Journal for Nature Conservation 40 (2017) 42–48

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc

Waterbird responses to regular passage of a birdwatching tour boat: Implications for wetland management

Tyler N. McFadden[a,1], Alejandro G. Herrera[b], Juan G. Navedo[a,*]

[a] Bird Ecology Lab, Instituto de Ciencias Marinas y Limnológicas, Universidad Austral de Chile, Valdivia, Chile
[b] Aves Cantábricas SL., Plaza de los Valles 10, 39300 Torrelavega, Cantabria, Spain

ARTICLE INFO

Keywords:
Waterbirds
Recreational disturbance
Flight-initiation distance
Santoña marshes
Buffer zones
Wetland management

ABSTRACT

Participation in outdoor recreation can increase support for wildlife conservation, but may also disturb wildlife. We examined responses of wintering waterbirds to the regular passage of a small boat specifically dedicated to birdwatching tours in a coastal Ramsar site in northern Spain. Disturbances were measured during two separate periods: 2006–2008 and 2012–2015. Incidence and magnitude of disturbance events were compared by grouping species based on their interest to birders (target vs. non-target) and compared across sectors of the tour route. Flight-initiation distances (FID) were used to estimate species-specific buffer zones, which can be used to manage recreational disturbance to waterbirds. We further examined relationships between species-specific traits and FID, time flying, and distance flying following disturbance. A single boat tour disturbed on average 0.3% of non-target and 2.8% of target wintering bird populations within the wetland, with the effect being more pronounced on target species due to their smaller populations. Wing loading was positively associated with distance flying after disturbance. Based on measured FIDs, we calculated an overall buffer zone for all species of 100 m, and species-specific buffer zones ranging from 41 to 211 m. Disturbance incidence and the number of birds disturbed per tour were both greatest in narrow tidal channels (< 200 m), where boats were forced to pass within 100 m of waterbirds. We urge caution in allowing boat passage through tidal channels in which boat operators cannot effectively maintain recommended buffer zones between their boat and waterbirds.

1. Introduction

Outdoor recreation and ecotourism related activities frequently occur in protected areas, and are rapidly increasing in popularity (Cordell, 2012; Higginbottom, 2004). These activities may benefit conservation efforts through local employment and increased awareness and support for wildlife conservation, but are also likely to disturb wildlife (Drewitt, 2007; Sekercioglu, 2002). Migratory waterbirds are particularly susceptible to recreational disturbance because large numbers of many species concentrate in relatively few, small and patchily-distributed wetlands during their annual migrations, using them as stopover or wintering sites (Myers et al., 1987; Stillman, West, Caldow, & Durell, 2007). In addition to supporting economic activities directly associated with the management or extraction of natural resources (e.g. shellfishing; Navedo & Masero, 2007), coastal wetlands are popular areas for many recreational activities, such as boating, fishing, hunting, wildlife viewing, and hiking, which may disturb waterbirds and degrade stopover site quality (Brown, Hickey, Harrington, & Gill, 2001; Drewitt, 2007). Of the waterbird populations with known trends, 38% are decreasing, and only 20% are increasing (Wetlands International, 2012). Understanding and mitigating the potential negative effects of recreational activities at internationally recognized important wetlands is a key challenge in the conservation of waterbird populations.

Recreational activities can cause disturbance for waterbirds, resulting in both physiological (Fowler, 1999; Mullner, Linsenmair, & Wikelski, 2004) and behavioral responses (Klein, 1993; McLeod, Guay, Taysom, Robinson, & Weston, 2013; Navedo & Herrera, 2012). These responses may ultimately affect survival and breeding success (Carney & Sydeman, 1999; Steven, Pickering, & Castley, 2011). Disturbance which results in flushing may impact birds by increasing energy expenditures (Bechet, Giroux, & Gauthier, 2004), reducing foraging time (Fitzpatrick & Bouchez, 1998; Thomas, Kvitek, & Bretz, 2003), and altering habitat use (Burger, 1986; Peters & Otis, 2006). Several studies show that repeated disturbance can influence the distribution of overwintering waterbirds, causing them to avoid a given site within a wetland (Cardoni, Favero, & Isacch, 2008; Klein, 1995) or abandon a site altogether (Burton, Evans, & Robinson, 1996). Some

