Buffer-Zone Distances to Protect Foraging and Loafing Waterbirds from Disturbance by Personal Watercraft and Outboard-Powered Boats

JAMES A. RODGERS JR.* AND STEPHEN T. SCHWIKERT

Bureau of Wildlife Diversity Conservation, Florida Fish and Wildlife Conservation Commission, 4005 South Main Street, Gainesville, FL 32601-9099, U.S.A.

Abstract: *Outdoor recreation and ecotourism can have negative effects on wildlife species, so it is important to determine buffer zones within which activities near critical wildlife areas are limited. We exposed 23 species of waterbirds (Pelecaniformes, Ciconiiformes, Falconiformes, Charadriiformes) to the direct approach of a personal watercraft (PWC) and an outboard-powered boat to determine their flush distances. We used 11 sites with a mixture of low, moderate, and high amounts of human activity along the east and west coasts of Florida during September–November 1998 and April–June 1999. We detected considerable variation in flush distances among individuals within the same species and among species in response to both types of vessels. Average flush distances for the PWC ranged from 19.5 m (Least Tern [*Sterna antillarum*]) to 49.5 m (Osprey [*Pandion haliaetus*]), whereas average flush distances for the outboard-powered boat ranged from 23.4 m (Forster's Tern [*S. forsteri*]) to 57.9 m (Osprey). Larger species generally exhibited greater average flush distances for both types of watercraft. A comparison of the flush distances elicited by each watercraft indicated that only the Great Blue Heron (*Ardea herodias*) exhibited significantly larger flush distances (*t test, $p < 0.01$) in response to the approach of the PWC than in response to the outboard, whereas four species (Anhinga [*Anhinga anhinga*], Little Blue Heron [*Egretta caerulea*], Willet [*Catoptrophorus semipalmatus*], and Osprey) exhibited significantly larger flush distances (*t test, $p < 0.05$) in response to the approach of the outboard-powered boat than in response to the PWC. Eleven species (68.8%) showed no significant difference (*t test, $p > 0.05$) in their flush distances in response to the fast-moving PWC and the outboard-powered boat. Our data suggest that a single buffer-zone distance can be developed for both PWC and outboard-powered vessels. Buffer zones of 180 m for wading birds, 140 m for terns and gulls, 100 m for plovers and sandpipers, and 150 m for ospreys would minimize their disturbance at foraging and loafing sites in Florida.*

Distancias de Amortiguamiento para Proteger a Aves Acuáticas en Actividades de Forraje y Descanso de la Perturbación por Embarcaciones Personales y Motores Fuera de Borda

Resumen: *La recreación exterior y el ecoturismo pueden tener efectos negativos sobre la vida silvestre, por lo que es importante determinar áreas de amortiguamiento dentro de las cuales se limiten actividades cerca de áreas críticas para la vida silvestre. Expusimos a 23 especies de aves acuáticas (Pelecaniformes, Ciconiiformes, Falconiformes, Charadriiformes) al acercamiento directo de embarcaciones personales (EP) y de una lancha con motor fuera de borda para determinar sus distancias de impacto. Utilizamos 11 sitios con una mezcla de actividad humana baja, moderada y alta a lo largo de las costas orientales de la Florida durante septiembre–noviembre 1998 y abril–junio 1999. detectamos una variación considerable en la distancia de impacto entre individuos de la misma especie y entre especies en respuesta a varios tipos de embarcaciones. Las distancias promedio de impacto para los EP varió de 19.5 (*Sterna antillarum*) a 49.5 m (águila pescadora, *Pandion haliaetus*) mientras que las distancias promedio de impacto para las lanchas con motor fuera de borda varió de 23.4 (*S. forsteri*) a 57.9 m (águila pescadora). Las especies grandes generalmente exhibieron mayor distancia promedio de impacto para ambos tipos de embarcación. La comparación de las distancias*

*email rodgerj@fwc.state.fl.us

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de impacto producidas por cada tipo de embarcación indicó que solo Ardea herodias *presentó distancias de impacto significativamente mayores (prueba de* t, $p < 0.01$*) a la aproximación de EP comparadas con la embarcación con motor fuera de borda, mientras que cuatro especies (*Anhinga anhinga, Egretta caerulia, Catoptrophorus semipalmatus *y* Pandion haliaetus*) presentaron distancias de impacto significativamente mayores (prueba de* t, $p < 0.05$*) a la aproximación de la lancha con motor fuera de borda comparadas con EP. Once especies (68.8%) no tuvieron diferencias significativas (prueba de* t, $p < 0.05$*) en las distancias de impacto para EP ni la lancha con motor fuera de borda. Nuestros datos sugieren que se puede establecer una distancia de amortiguamiento tanto para EP, como para las embarcaciones con motor fuera de borda. Zonas de amortiguamiento de 180 m para aves vadeadoras, 140 m para golondrinas de mar y gaviotas, 100 m para chorlitos y lavanderas y 150 m para águilas pescadoras minimizarían la perturbación en sitios de forrajeo y descanso en Florida.*

