ± 30.6 m) to a walking approach were about twice the mean individual bird-flush distances (27.9 ± 9.4 m and 25.0 ± 9.6 m, respectively) from their nests after returning from an upflight (Fig. 1).

We found significant ($p < 0.05$) negative relationships—flush distances shorter with successive on-foot approaches—only for Laughing Gulls (*Larus atricilla*) at the Island DS-3D colony ($r^2 = 0.14$, $p < 0.04$, $n = 31$) and Cattle Egrets (*Bubulcus ibis*) at the Port Orange colony ($r^2 = 0.66$, $p < 0.001$, $n = 12$). We found a significant ($p < 0.05$) positive relationship—flush distances increased with successive on-foot approaches—for individual Black Skimmers at the St. George Island causeway colony during the incubation period of 1989 and 1990 ($r^2 = 0.66$, $p < 0.001$, $n = 22$; $r^2 = 0.25$, $p < 0.001$, $n = 56$; respectively), but not during the later nestling period. We also investigated autocorrelation (especially first order) using autocorrelation plots, plots of lagged-regression residuals, and Durbin-Watson tests (D) for independence of serial correlation among residuals. We detected significant ($p < 0.05$) positive first-order autocorrelation only for flush distances of individual Least Terns during the incubation period at St. George Island causeway (1989: $D = 0.906$, autocorrelation = $+0.513$, $n = 18$; 1990: $D = 1.543$, autocorrelation = $+0.224$, $n = 77$). Consequently, the individual flush distances for Least Terns and Black Skimmers at the St. George Island causeway colony represented in Figure 1 are the data collected during the nestling period that did not exhibit a significant relationship or autocorrelation between successive walking approaches. As the recommended set-back distances for these two species were calculated from the larger up-flight distances (see Fig. 1 and Table 1), these effects are discussed here but did not confound our set-back recommendations.

Boat Approach

Brown Pelicans exhibited the shortest individual flush distance (4 m) and mean flush distance (9.4 ± 5.5 m), whereas Great Egrets (*Casmerodius albus*) possessed the longest mean flush distance (28.9 ± 8.6 m) at the approach of a boat (Fig. 2). As with the walking approach, there were significant differences (ANOVA/Tukey's M.R.T., $p < 0.05$) in the flush distances among some species of the tree-nesting guild that prevented pooling these data into taxa higher than the species level.

Table 1. Recommended set-back (RS) distances between breeding colonial waterbirds and a walking or motor boat approach directly toward the nest.

Order and Species	RS Distance (m) ^a	
	Walking	Motor Boat
Pelecaniformes		
Brown Pelican (<i>Pelecanus occidentalis</i>)	76	65
Double-crested Cormorant (<i>Phalacrocorax auritus</i>)	96	71
Anhinga (<i>Anhinga anhinga</i>)		89
Ciconiiformes		
Great Blue Heron (<i>Ardea herodias</i>)	100	82
Great Egret (<i>Casmerodius albus</i>)	91	87
Snowy Egret (<i>Egretta thula</i>)		67
Tricolored Heron (<i>E. tricolor</i>)	88	59
Little Blue Heron (<i>E. caerulea</i>)		71
Cattle Egret (<i>Bubulcus ibis</i>)		70
Black-crowned Night-Heron (<i>Nycticorax nycticorax</i>)	97	
White Ibis (<i>Eudocimus albus</i>)	76	
Wood Stork (<i>Mycteria americana</i>)	65	63
Charadriiformes		
Least Tern ^b (<i>Sterna antillarum</i>)	154	
Black Skimmer ^b (<i>Rynchops niger</i>)	178	

^a RS distance was calculated by using the formula $RS = \exp(\hat{\mu} + 1.6495 \hat{\sigma}) + 40$ m. Values were rounded to nearest whole number.

^b RS distances for these species were based on the upflight response.