* Corresponding author.
E-mail address: jgnavedo@uach.cl (J.G. Navedo).
[1] Present address: Department of Biology, Stanford University, 371 Serra Mall, Stanford, CA, 94305, USA.

http://dx.doi.org/10.1016/j.jnc.2017.09.004
Received 24 March 2017; Received in revised form 8 September 2017; Accepted 9 September 2017
1617-1381/

individuals, however, may be able to compensate for increased energy costs (Colwell, 2010; Gill, 2007) or habituate to disturbance (*sensu* Bejder, Samuels, Whitehead, Finn, & Allen, 2009).

Given the potential impacts of recreational disturbance on waterbirds, managers may seek to manage human access to mitigate its effects, thus applying a precautionary approach (Cooney, 2004; Harrington, 2003) to managing wetlands for globally declining waterbird populations. One common strategy is to implement buffer or exclusion zones (e.g. Rogers & Schwikert, 2002), the size of which are typically determined using flight-initiation distance (FID), the distance at which birds begin to flee in response to a disturbance stimulus. Despite the large body of literature dealing with the effects of recreational disturbance on waterbirds (Drewitt, 2007), little is known about the factors that explain species tolerance to disturbance (but see Blumstein, 2006; Samia, Nakagawa, Nomura, Rangel, & Blumstein, 2015), making it difficult to predict which species are most susceptible to disturbance or develop appropriate buffer zones *a priori*. Previous studies reported positive relationships between body mass and FID in birds (Weston, McLeod, Blumstein, & Guay, 2012). One possible mechanism explaining this relationship is that larger birds exhibit greater wing loading and therefore require more time to take flight (Fernández-Juricic et al., 2006). Understanding which factors (e.g. body mass, wing loading, diet, foraging strategy, etc.) influence tolerance to human disturbance may allow managers to better predict which species are most vulnerable to disturbance and develop strategies to minimize its occurrence (Samia et al., 2015). Previous studies largely focused on the effects of disturbance caused by pedestrians (McLeod et al., 2013), and do not adequately cover the full range of common disturbance stimuli that occur in waterbird habitats. In particular, few studies have evaluated non-breeding waterbird responses to motorized boats in wetland environments, although recreational and commercial boats are prevalent disturbance stimuli year-round in these particular areas (Cordell, 2012; Robinson & Pollitt, 2002).

Birding is a popular and rapidly growing recreational activity throughout the world, and birders frequently participate in boat tours to observe wetland birds (Cordell, 2012; Sekercioglu, 2002). In the current study, we measured waterbird disturbance events associated with the passage of a motorized birdwatching tour boat in a coastal wetland of international importance for the conservation of waterbird populations in northern Spain. We evaluated the frequency and size of disturbance events relative to waterbird population size, compared disturbance responses across environmental conditions and tour route sectors, and evaluated changes in tolerance to boat passage over the course of the study. We examined species-specific traits that may influence disturbance responses, and evaluated whether the tour impacted target species (i.e. species of greater interest to birders) differently than non-target species. Finally, we report species-specific buffer zones based on FID and discuss several local and global strategies for mitigating waterbird disturbance associated with boat passage.

2. Materials and methods

2.1. Study area

Santoña, Victoria and, Joyel Marshes Natural Park (SMNP; 43°25′N, 3°25′ W; Fig. 1) is an estuarine area located in the eastern part of the Cantabrian region (northern Spain), comprising ~1200 ha of intertidal mudflats. SMNP is a designated Ramsar site and Special Protection Area. Hunting has been prohibited since 1993. Tides are semi-diurnal, exposing the intertidal zone for 5.5–6.5 h each day (Navedo & Masero, 2007). Due to its location along the East Atlantic Flyway and its favourable ecological and hydro-morphological characteristics (Recio et al., 2013), the SMNP supports an average of ~20,000 overwintering waterbirds (Navedo, Masero, & Juanes, 2007). These include relatively abundant species such as ~5000 dunlin (*Calidris alpina*), ~4000 Eurasian wigeon (*Anas penelope*), ~1000 mallard (*A. platyrhynchos*), ~750 Eurasian curlew (*Numenius arquata*), ~250 grey plover (*Pluvialis squatarola*), ~180 common redshank (*Tringa totanus*), and ~40 greenshank (*T. nebularia*; Navedo et al., 2007). SMNP is also the only area in the Iberian Peninsula that regularly supports small wintering populations of horned grebe (*Podiceps auritus*), brant goose (*Branta bernicla*), red-breasted merganser (*Mergus serrator*), common scoter (*Melanitta nigra*), great loon (*Gavia immer*), and red-throated loon (*G.stellata*; Navedo, 2006). As such, SMNP is widely recognized as one of the top winter birdwatching destinations in Spain and attracts growing numbers of birders who come to observe species that are not found elsewhere in the region (Montero, 2005).