Introduction

Human activities can affect an animal's ability to feed, rest, and breed if it is unable to habituate to the disturbance caused by the activity (Whittaker & Knight 1998; Fernández-Juricic & Tellería 2000). Conflicts often arise because many aquatic habitats, such as shorelines, beaches, sandbars, and islands, used by foraging and loafing waterbirds also are attractive to outdoor recreationists and ecotourists. For example, Burger (1981) reported a reduced number of shorebirds near people who were walking or jogging, and about 50% of flushed birds flew elsewhere. Burger and Gochfeld (1998) also found that many species of waterbirds decreased their foraging time and increased their vigilance when people were nearby. More sensitive species may find it difficult to secure adequate food or loafing sites as their preferred habitat becomes fragmented and recreation-related disturbances increase (Skagen et al. 1991; Pfister et al. 1992).

The distance between human activities and wildlife is a major factor in determining if and when birds exhibit agonistic behaviors or flee disturbances (Burger 1981; Belanger & Bedard 1989; Burger & Gochfeld 1991*a*,1991*b*; Grubb & King 1991; Klein 1993; Roberts & Evans 1993; Fernández-Juricic and Tellería 2000). Avian flush distance in response to various types of disturbance is one variable used in developing zones that restrict human activities (Knight & Knight 1984; Rodgers & Smith 1995, 1997). Such buffer zones or set-back distances are one strategy used to minimize the effects of human activities on waterbirds (Erwin 1989; Rodgers & Smith 1995, 1997). Carney and Sydeman (1999) provide a review of the effects of human recreational activities and buffer zones on nesting waterbirds. Set-back distances based on stimulus-response data have only recently been developed to protect breeding colonies (Erwin 1989; Rodgers & Smith 1995) and foraging and loafing birds (Rodgers & Smith 1997) from the approach of humans on foot, in motor vehicles, and in slow-moving outboard-powered boats. The single published study of avian response to personal watercraft (PWC), commonly referred to as jetskis, investigated only Common Terns (*Sterna hirundo*; Burger 1998).

There are an estimated 1.3 million PWC in the United States, and 106,000 vessels are sold annually (Burger & Leonard 2000; Personal Watercraft Industry Association 2000). Due in part to its warm waters and climate and extensive coastal shorelines, Florida had 143,548 registered PWC in 1999 (D. Perryman, personal communication), which does not include the number of PWC brought into the state by visitors. In addition to their ability to accelerate and decelerate during erratic turns and maneuvers, PWC can travel into relatively shallow, secluded wetlands that are favored by foraging and loafing waterbirds. Because of these characteristics, PWC have the potential to cause disturbance to the wide variety of resident, wintering, and migrating waterbirds along both coasts of Florida.

Buffer zones are most effective when their size is based on stimulus-response experiments rather than anecdotal observations of wildlife responses to human activities. We used a stimulus-response technique to examine flushing distances in response to human activities previously developed to protect waterbirds in Florida (Rodgers & Smith 1995, 1997). The goal of our study was to determine buffer distances that would minimize disturbance to foraging and loafing waterbirds by both fast-moving PWC and outboard-powered vessels in Florida.

Methods

Study Area and Data Collection

We conducted our study along the east and west coasts of Florida during September–November 1998 and April–June 1999. We visited 11 sites with a mixture of low (≤5 boats/hour), moderate (>5 to <10 boats/hour), and high (≥10 boats/hour) amounts of human activity visible within 1000 m of the birds. We visited multiple sites to avoid problems of bias, habituation, and autocorrelation in the response of birds. We used two types of watercraft to flush birds: a 14-foot Monarch aluminum jonboat (length 4.4 m, width 1.8 m) with a 30-horsepower Mercury outboard motor and a Sea·Doo PWC model GTX (length 3.2 m, width 1.2 m). The noise levels (decibels) recorded during a direct approach of the PWC were 83 dBA at 10 m, 77 dBA at 20 m, 72 dBA at 30 m, 69 dBA at 40 m, and 64 dBA at 50 m; the noise levels of the outboard-powered boat were 87 dBA at 10 m, 82 dBA at 20 m, 76 dBA at 30 m, 71 dBA at 40 m, and 66 dBA at 50 m.

We flushed birds only when they were engaged in foraging and loafing behaviors. Because it was not always possible to detect the initial alert response to the approaching vessel, we used the more readily detected and easily measured flush distance as an index of watercraft disturbance (Rodgers & Smith 1995, 1997). Flush distance was defined as the distance from the vessel to the bird at the moment it began walking, running, or flying away from the approaching watercraft. When approaching a group of birds, we measured the distance between the watercraft and the first bird in the group that flushed, using a Bushnell yardage pro laser range finder with a calibrated accuracy of ± 1 m.