Canoe Approach

Double-crested Cormorants (*Phalacrocorax auritus*) flushed at significantly greater distances ($t = 2.580$, $p < 0.05$) than Anhingas (*Anhinga anhinga*) in our limited data set (Fig. 2).

Comparisons of HDMs

Brown Pelicans ($t = 2.333$), Double-crested Cormorants ($t = 6.168$), Great Blue Herons ($t = 5.172$), and Tricolored Herons (*Egretta tricolor*, $t = 4.351$) exhibited significantly ($p < 0.05$) shorter flush distances to an approaching boat than to walking humans, whereas the Great Egret showed similar flush distances ($t = 1.174$, $p > 0.05$) to approaches on foot and in a boat (Figs. 1 and 2). Flush distances for canoe and motor boat approaches (Fig. 2) were similar ($t = 1.370$, $p > 0.05$) for the Anhinga.

Double-crested Cormorants exhibited significantly ($p < 0.05$) greater flush distances than Brown Pelicans for

motor boat ($t = 8.291$) but not for walking ($t = 1.140$). Great Blue Herons and Great Egrets appear to be two of the more sensitive species when approached on foot or in a boat (Figs. 1 and 2).

Nesting and Interyear Comparisons

There were no significant ($p > 0.05$) differences in flush distances between incubating and brooding adult Brown Pelicans (17.2 ± 10.1 m [$n = 38$] and 22.5 ± 9.3 m [$n = 25$], respectively; $t = 1.527$) and Double-crested Cormorants (24.2 ± 12.6 m [$n = 24$] and 33.2 ± 14.5 m [$n = 14$], respectively; $t = 1.185$) for the walking HDM. There were no significant ($p > 0.05$) differences in flush distances collected between 1989 and 1990 among adult Brown Pelicans for the walking HDM (18.0 ± 6.3 m [$n = 45$] and 23.0 ± 5.6 m [$n = 18$], respectively; $t = 1.383$) and individual flush distances of adult Least Terns (33.4 ± 9.9 m [$n = 18$] and 26.3 ± 10.7 m [$n = 53$], respectively; $t = 1.318$), and individual Black Skimmers for the walking HDM (21.5 ± 8.3 m [$n = 22$] and 28.5 ± 13.6 m [$n = 25$], respectively; $t = 1.188$) approaches.

Adult Least Terns (27.9 ± 9.4 m, $n = 71$) and Black Skimmers (25.0 ± 9.6 m, $n = 47$) exhibited significantly greater individual flush distances ($t = 1.668$ and 1.854 , respectively; $p < 0.05$) than unattended, mobile nestling terns (17.2 ± 12.3 m, $n = 21$) and skimmers (16.3 ± 4.4 m, $n = 19$) during a walking approach. Adult (19.2 ± 7.4 m, $n = 63$) and nestling (21.3 ± 3.5 m, $n = 12$) Brown Pelicans exhibited similar ($t = 1.523$, $p > 0.05$) flush distances to walking approaches.

Discussion

Our study detected interspecific response variation to the same HDM among colonial waterbirds, especially among the tree-nesting guild. Great Blue Herons and Great Egrets generally exhibited the largest flush distances, whereas Brown Pelicans and Wood Storks generally possessed the smallest flush distances. Other studies also have found similar variation among species (Manuwal 1978; Ollason & Dunnet 1980; Burger & Gochfeld 1981; Erwin 1989). Mueller and Glass (1988) noted that some species of waterbirds—Snowy Egrets (*E. thula*), Tricolored Herons, and White-faced Ibises (*Plegadis chibi*)—were more adversely affected by disturbance than other species. We also found that some species, such as Brown Pelicans and Cattle Egrets, were relatively tolerant of human disturbance. This may be due to their long association with and habituation to human activities in Florida; pelicans frequently associate with fishing activities and “panhandle” at docks and piers, and Cattle Egrets often follow farm machinery.