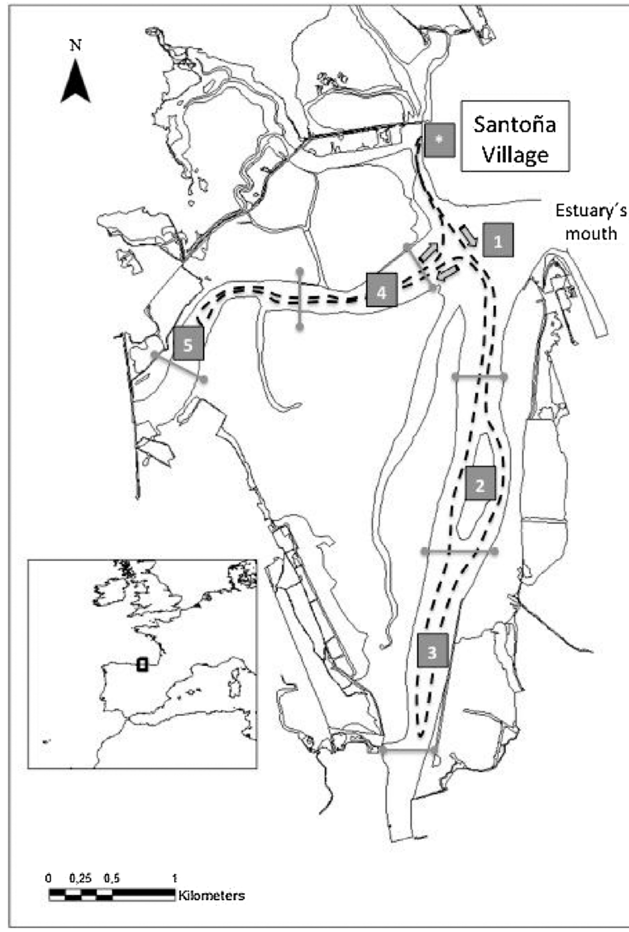

Fig. 1. Location of study area within Santoña, Victoria, and Joyel Marshes Natural Park, Spain. Solid lines and numbers delineate the five survey sectors. Dotted line shows birdwatching boat tour route. Surveyors accompanied monthly winter tours along this route during 2006–2008 and 2012–2015.

In 2005, an ecotourism company proposed establishing a boat-based winter birdwatching tour to visit the central areas of SMNP and applied for approval from regional authorities (i.e. SMNP director, Gobierno de Cantabria). The route of the proposed tour (Fig. 1) passes through the Treto and Ano tidal channels, but avoids a narrower (< 80 m wide) central tidal channel where the risk of waterbird disturbance was deemed too great. The proposed tour was evaluated and approved on the condition that a systematic study be carried out to measure the potential disturbances to SMNP wintering waterbirds associated with this specific boat tour. The study, which we report here, was performed during the wintering season for waterbirds, over two separate periods (2006–2008 and 2012–2015), each consisting of three consecutive winter seasons: January 2006–March 2006, December 2006–February 2007, January 2008–March 2008, December 2012–March 2013, December 2013–February 2014, December 2014–March 2015.