For each approach toward an experimental bird or group of birds, two people used a standardized stimulus-response technique for both types of watercraft. A lead observer on one PWC located the subject bird from a distance of at least 250 m and approached it in a direct but irregular path at a speed of 35–40 km/hour. At the instant the bird began to move from its foraging or loafing location, a marker buoy was dropped into the water. A second observer on another PWC moved to the marker buoy and measured the straight-line distance from the marker to the former location of the flushed bird. The use of the jonboat was different in that both people were in the boat, but the approach toward the bird, marking the flushing point, and measuring the flush distance were similar.

We restricted data collection to between 0700 and 1600 hours on clear to partly cloudy days with windspeed of $<$20 km/hour. To reduce the effect of autocorrelation between the first bird flushed and subsequent flushing events, and to minimize our effects on avian activities, we limited the number of disturbances to one or two approaches at each site within 1000 m of another site. Flush distance for an individual bird or flock was measured only once. Because of these restrictions, sample sizes often were unbalanced (i.e., not all species were represented by sample sizes of $\geq$10) in terms of species, age, and site-variable classes (e.g., level of disturbance, location).

Data Analysis

We plotted the empirical quantiles versus the quantiles of a standard normal distribution and histograms for untransformed flush distances for species with $\geq$10 observations using the UNIVARIATE procedure (SAS Institute 1990*a*). We used the Shapiro-Wilk statistic to test whether the data were normally distributed for each species $\times$ vessel type and species $\times$ vessel type $\times$ site comparison. Residuals from an analysis of variance (ANOVA) model plotted against the predicted values were also examined for a random scatter that suggested homogeneity of variance and the appropriate transformation of the flush distances. Analysis of the data indicated that the distances most often exhibited a right-skewed distribution and required a log transformation to normalize the data. We used ANOVA/Fisher's least-significant difference (LSD) tests (SAS Institute 1990*b*,1990*c*) on subsets (i.e., species $\times$ vessel type and species $\times$ species) to test the null hypothesis that no significant ($p >$ 0.05) differences exist in the flush distances among species and vessel type.

We could not examine the effect of the amount of human activity on the flushing distance of birds because of small sample sizes for individual species. Because we pooled the data for all sites when comparing the flush distances between PWC and outboard-powered boats, there is the likelihood of Type II error, the probability of not detecting a difference in the flushing distances between PWC and outboard-powered boats when a difference exists. The possible management implication is that different buffer zones will not be established for the two vessel types when warranted.

We calculated recommended buffer distances for individual species using a formula based on the mean and 1 SD of the sampled populations (Rodgers & Smith 1995, 1997). We could not always determine when the bird under observation first exhibited an alert response to the approach of our watercraft because of concurrent activity of other birds or reactions to prey while a bird foraged. But the mean difference between when a bird exhibited alert behavior and flushed was 17.55 m (SD = 11.89 m; range, = 3–67 m, n = 266 flushes pooled among all species and both vessel types). The estimated upper limit for the ninety-fifth percentile of the alert distance prior to flushing was 36.87 m, which agrees closely with previous observations from blinds when single birds approached by a person became alert 25–40 m prior to flushing (Rodgers & Smith 1995). The addition of 40 m to the calculation of buffer distances for our sampled populations is a conservative strategy to minimize agonistic responses by birds and take into consideration the possibility that mixed-species assemblages (Thompson & Thompson 1985) and conspecific flocks (Gutzwiller et al. 1998) are more vigilant and sensitive than single-species groups or individuals.

We derived buffer distances in the following manner for each species with $\geq$10 observations. For a given species, X_i was the observed flush distance for an individual approach i, and the transformed distance was $Y_i = \ln(X_i)$.

We assumed that X_i are independent and identically distributed and follow a lognormal distribution with parameters μ (mean) and σ (SD) such that $\mu = E(Y_i)$ and $\sigma^2 = \text{var}(Y_i)$. The desired buffer distance was defined as the approximate upper one-sided 95% confidence limit for the back-transformed value $E(X)$ plus 40 m:

$$\text{buffer distance} = \exp(\hat{\mu} + Z_{0.95}\hat{\sigma}) + 40 \text{ m}, \qquad (1)$$

where $\hat{\mu}$ and $\hat{\sigma}$ are the sample mean and standard deviation for the observed values of $Y_i = \ln (X_i)$, $i = 1, ..., n$, and $Z_{0.95}$ is the 0.95 quantile of a standard normal variable (i.e., $Z_{0.95} = 1.6495$). We believe that the ninety-fifth percentile criterion provides a sufficiently conservative and reasonable margin in the establishment of buffer zones for waterbirds.