Several species (Brown Pelican, Double-crested Cormorant, Great Blue Heron, Tricolored Heron) exhibited shorter mean flush distances to a boat approach com-

pared to a walking approach. Vos et al. (1985) reported that most boating activity caused the least disturbance to Great Blue Herons. Grubb and King (1991) also found that pedestrian traffic was the human activity most disturbing to Bald Eagles (*Haliaeetus leucocephalus*), and Klein (1993) found that human traffic was more disruptive than vehicular traffic to several species of foraging waterbirds.

We did not detect differences in the flush distances between incubating and brooding adults. Likewise, Erwin (1989) reported no significant correlations between response distances and nesting phase, though he did note a weak ($p = 0.10$) relationship for Least Terns and nesting phase. In our study, three species (Brown Pelicans, Least Terns, and Black Skimmers) demonstrated that a set-back distance that prevents flushing by nesting adults also should provide an adequate buffer zone to prevent flushing (nest evacuation) by older, mobile juvenile birds. In addition, the upflight distances were greater than the individual flush distances of nesting Least Terns and Black Skimmers and therefore should be used to calculate set-back distances for these species.

We detected both decreasing distance responses to repeated approaches (among Cattle Egrets, Laughing Gulls) and increasing distance responses to sequential approaches (among Black Skimmers), as well as, first-order autocorrelated responses (among Least Terns) during our analyses. It appears that the responses of individuals of these four species to a sequential on-foot approach may have been affected by our previous approaches. Both acclimation to disturbance and increased sensitivity to disturbance phenomena should be considered by researchers in future studies. We could have adjusted for the effects of first-order autocorrelation by multiplying the estimated variance by a function of the estimated autocorrelation coefficient. Because of the much greater distances for the upflight responses of Least Terns and Black Skimmers, however, we did not use data on the flush distances of individual birds for these two species when estimating the recommended set-back distances as we did for the other colonial waterbirds. In addition, we did not estimate set-back distances for Cattle Egrets and Laughing Gulls because of a significant negative relationship in successive approach and flush distances for these two species. To compensate for the effects of acclimation, these species could be represented by a statistic related to the predicted regression value of the first observation, rather than a statistic based on the species mean. However, we did not have enough data to do this. Future research by other investigators should consider these factors when designing and testing hypotheses.

One proposed advantage of coloniality for single-species and multi-species assemblages or nesting guilds is antipredator defense via early warning to colony

members (see reviews in Burger 1981b; Wittenberger & Hunt 1985). Least Terns and Black Skimmers exhibited similar long upflight distances, an advantage for these ground-nesting guild species. The tree-nesting guild species (Pelecaniformes and Ciconiiformes) showed smaller flush distances, however, possibly the result of nesting above ground level and security from approach of some mammalian predators. These tree-nesting species also exhibited greater interspecific differences in their flush distances. A possible advantage of these mixed-species nesting assemblages would be group vigilance that allows the alerted birds to flee from a predator (Krebs 1978). The intermediate-sized day herons (such as Little Blue Heron, Tricolored Heron, Snowy Egret) that tend to nest under the vegetative canopy (see Burger 1978) would gain an advantage by nesting with the more vigilant (larger flush distances) Great Blue Herons and Great Egrets that tend to nest higher in the canopy.

It appears that acclimation to tangential vehicle traffic also occurs among some colonial waterbirds. Although we made no direct test in this study to determine the minimum distance to elicit a flush response to a tangentially moving vehicle, data from another study demonstrated that Least Terns ($\bar{x} = 11.0$ m, range = 7–15 m, $n = 103$ nests) and Black Skimmers ($\bar{x} = 12.6$ m, range = 9–17 m, $n = 66$ nests) nested closer ($t = 2.247$ and 3.225 , respectively; $p < 0.001$) to the road edge compared to their individual flush distances (least tern: $\bar{x} = 26.6$ m, range = 12–59 m, $n = 54$ nests; Black Skimmer: $\bar{x} = 25.0$ m, range = 12–44 m, $n = 47$ nests) in response to walking approaches at the St. George Island causeway colony. The factor limiting nest site proximity to the roadway at this colony was apparently the lack of suitable substrate within the adjacent grass-covered right-of-way. Only rarely did terns and skimmers nesting at the St. George Island causeway colony flush in mass due to nearby (about 10–15 meters) tangential vehicular traffic such as large, noisy tractor-trailers. This suggests that habituation to some types of human disturbance is possible for some species at some sites, especially when breeding habitat is limited as for larids in Florida. Similar instances of acclimation by colonial waterbirds have been reported by Grubb (1978) and Anderson (1988).