2.2. Data collection

An experienced ornithologist accompanied 48 boat tours (surveys) along a fixed tour route (Fig. 1), registering all birds flushed during each 2.5 h boat trip. All tours were performed within the four central hours of low tide during calm weather without wind or precipitation. Tour operators used a 7.26 m long motorized boat (8-person capacity) which travelled at ≤6 kph. The tour maintained a fixed route through the center of tidal channels and paused on demand, but did not veer off course, for birders to observe species of interest. For analytical purposes, we divided the survey route into 5 sectors of similar length (~ 1.4 km) that differed in channel width (range of maximum channel widths: 110–413 m). For each flushing event, the observer recorded (i) the sector in which it took place, (ii) the species and number of individuals flushed, (iii) FID, (iv) the length of time that birds flew following disturbance (time flying), and (v) the distance birds flew following disturbance (distance flying). FID is frequently used as a metric of tolerance to disturbance stimuli and is considered a species-specific trait (Blumstein, Anthony, Harcourt, & Ross, 2003). We used time flying and distance flying as proxies of the energetic cost of escape (Durell et al., 2005). We estimated FID and distance flying in meters based on distance from the boat to closest shoreline and navigation buoys, and measured time flying in seconds using a digital chronometer. All measures were estimated by the same observer (AGH).

We used mean wintering abundances of each species at SMNP extracted from Navedo et al. (2007) to explore waterbird disturbance levels relative to population size. Following Navedo and Herrera (2012), we calculated the mean percentage of the wintering population of each waterbird species directly disturbed by a single boat tour (% pop disturbed survey^{-1}) using the formula: % pop disturbed survey^{-1} (sp.$_i$) = [(mean n birds × incidence)/winter population sp.$_i$] × 100; where 'mean n birds' was the mean number of birds of the species i that fled in each flushing event; 'incidence' was calculated by dividing the number of surveys with an observed flush (sp.$_i$) by the total number of surveys (48); and 'winter population sp.$_i$' was the mean number of individuals of species i wintering in SMNP (Navedo et al., 2007).

We assigned species *a priori* to one of two species types (target or non-target) based on their general level of interest to birders in this area. Target species were those which were most highly sought after by birders participating in the boat tours. Species for which only one disturbance event was recorded during the course of the study were *post hoc* assigned to a third species type: casual. We extracted species body mass data from Nudds et al. (2006). We used wing loading data from Alerstam et al., (2007) when available and supplemented them with data from Nudds et al. (2006).

We calculated species-specific buffer zones based on FID for each species for which ≥ 2 disturbance events were recorded. Recommended buffer zones were calculated following Koch and Paton (2014) using the formula: buffer zone = 2 × (mean FID ± 1.6495 SD FID). This conservative calculation accounts for physiological responses to disturbance which occur before behavioral responses can be easily detected in the field. We also calculated an overall buffer zone for all species using the same formula and pooling the FID for all flushing events (including species for which only one disturbance event was recorded).

2.3. Statistical analysis

We used two-sample t-tests to analyze differences between target and non-target species in FID, time flying, distance flying, incidence, number of birds disturbed per disturbance event and % pop disturbed survey^{-1}. Differences in FID, time flying, and distance flying by period were also evaluated using two-sample t-tests. We only evaluated differences between periods in Eurasian wigeon and common scoter because these were the only two species for which we had sufficient data in both survey periods to statistically evaluate changes in disturbance response variables. We assessed normality using probability plots and Shapiro-Wilk tests, and log-transformed data when necessary to comply with t-test normality assumptions. We used Wilcoxon Rank Sum tests when data could not be normalized through log-transformation.

We used Linear Mixed Models (LMM) to examine the biotic and abiotic factors influencing FID (log10 transformed). We included as fixed factors variables which may contribute to a bird's decision to fly, and may therefore influence FID: tidal amplitude (coefficient ranging from 20 to 120; higher values correspond to lower low tides), date in winter (days since November 1), minimum daily temperature (°C), the number of birds disturbed in each disturbance event, and the survey period. Tidal amplitude may affect the availability of roosting and foraging sites (Navedo & Herrera, 2012), while temperature and date in winter (especially for migratory species) may influence the relative costs of taking flight in terms of energy or foraging time lost (Wiersma & Piersma, 1994). We evaluated three random factors (both separately and nested within each other) to account for potential non-independence of observations among species, sector, and survey number. Starting with a model where the fixed component contained all explanatory variables (the *beyond optimal model*), we determined the optimal structure of the random component using Restricted Maximum Likelihood (REML) estimators and comparing AIC_{REML} values. Once we found the optimal random structure, we modeled the fixed term and compared models using Maximum Likelihood (ML) estimators and present the final model using REML estimators (Zuur, Ieno, Walker, Saveliev, & Smith, 2009). Models were ranked by their corrected Akaike's information criterion (AIC) for small samples (AICc). Models with ΔAICc < 2 were considered to be the best supported models (Burnham & Anderson, 2002). We calculated AICc weights (w_i) to infer the relative support of each model, as well as marginal and conditional R^2 values, which describe the proportion of variance explained by the fixed effects alone and the combined fixed and random effects, respectively.