We used ordinary least-squares regression analysis to examine the relationship between the flush distance and size of waterbirds for each type of vessel. The full model compared the mean flush distance (dependent variable) with mean total body length, mean wing chord, and mean weight (independent variables) for each species. We used a weighted least-squares fit of the inverse of the standard error of the mean for the flush distance of each species. Measurements of total body length and wing chord were taken from specimen tags on birds in the collection at the Florida Museum of Natural History, Gainesville. Avian body masses were derived from Dunning (1993). Independent variables were backward-eliminated from the model with the REG procedure (SAS Institute 1990*b*,1990*c*), based on F statistics, p values, and the variable's contribution to r^2 from the squared semipartial correlation coefficients using Type I sums of squares. The final model for each watercraft contained only flush distance and total length.

Results

Avian Flush Distances

We exposed 23 species of waterbirds (Pelecaniformes, Ciconiiformes, Charadriiformes, Falconiformes) to the rapid approach of a personal watercraft ($n = 1189$ flushes) and an outboard-powered boat ($n = 903$ flushes), for a total of 2092 stimulus-response flushes. We found considerable variation in flush distances among individuals within the same species and significant differences (ANOVA/Fisher's LSD test, $p < 0.001$) among species of waterbirds to the approach of the PWC (Table 1). Within similar taxonomic families, significant differences (ANOVA/Fisher's LSD test) also existed among the terns ($p < 0.001$), herons ($p < 0.001$), and shorebirds ($p < 0.02$) listed in Table 1. Extreme flush distances ranged from 5 to 159 m, and average distances among species ranged from 19.53 (Least Tern [*S. antillarum*]) to 49.53 m (Osprey [*Pandion haliaetus*]). Despite its close association with human activities along the coast, the Brown Pelican (*Pelecanus occidentalis*) exhibited one of the larger average flush distances.

Considerable variation in flush distances also existed among individuals within the same species, and significant differences (ANOVA/Fisher's LSD test, $p < 0.001$) occurred among the responses of species of waterbirds to the approach of the outboard-powered boat (Table 1). Within similar taxonomic families, significant differences (ANOVA/Fisher's LSD test) occurred among the terns ($p < 0.001$), herons ($p < 0.001$), and shorebirds ($p < 0.001$) listed in Table 1. Extreme flush distances ranged from 8 to 156 m, and average distances among species ranged from 23.36 (Forster's Tern [*S. forsteri*]) to 57.91 m (Osprey). The Brown Pelican again exhibited one of the larger average flush distances.

A comparison of the approaches by the PWC and the outboard-powered boat indicated that 11 species (68.8%) showed no significant difference (t test, $p > 0.05$) in average flush distance in response to either vessel (Table 1). Only the Great Blue Heron (*Ardea herodias*) exhibited significantly larger (t test, $p < 0.01$) flush distances in response to the approach of the PWC. Four species (Anhinga [*Anhinga anhinga*], Little Blue Heron [*Egretta caerulea*], Willet [*Catoptrophorus semipalmatus*], and Osprey) exhibited significantly larger (t test, $p < 0.05$) flush distances in response to the approach of the outboard-powered boat.

Flush Distance versus Bird Size

Mean weight (PWC: df = 13, $p = 0.65$; outboard: df = 13, $p = 0.36$) was eliminated from the four-variable model, and mean wing chord (PWC: df = 14, $p = 0.35$; outboard: df = 14, $p = 0.21$) was deleted from the three-variable model analyzing the relationship between bird size and mean flush distance. There was a significant correlation, however, between the mean total body length and mean flush distance elicited by both PWC (df = 15, $p < 0.0001$, $r^2 = 0.76$) and outboard-powered vessels (df = 15, $p = 0.0003$, $r^2 = 0.60$). Thus, larger avian species exhibited greater average flush distances in response to both PWC and outboard-powered boats (e.g., compare smaller shorebirds with larger herons in Table 1). The final models were as follows: PWC, log (flush distance) = 1.30 + 0.56 (log [total length]); outboard-powered boat, log (flush distance) = 1.50 + 0.52 (log [total length]).

Discussion

We found considerable variation in the flush distances within and among species in response to the approach of both PWC and outboard-powered vessels. Other studies have also demonstrated variation in flush distances

Table 1. Flush distances (m) of waterbirds in response to the fast approach of a personal watercraft and an outboard-powered boat.