Recommendations and Implementation

A major conclusion of our study is that all species must be considered when recommending set-back distances around mixed-species waterbird colonies. Association with mixed-species aggregations may even increase the flushing distances for some species (Stinson 1988). Several authors have recommended set-back distances to protect colonial waterbirds from human disturbance.

Vos et al. (1985) recommended buffer zones of 250 meters on land and 150 meters on water for Great Blue Herons. Anderson (1988) proposed a minimum of 600 meters for Brown Pelicans nesting on an island off the west coast of Mexico, but this "minimum threshold" value was derived from indirect estimates of human traffic along roadways. Schreiber and Schreiber (1978) recommended that Double-crested Cormorants nesting in single-species or mixed-species colonies should not be approached "closer than 75 m." The most extensive study that specifically examined disturbances to colonial waterbirds was by Erwin (1989). Based on a mean (\pm SD) flushing distance formula, Erwin (1989) recommended a buffer zone of 100 meters for Least Terns and wading birds and 200 meters for Black Skimmers and Common Terns (*S. hirundo*). For terns and skimmers, Erwin (1989) used the upflight response to recommend set-back distances.

Our attempts to quantify the onset of alert and agonistic behaviors by colonial waterbirds in response to exposure to various HDMs proved very difficult. Because of much concurrent nesting activity, it was not always possible to detect when the bird under observation exhibited an alert/agonistic response to the HDM. However, observations from blinds indicated that nesting birds generally became agitated by an approaching disturbance 25–40 meters ($n = 33$) prior to flushing from the nest. This distance is similar to the additional buffer-zone distance of 50 meters recommended by Vos et al. (1985). The addition of 40 meters (+40 m) to the flushing distances of our sampled populations would be a conservative approach to minimize alert/agonistic responses and likewise allow for effects related to variation in vegetative cover, intraseasonal differences, and food supply that might cause increased stress on the colony (Hunt 1972; van der Zande & Vestral 1985), and other environmental variables that can influence flush distances.

We estimated recommended set-back (RS) distances for individual species of breeding colonial waterbirds calculated from the mean and standard deviation of our sampled populations (Table 1). For a given species, let X_i represent the observed flushing distance for an individual nest approach i and $Y_i = \ln(X_i)$. We assumed that the X_i are independent, identically distributed and follow a lognormal distribution with the parameters μ and σ such that $\mu = E(Y_i)$ and $\sigma^2 = \text{var}(Y_i)$. Using $Q_{0.95}$ as the ninety-fifth percentile of this distribution ($0.95 = P(X_i \leq Q_{0.95})$), the desired RS distance was considered to be $Q_{0.95} + 40$. To estimate $Q_{0.95}$ and the RS, the relationship between percentiles of the lognormal and normal distributions was used. Thus, for the ninety-fifth percentile of a standard normal distribution, $Z_{0.95} = 1.6495$ and

$$Q_{0.95} = \exp(\mu + 1.6495\sigma).$$

Then, the estimated RS distance was calculated as

$$\hat{RS} = \exp(\hat{\mu} + 1.6495\hat{\sigma}) + 40,$$

where $\hat{\mu}$ and $\hat{\sigma}$ are the sample mean and standard deviation for the observed values of $Y_i = \ln(X_i)$, $i = 1, \dots, n$. We believe that the one-tailed 5% criterion provides a sufficiently conservative margin in the establishment of RS distances for colonial waterbirds while providing a procedure that does not require assumptions that are unreasonable for our data.