We tested for differences by sector in incidence and number of birds disturbed per survey using Analysis of Variance (ANOVA). Dependent variables were cube-root transformed to comply with the ANOVA normality of residuals assumption and pairwise comparisons were made using Tukey-Kramer post hoc tests, where $\alpha = 0.05$. We evaluated relationships between species-specific traits (wing loading, body mass) and FID, time flying, and distance flying using single linear regression. All values are expressed as means ± SE. Statistical analyses were performed in RStudio (Version 1.0.143, ©2009–2017 RStudio, Inc.).

3. Results

During 48 surveys, we recorded 116 disturbance events, affecting 1808 individuals of 18 waterbird species (Table 1). There were 5 surveys in which we registered zero disturbance events. Eurasian wigeon, Eurasian coot, and common scoter were numerically the three most affected species, representing 71%, 17%, and 6% of all birds flushed, respectively. We observed the greatest incidence of disturbance events per survey in Eurasian wigeon (0.46), common scoter (0.38), and great-crested grebe (*Podiceps cristatus*; 0.25). Mean FID, time flying, and distance flying for all species was 27 ± 1 m, 27 ± 1 s, and 194 ± 20 m, respectively. Recommended species-specific buffer zones ranged from 41 m (great black-backed gull [*Larus marinus*]) to 211 m (velvet scoter [*Melanitta fusca*]). We calculated an overall recommended buffer zone of 100 m for all species.

The best supported linear mixed effects model explaining variation in FID included the number of birds disturbed and the sampling period as fixed effects and species as a random factor (Table 2). FID increased with the number of birds disturbed, and was lower in period 2 than in period 1. Tidal amplitude, date in winter, and minimum daily temperature had no significant effects on FID. The model with species as a random intercept performed considerably better than the linear regression model without random effects ($L = 34.64$, df = 1,

Table 1
Summary disturbance data for each waterbird species flushed during winter boat tours in Santoña, Victoria, and Joyel Marshes Natural Park, Spain, 2006–2008 and 2012–2015. Boats maintained a fixed route through the center of tidal channels and paused on demand, but did not veer off course, for birders to observe species of interest. Wintering population numbers are provided from Navedo et al. (2007) . Conservation status data are from the IUCN Redlist (iucnredlist.org; LC = least concern, NT = near threatened, VU = vulnerable). Results are presented as means (SE).