	Personal watercraft			*Outboard-powered boat*			
Species	*number*	*range*	*mean ± SD*	*number*	*range*	*mean ± SD*	*Difference**
Anhinga (*Anhinga anhinga*)	61	19–115	44.51 ± 20.35	55	11–135	53.16 ± 23.06	$p < 0.04$
Brown Pelican (*Pelecanus occidentalis*)	71	5–130	47.11 ± 31.79	76	20–134	52.80 ± 22.70	n.s.
Double-crested Cormorant (*Phalacrocorax auritus*)	90	5–111	49.45 ± 25.68	73	15–129	42.76 ± 19.94	n.s.
Great Blue Heron (*Ardea herodias*)	125	8–123	49.52 ± 22.72	93	10–137	42.16 ± 20.27	$p < 0.01$
Great Egret (*Ardea alba*)	125	10–130	45.53 ± 18.72	90	16–156	50.99 ± 22.64	n.s.
Little Blue Heron (*Egretta caerulea*)	66	16–111	37.29 ± 15.16	51	16–108	49.34 ± 22.23	$p < 0.01$
Snowy Egret (*Egretta thula*)	54	5–85	31.50 ± 17.47	67	9–97	31.78 ± 15.29	n.s.
Tricolored Heron (*Egretta tricolor*)	50	11–91	42.72 ± 19.96	42	10–98	44.36 ± 22.28	n.s.
Reddish Egret (*Egretta rufescens*)	22	19–70	41.14 ± 15.10				
White Ibis (*Eudocimus albus*)	54	5–112	42.15 ± 23.59	53	9–81	35.57 ± 17.26	n.s.
Roseate Spoonbill (*Ajaia ajaja*)	15	39–61	44.98 ± 6.75				
Wood Stork (*Mycteria americana*)	12	17–74	36.17 ± 16.84				
Caspian Tern (*Sterna caspia*)	21	10–70	31.15 ± 11.80				
Royal Tern (*Sterna maxima*)	59	11–138	35.91 ± 21.77	26	10–71	29.03 ± 15.34	n.s.
Forster's Tern (*Sterna forsteri*)	33	9–51	23.50 ± 9.79	30	9–52	23.36 ± 8.54	n.s.
Least Tern (*Sterna antillarum*)	17	5–46	19.53 ± 10.12				
Ring-billed Gull (*Larus delawarensis*)	10	19–88	41.76 ± 21.37				
Laughing Gull (*Larus atricilla*)	59	5–64	28.28 ± 14.86	48	11–56	27.76 ± 10.60	n.s.
Black-bellied Plover (*Pluvialis squatarola*)	46	9–68	23.88 ± 10.12	41	11–48	22.92 ± 9.06	n.s.
American Oystercatcher (*Haematopus palliatus*)	48	5–80	29.12 ± 13.76	37	11–59	30.27 ± 11.48	n.s.
Willet (*Catoptrophorus semipalmatus*)	52	7–65	24.47 ± 10.99	63	17–82	31.41 ± 10.23	$p < 0.01$
Short-billed Dowitcher (*Limnodromus griseus*)	28	9–45	21.37 ± 8.68				
Osprey (*Pandion haliaetus*)	71	20–159	49.53 ± 21.75	58	30–140	57.91 ± 22.23	$p < 0.04$

**A test was performed on log-transformed data.*

within and among species of waterbirds in response to human activities (Erwin 1989; Rodgers & Smith 1995, 1997; Burger 1998). Avian responses to approaching threats and enemy recognition are the result of a combination of motivation, immediate context, and recent experience with the threat (McLean & Rhodes 1991). Birds also appear to be able to distinguish between types of enemies and to vary their responses to different approaching threats.

Eleven of 16 species showed no significant difference in flush distance between the rapid approach of PWC and outboard-powered vessels. Despite the reputation of the PWC for noise and wildlife disturbance, the direct approach of an outboard-powered boat more often elicited a significantly greater flush distance (4 of 5 comparisons, or 80%). This response by individual non-nesting waterbirds in Florida contrasts with the observations of Burger (1998) that significantly more nesting Common Terns responded to PWC than to various types of motorboats in New Jersey.

Considering the similar visibility of the occupants and similar sound-generating characteristics but different size of the PWC and outboard-powered vessels used in our study, we were surprised that the larger outboard-powered boat did not always elicit greater flush distances. This may be due to the relatively large vertical and horizontal spray produced by the typical deep-V hull of the PWC compared with the semi-V hull of the outboard-powered boat, which may make the PWC appear larger to a bird (Fig. 1). Based on a slide of the frontal view of an approaching vessel projected on a screen, we calculated the hull and horizontal spray width to be 10–11 m for the PWC and 5–6 m for the outboard-powered boat.

Using data collected during a previous study (Rodgers & Smith 1997), we also compared the flush distances of three species of birds in response to a slow (1.8–3.6 km/hour) versus fast (35–40 km/hour) approach with the same outboard-powered boat. A fast approach resulted in significantly larger (t test) flush distances for Brown Pelicans ($p < 0.002$), Anhingas ($p < 0.02$), and Great Egrets (*A. alba*, $p < 0.02$). Burger (1998) also found that the speed of watercraft had a significant effect on the flight behavior of Common Terns.

A major difference between the operation of a PWC and an outboard-powered boat is the ability of the PWC to be operated at fast speeds in shallow water. But with the advent of jet-foot and transom jack-plate devices for outboard motors, outboard-powered boats and jet boats also can be operated at fast speeds in shallow water. Thus, both PWC and outboard-powered vessels have the potential to disturb foraging and loafing waterbirds in shallow water. Our data on flush distances suggest that a single buffer-zone distance can be developed to prevent waterbird disturbance by both PWC and outboard-powered vessels.