Human disturbance during wildlife viewing can subtly disrupt community dynamics (Skagen et al. 1991). Therefore, at mixed-species colonies of waterbirds, the most sensitive species—the most “skittish” species with the greatest flush distance—should be used for determining the RS distance. We further recommend that the upflight distances be used to calculate the RS distance for mixed tern and skimmer colonies. Due to low sample sizes, we were unable to estimate a RS distance for most species disturbed by approach of a canoe. For Anhingas, however, the RS distance for a canoe approach (88 m) is similar to that of a motor boat (89 m). Thus, we tentatively recommend that a RS distance for canoes and other similar vessels be the same as for a motor boat (Table 1). For mixed-species colonies that are subject to multiple HDMs, our data suggest that a RS distance of about 100 meters for wading-bird colonies and about 180 meters for tern/skimmer colonies should provide an adequate buffer zone around the populations we sampled in Florida.

We urge conservation personnel to use prudence when implementing the RS distances in Table 1 for single-species or mixed-species colonies elsewhere. For example, on remote islands seldom visited by humans, terns and other pelagic ground-nesters may be more sensitive than in our study. At the other extreme, some species may exhibit degrees of acclimation to various disturbances for short periods of time (as with the St. George Island causeway colony). But, we believe acclimation phenomena should neither be used as justification for reducing buffer-zone distances nor for attempting to habituate any species to HDMs after birds have colonized a site. Some mitigation may be possible for shorter RS distances when physical barriers prevent direct visual contact between breeding birds and HDMs with low noise levels. Also, some evidence suggests that tangential approach by a HDM (such as vehicular traffic) may allow for a shorter RS distance. This effect may be similar to one observed by Burger and Gochfeld (1981) for Herring Gulls (*L. argentatus*) that responded to the potential threat of approach by a researcher at greater distances if the approach was direct rather than tangential. Henson and Grant (1991) also noted that breeding Trumpeter Swans (*Cygnus buccinator*) only reacted to common vehicular traffic when the vehicles stopped

along roadways or sounded their horns. We have observed similar behavioral responses by Least Terns and Black Skimmers at the St. George Island causeway colony and by Cattle Egrets at an I-75 colony during this study.

Conservation personnel must monitor breeding colonies for changes in species composition so that the RS distance can be adjusted for the presence of new, more sensitive species with greater flush distances. Likewise, the perimeter of breeding colonial waterbirds must be monitored annually so that the RS distance reflects current colony boundaries (see Buckley & Buckley 1972; Kerns & Howe 1967; Beaver et al. 1980). Managers also must know if a breeding colony is used as a winter roost to determine if the RS distance should be maintained during the nonbreeding season. If the RS distance is discontinued during the nonbreeding season, it should be re-established several weeks prior to the arrival of breeding birds based on previous monitoring of the breeding chronology of the colony. Effects on the prelaying portion of the breeding cycle associated with disturbance may include disrupted occupation of colony sites (Conover & Miller 1978), subcolony prelaying abandonment (Safina & Burger 1983), or other adverse effects on pair-bond establishment and nest-site selection behavior.

We recommend additional research to examine the effects of variable approach speeds (especially rapid, erratic movements), tangential approaches, presence of seasonal variation in response to disturbance, and other types of HDMs (such as jet-ski vehicles, aircraft overflights, etc.). We realize that there are limits to our method of calculating estimated RS distances for each species and that the values are more subjective than implied from the RS equation. Because of the variation in flush distances among individual birds and species, RS distances may need to be developed on an individual-colony basis. However, we believe the principles and techniques developed here may be applied elsewhere to serve as a general model for specific design of RS distances for each species, location, and situation.

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