Species	Species type	Conservation status	Wintering Population	Body Mass (kg)	Wing loading (kg m^{-2})	Number disturb. events	Number birds disturbed	% pop. disturbed per survey	FID (m)	Time flying (sec)	Distance flying (m)	Recommended buffer zone (m)
Anas penelope	Non-target	LC	4253	0.771	9.619	22	1281	0.62 (0.11)	36 (2)	19 (3)	126 (30)	110
Fulica atra	Non-target	LC	1392	0.893	11.130	10	310	0.46 (0.10)	23 (2)	22 (3)	150 (44)	70
Melanitta nigra	Target	LC	30	0.951	14.580	18	109	7.57 (2.22)	37 (4)	25 (5)	326 (87)	130
Phalacrocorax carbo	Non-target	LC	306	2.109	9.942	8	20	0.14 (0.05)	23 (4)	25 (7)	131 (41)	78
Podiceps cristatus	Non-target	LC	35	0.673	14.672	12	18	1.07 (0.19)	23 (1)	42 (6)	182 (45)	60
Podiceps nigricollis	Non-target	LC	148	0.292	12.661	7	11	0.15 (0.03)	15 (2)	14 (1)	39 (4)	43
Melanitta fusca	Target	VU	12	1.758	17.257	4	10	1.74 (0.60)	48 (18)	29 (3)	308 (78)	211
Podiceps auritus	Target	VU	16	0.453	12.091	9	10	1.30 (0.13)	20 (2)	18 (4)	44 (7)	62
Anas platyrhynchos	Non-target	LC	800	1.081	10.188	2	8	0.02 (0.01)	23 (3)	29 (3)	263 (13)	57
Numenius arquata	Non-target	NT	767	0.805	6.717	5	5	0.01 (0)	25 (2)	21 (6)	106 (39)	66
Ardea cinerea	Non-target	LC	52	1.442	3.872	4	4	0.16	20 (5)	29 (15)	150 (74)	70
Larus marinus	Target	LC	10	1.660	5.793	4	4	0.83	17 (1)	24 (7)	154 (90)	41
Mergus serrator	Target	LC	3	1.021	14.808	2	4	2.78	18 (3)	30 (10)	250 (50)	47
Egretta garzetta	Non-target	LC	103	0.500	3.985	3	3	0.06	18 (2)	21 (10)	157 (112)	46
Gavia stellata	Casual	LC	2	1.552	16.910	1	3	–	15	10	200	–
Somateria mollissima	Casual	NT	1	2.065	15.382	1	3	–	15	20	150	–
Anas acuta	Casual	LC	186	1.012	11.650	1	2	–	25	18	200	–
Aythya fuligula	Casual	LC	42	0.693	14.641	1	1	–	20	50	250	–
Branta bernicla	Casual	LC	2	1.300	11.568	1	1	–	20	15	70	–
Platalea leucorodia	Casual	LC	27	1.892	7.169	1	1	–	20	12	50	–
All species	–	–	–	–	–	116	1808	1.21 (0.53)	27 (1)	27 (1)	194 (20)	100

$P < 0.0001$), with FID observations within species being highly correlated (correlation: 0.454). Neither the inclusion of sector or survey number as random intercepts improved the linear regression model, so these variables were dropped from the analysis (sector: $L = < 0.0001$, df = 1, P = 0.9999; survey number: $L = 2.53$, df = 1, P = 0.112).

We observed a mean of 8.8 ± 0.3 (range: 5–12) target species during each birdwatching tour. Species type (target vs. non-target) had no significant effect on FID, time flying, distance flying, incidence of disturbance events per survey, or the number of birds disturbed per disturbance event (Table 3). However, the percentage of each wintering bird population disturbed per survey was nearly 10 times greater among target species (2.8 ± 1.2%) than non-target ones (0.3 ± 0.1%; Table 3).

FID among Eurasian wigeon was 1.4 times greater in survey period 1 than in period 2 (P = 0.0026), but neither time nor distance flying differed significantly between periods (Table 4). Similarly, FID among common scoter was 1.6 times greater in survey period 1 than in period 2 (P = 0.0299). For this species time flying did not differ between periods (P = 0.8903), but distance flying was 4 times greater in period 2 than in period 1 (P = 0.0017).

The incidence of disturbance events per survey in each sector ranged from 0.17 ± 0.08 in sector 4 to 0.98 ± 0.16 in sector 5, and differed between sectors ($F = 11.29$, $P \le 0.0001$, Fig. 2). The highest incidence of disturbance events occurred in sectors 2 (0.83 ± 0.17 events $survey^{-1}$) and 5 (0.98 ± 0.16 events $survey^{-1}$). The number of birds disturbed per survey in each sector ranged from 0.19 ± 0.09 in sector 4 to 24.5 ± 10.6 in sector 2, and differed between sectors

Table 3
Differences in disturbance responses by target and non-target waterbirds (according to birder preference) to the passage of winter boat tours in Santoña, Victoria, and Joyel Marshes Natural Park, Spain, 2006–2008 and 2012–2015. 'Incidence' and 'N birds disturbed', respectively, are the mean number of flushing events and the mean number of birds disturbed per tour (n = 48). '% of population disturbed' is the mean percentage of wintering bird populations disturbed per tour. Results are presented as means (SE).