Avoidance responses benefit wildlife when an encounter with humans can cause injury or death, but flushing re-

Figure 1. Frontal view of an approaching personal watercraft. Note the large, horizontal spray associated with the vessel.

sponses may prevent the birds from using preferred foraging sites or may cause elevated levels of stress (Whittaker & Knight 1998; Fernández-Juricic & Tellería 2000). Waterbirds are most often vulnerable to human activities when they are nesting, loafing, or foraging. Nest defense may result in survival of the eggs or young and reduce energy expenditures associated with flushing by parents when exposed to low-threshold disturbances. Fleeing a disturbance at a foraging or loafing site allows a bird to return later if the disturbance abates. Belanger and Bedard (1990) found, however, that human activities resulting in flight and alertness increased energy expenditure by Snow Geese (*Chen caerulescens*) and reduced their energy intake due to lower feeding rates. For these reasons, waterbird staging areas along migratory corridors and frequently used foraging sites of resident birds merit protection from human activities. Access by birds to disturbance-free wetlands to secure food for nestlings may be as important as disturbance-free breeding sites with suitable nesting substrate in determining the stability of a population or colony (Rodgers & Smith 1997).

Waterbirds are especially vulnerable to human activities because their size, animated behavior, and physical beauty tend to attract humans (Carney & Sydeman 1999). Although wildlife viewing can generate conservation interest and revenue, these activities may cause waterbirds to abandon sites that managers are attempting to protect (Burger et al. 1995; Burger & Gochfeld 1998; Burger & Leonard 2000). This may result in a conservation Catch-22: the goals of wildlife viewing and ecotourism are to provide outdoor recreational opportunities and enhance conservation awareness, but repeated escape responses by birds can lead to their avoidance of the same foraging and loafing sites favored for outdoor recreation.

Implications for Conservation and Management

Selective pressures on body shape and wing morphology (length, shape, loading, and aspect ratio) are a complex interaction between energetic demands and ecological function that result in variation in flight capabilities and speeds among birds (Rayner 1988). Shorebirds have high-aspect-ratio wings that allow for rapid takeoffs and high flight speeds, whereas herons have low-aspect-ratio wings that result in slower take-offs and lower flight speeds but better gliding performance (Rayner 1988). Despite its close association with and known habituation to boating activities along the coast of Florida, the Brown Pelican exhibited one of the larger average flush distances. The greater flush distances exhibited by large species of waterbirds to both PWC and outboard-powered vessels in our study probably are due to the fact that they require more time to take flight. The largest flush distances should be used when buffer zones are implemented for mixed-species groups of birds at foraging and loafing sites (Rodgers & Smith 1997).

Based on our formula for calculating a buffer zone based on the upper one-sided 95% confidence limit for the mean and 1 SD of the flush distance plus 40 m, buffer zones of about 180 m for wading birds (Pelecaniformes and Ciconiiformes), 140 m for terns and gulls, 100 m for plovers and sandpipers, and 150 m for Ospreys would minimize their disturbance by human activities at foraging and loafing sites in Florida (Table 2). Individual species exposed to both PWC and outboard-powered vessels require the largest of the calculated buffer distances in Table 2. A well-designed educational and enforcement program of conservation laws should augment the posting of important wildlife resources (Burger & Leonard 2000). A key role for all stakeholders should be devising ways to use an ecosystem without losing biotic diversity, and encouraging more respect for natural resources by user groups (Angermeier 2000).

Table 2. Minimum recommended buffer-zone distances (m) between waterbirds and fast approach of watercraft directly toward waterbirds to prevent flushing.*

	Type of activity	
Species	*Personal watercraft*	*Outboard-powered boat*
Anhinga	134	149
Brown Pelican	183	147
Double-crested Cormorant	156	132
Great Blue Heron	145	133
Great Egret	130	146
Little Blue Heron	113	144
Snowy Egret	118	110
Tricolored Heron	132	141
Reddish Egret	115	
White Ibis	146	119
Roseate Spoonbill	98	
Wood Stork	118	
Caspian Tern	98	
Royal Tern	137	109
Forster's Tern	87	83
Least Tern	86	
Ring-billed Gull	137	
Laughing Gull	107	92
Black-bellied Plover	88	84
American Oystercatcher	103	96
Willet	91	94
Short-billed Dowitcher	82	
Osprey	142	149

**Minimum recommended set-back (RS) distances calculated by the formula* $RS = \exp(\hat{\mu} + 1.6495\,\hat{\sigma}) + 40$ *m.*

We urge conservation personnel to use discretion when implementing the buffer distances in Table 2. Disturbance due to a particular activity can vary according to the operation and number of vessels (Stokes et al. 1996; Wood 1999). Other species or populations may be more or less sensitive than those in our study (Burger & Gochfeld 1991*b*). For example, Great White Herons (*A. h. occidentalis*) in the Florida Keys exhibited significantly larger (t test, $p = 0.02$) mean flush distances (67.23 m) to the approach of a PWC than mainland Great Blue Herons (49.52 m). Association with conspecific flocks or more conspicuous species (Gutzwiller et al. 1998) or mixed-species aggregations (Thompson & Thompson 1985) may even increase flush distances for some species. Because boats in confined areas may be closer to shorelines, waterbirds in tidal creeks and rivers may be exposed to more human activity than birds at other shoreline habitats (Bratton 1990).

Buffer distances may be shortened in no-wake zones (Rodgers & Smith 1995, 1997) where there are low levels of human activity and limited intrusion (Gutzwiller & Anderson 1999) or when physical barriers prevent direct visual contact between birds and human activities with low noise levels (Kury & Gochfeld 1975; Stalmaster & Newman 1978). Although it is unlikely that the consequences of trails, roadways, and channels will ever be mitigated completely (Fletcher et al. 1999; Trombulak & Frissell 2000), an indirect course may elicit less response and allow for a shorter buffer distance (Burger & Gochfeld 1981). We used a direct approach to flush birds in our study, which we consider the most disturbing to wildlife (Fig. 1). Watercraft often do not make a direct approach but travel in a tangential path in relation to wildlife. Acclimation to tangential vehicle traffic has been reported in nesting Least Terns and Black Skimmers (*Rynchops niger*) in Florida (Rodgers & Smith 1995). Likewise, Cattle Egrets (*Bubulcus ibis*) and other herons readily forage and roost along busy highways and canals.

Conservation personnel should monitor changes in species composition at regulated sites to adjust buffer distances to reflect the presence of new, more sensitive species with larger flush distances. Implementation of a buffer zone should include periodic evaluation of effectiveness and corrective measures based on a comparison of the numbers and distribution of birds before and after implementation of a buffer zone.

An ideal buffer zone prevents human activity from crossing a predetermined disturbance threshold. Buffer zones are most effective when spatial and temporal restrictions are congruent (Richardson & Miller 1997). Although conservation plans could be tailored to each species, habitat, season, and source of disturbance, it may prove difficult or impractical to establish variable buffer zones for a variety of human activities. Likewise, it may be difficult to post a single site with two buffer distances corresponding to nesting and non-nesting times of the year. For these reasons, the species most sensitive to disturbance and the most disturbing human activity should be used to establish one buffer distance.

Our recommended buffer distances for non-nesting Pelecaniform, Ciconiiform, and most Charadriiform birds (Table 2) should be adequate to protect most nesting birds from human activities. Based on a previous study, five of nine species exhibited significantly greater flush distances when foraging or loafing than when nesting (Rodgers & Smith 1997). Grubb and King (1991) found that Bald Eagles (*Haliaeetus leucocephalus*) flushed most often while foraging and flushed more often from perches than from a nest. But the distances in Table 2 may not be adequate to prevent the upflight response of some ground-nesting waterbirds, particularly terns (Rodgers & Smith 1995). Burger (1998) suggested a minimum buffer distance of 100 m around Common Tern colonies to reduce disturbance by PWC.

We recommend additional research to determine appropriate buffer distances for tangential approaches, seasonal variation in response to human activities, and the effects of larger motorboats. Because of the variation in flush distances among individual birds and species, it may be necessary to develop buffer distances on a local basis using the above formula and locally collected data. The principles and techniques we discuss here may be applicable elsewhere and may serve as a general model for designing specific buffer distances based on each species, location, and type of human activity.

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Literature Cited

Angermeier, P. L. 2000. The natural imperative for biological conservation. Conservation Biology **14:**373–381.

Belanger, L., and J. Bedard. 1989. Responses of staging Greater Snow Geese to human disturbance. Journal of Wildlife Management **53:**713–719.

Belanger, L., and J. Bedard. 1990. Energetic cost of man-induced disturbance to staging Snow Geese. Journal of Wildlife Management **54:**36–41.

Bratton, S. P. 1990. Boat disturbance of ciconiiformes in Georgia estuaries. Colonial Waterbirds **13:**124–128.

Burger, J. 1981. The effect of human activity on birds at a coastal bay. Biological Conservation **21:**231–241.

Burger, J. 1998. Effects of motorboats and personal watercraft on flight behavior over a colony of Common Terns. Condor **100:**528–534.

Burger, J., and M. Gochfeld. 1981. Discrimination of the threat of direct versus tangential approach to the nest by incubating Herring and Great Black-backed Gulls. Journal of Comparative Physiology and Psychology **95:**676–684.

Burger, J., and M. Gochfeld. 1991*a*. Human activity influence and diurnal and nocturnal foraging of Sanderlings (*Calidris alba*). Condor **93:**259–265.

Burger, J., and M. Gochfeld. 1991*b*. Human distance and birds: tolerance and response distances of resident and migrant species in India. Environmental Conservation **18:**158–165.