	Target	Non-target	Test statistic	P value
Flight initiation distance (m)	28 (6)	23 (2)	$t_{12} = -0.9362$	0.3676
Time flying (sec)	25 (2)	25 (3)	$t_{12} = -0.1390$	0.8917
Distance flying (m)	216 (53)	145 (20)	$t_{12} = -1.5323$	0.1514
Incidence	0.15 (0.06)	0.17 (0.04)	$t_{12} = 0.2014$	0.8438
N birds disturbed	3 (1)	11 (7)	$T = 23$	0.9860
% of population disturbed	2.8 (1.2)	0.3 (0.1)	$t_{12} = -3.6404$	0.0034

Table 2
Maximum likelihood (ML) parameter estimates and standard errors derived from likelihood ratio tests using Linear Mixed Models (LMM) to evaluate variation in flight initiation distances (FID, meters) of waterbirds flushed during winter boat tours in Santoña, Victoria, and Joyel Marshes Natural Park, Spain. 'N° birds' is the log10-transformed number of birds flushed in each disturbance event. 'Period' is a binary variable referring to the two periods in which surveys were conducted: 2006–2008 and 2012–2015. Marginal R^2 and Conditional R^2 describe the proportion of variance explained by the fixed effects alone and the combined fixed and random effects, respectively. Models ($\Delta AICc < 2$) are ranked according to Akaike weights (wi).

Random effects	N° birds (log10)	Period	Temperature (°C)	AIC_c	ΔAIC_C	wi	Marginal R^2	Conditional R^2
Species	0.145 ± 0.034 $t = 4.31$ $P < 0.0001$	−0.073 ± 0.030 $t = -2.44$ P = 0.0168	–	−118.61	0	0.43	0.33	0.62
Species	0.139 ± 0.034 $t = 4.10$ $P < 0.001$	−0.075 ± 0.030 $t = -2.50$ P = 0.0141	−0.005 ± 0.004 $t = -1.40$ P = 0.1652	−118.40	0.21	0.39	0.34	0.62

Table 4
Differences in disturbance responses between survey periods among Eurasian wigeon (*Anas penelope*) and common scoter (*Melanitta nigra*) to the passage of winter boat tours in Santoña, Victoria, and Joyel Marshes Natural Park, Spain, 2006–2008 and 2012–2015. Results are presented as means (SE).

	Period 1 2006–2008	Period 2 2012–2015	Test statistic	P value
Eurasian wigeon				
FID (m)	43 (3)	30 (2)	$t_{20} = -3.4322$	0.0026
Time flying (sec)	26 (2)	26 (7)	$T = 25$	0.6023
Distance flying (m)	125 (11)	255 (85)	$T = 36$	0.5420
Common scoter				
FID (m)	46 (8)	29 (1)	$t_{16} = -2.3826$	0.0299
Time flying (sec)	34 (5)	35 (6)	$t_{11} = 0.14118$	0.8903
Distance flying (m)	190 (23)	757 (132)	$T = 41.4$	0.0017

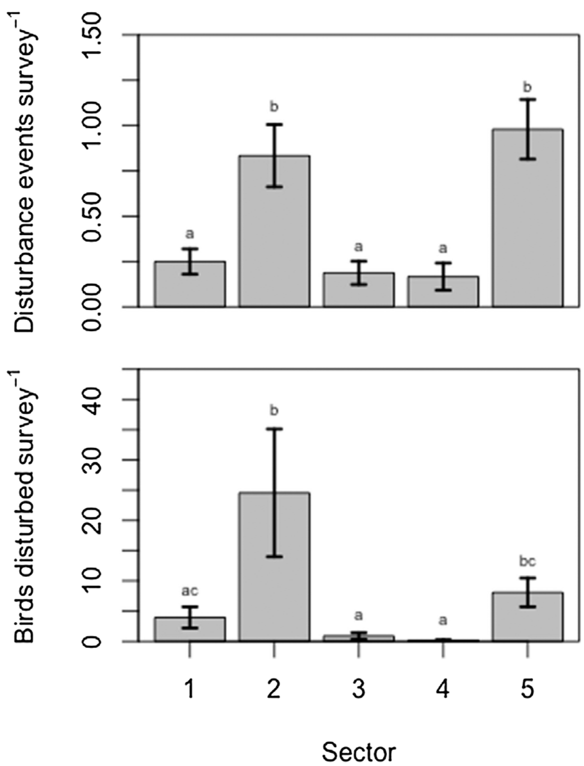

Fig. 2. Mean number of disturbance events observed (top) and mean number of birds disturbed (bottom) during a single boat tour in each survey sector, Santoña, Victoria, and Joyel Marshes Natural Area, Spain, 2006–2008 and 2012–2015. Errors bars represent mean ± SE. Sectors with the same letter above bars are not significantly different.