Burger, J., and M. Gochfeld. 1998. Effects of ecotourists on bird behavior at Loxahatchee National Wildlife Refuge, Florida. Environmental Conservation **25:**13–21.

Burger, J., and J. Leonard. 2000. Conflict resolution in coastal waters: the case of personal watercraft. Marine Policy **24:**61–67.

Burger, J., M. Gochfeld, and L. J. Niles. 1995. Ecotourism and birds in coastal New Jersey: contrasting responses of birds, tourists, and managers. Environmental Conservation **22:**56–65.

Carney, K. M., and W. J. Sydeman. 1999. A review of human disturbance effects on nesting colonial waterbirds. Waterbirds **22:**68–79.

Dunning, J. B., editor. 1993. CRC handbook of avian body masses. CRC Press, Boca Raton, Florida.

Erwin, R. M. 1989. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. Colonial Waterbirds **12:**104–108.

Fernández-Juricic, E., and J. L. Tellería. 2000. Effects of human disturbance on spatial and temporal feeding patterns of Blackbird *Turdus merula* in urban parks in Madrid, Spain. Bird Study **47:**13–21.

Fletcher, R. J. Jr., S. T. McKinney, and C. E. Bock. 1999. Effects of recreational trails on wintering diurnal raptors along riparian corridors in a Colorado grassland. Journal of Raptor Research **33:**233–239.

Grubb, T. G., and R. K. King. 1991. Assessing human disturbance of breeding Bald Eagles with classification tree models. Journal of Wildlife Management **55:**500–511.

Gutzwiller, K. J., and S. H. Anderson. 1999. Spatial extent of human-intrusion effects on subalpine bird distributions. Condor **101:**378–389.

Gutzwiller, K. J., H. A. Marcum, H. B. Harvey, J. D. Roth, and S. H. Anderson. 1998. Bird tolerance to human intrusion in Wyoming montane forests. Condor **100:**519–527.

Klein, M. L. 1993. Waterbird behavioral responses to human disturbances. Wildlife Society Bulletin **21:**31–39.

Knight, R. L., and S. K. Knight. 1984. Responses of wintering Bald Eagles to boating activity. Journal of Wildlife Management **48:**999–1004.

Kury, C. R., and M. Gochfeld. 1975. Human interference and gull predation in cormorant colonies. Biological Conservation **8:**23–34.

McLean, I. G., and G. Rhodes. 1991. Enemy recognition and response in birds. Pages 173–211 in D. M. Power, editor. Current ornithology. Volume 8. Plenum Press, New York.

Personal Watercraft Industry Association (PWIA). 2000. PWIA splash page. PWIA, Washington, D.C. Available at http:/www.pwia.org (accessed 7 July 2000).

Pfister, C., B. A. Harrington, and M. Lavine. 1992. The impact of human disturbance on shorebirds at a migration staging area. Biological Conservation **60:**115–126.

Rayner, J. M. V. 1988. Form and function in avian flight. Pages 1–66 in

R. F. Johnson, editor. Current ornithology. Volume 5. Plenum Press, New York.

Richardson, C. T., and C. K. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin **25:**634–638.

Roberts, G., and P. E. Evans. 1993. Responses of foraging Sanderlings to human approaches. Behaviour **126:**29–43.

Rodgers, J. A. Jr., and H. T. Smith. 1995. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conservation Biology **9:**89–99.

Rodgers, J. A. Jr., and H. T. Smith. 1997. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. Wildlife Society Bulletin **25:**139–145.

SAS Institute. 1990*a.* SAS procedures guide, version 6. SAS Institute, Cary, North Carolina.

SAS Institute. 1990*b.* SAS/STAT users' guide, version 6. Volume 1. SAS Institute, Cary, North Carolina.

SAS Institute. 1990*c.* SAS/STAT users' guide, version 6. Volume 2. SAS Institute, Cary, North Carolina.

Skagen, S. K., R. L. Knight, and G. H. Orians. 1991. Human disturbances of an avian scavenging guild. Ecological Applications **1:** 215–225.

Stalmaster, M. V., and J. R. Newman. 1978. Behavioral responses of wintering Bald Eagles to human activity. Journal of Wildlife Management **42:**506–513.

Stokes, T., K. Hulsman, P. Ogilvie, and P. O'Neill. 1996. Management of human visitation to seabird islands of the Great Barrier Reef Marine Park region. Corella **20:**1–13.

Thompson, D. B. A., and M. L. P. Thompson. 1985. Early warning and mixed species association: the 'Plover's page' revised. Ibis **127:** 559–562.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology **14:**18–30.

Whittaker, D., and R. L. Knight. 1998. Understanding wildlife responses to humans. Wildlife Society Bulletin **26:**312–317.

Wood, P. B. 1999. Bald Eagle response to boating activity in northcentral Florida. Journal of Raptor Research **33:**97–101.