($F = 4.144$, P = 0.0029, Fig. 2). We also observed compositional differences in the types of species disturbed in each sector. In sector 2, 32 of 40 disturbance events involved wading birds or shallow water foraging waterbirds and only 6 events involved diving waterbirds. In sector 4, all 8 disturbance events involved diving waterbirds. In sector 5, 40 of 47 disturbance events involved diving waterbirds, and 15 of the 18 disturbance events involving common scoter occurred in this sector. Disturbance events in sectors 1 and 3 involved both diving and shallow water foraging waterbirds, as well as wading birds to a lesser extent.

Wing loading ranged from 3.87 kg m^{-2} in grey heron (*Ardea cinerea*) to 17.26 kg m^{-2} in velvet scoter, and was generally greatest among diving waterbirds (e.g. scoters, loons, grebes, mergansers, diving ducks), followed by shallow water foraging waterbirds (dabbling ducks, coots, geese), and then wading birds (Table 1). We found no significant relationship between wing loading and FID (P = 0.5365) or time flying (P = 0.4530). However, distance flying was positively associated with wing loading (β = 9.076, R^2 = 0.1955, P = 0.0506; Fig. 3). There

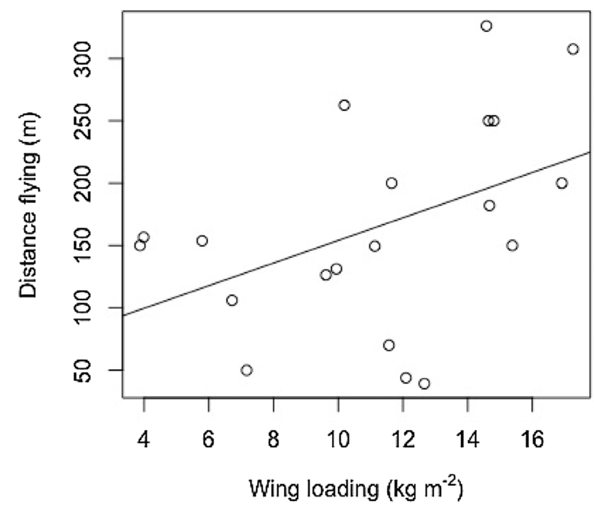

Fig. 3. Relationship between wing loading (kg m^{-2}) and distance flying (m) in response to the passage of a birdwatching tour boat, Santoña, Victoria, and Joyel Marshes Natural Area, Spain, 2006–2008 and 2012–2015. Each data point represents mean distance flying for a single waterbird species. Regression line: β = 9.076, R^2 = 0.1955, P = 0.0506.

were no significant relationships between body mass and FID (P = 0.7440), time flying (P = 0.4894), or distance flying (P = 0.6996).

4. Discussion

The passage of a single tourist boat caused measurable portions of target species wintering waterbird populations to flush (mean = 2.84%; range: 0.83–7.57%), yet only disturbed small portions of non-target species wintering populations (mean = 0.30%; range: 0.01–1.07%). This difference is a result of target species having much smaller wintering populations in SMNP, which is also the reason they are generally highly sought after by birders (J. G. Navedo, Universidad Austral de Chile, personal communication). Target species did not however exhibit greater disturbance incidence or stronger responses to boat passage (e.g. increased FID, time flying, or distance flying) compared to others, demonstrating that current tour operations did not influence the magnitude of disturbance response. Target species may exhibit stronger responses in the context of other birding tours if boats were to approach species of interest, as opposed to simply stopping to observe birds, or if tours used larger boats and/or navigated at higher speeds (Bellefleur, Lee, & Ronconi, 2009; Ronconi & St Clair, 2002).

Although we did not directly measure population-level impacts through individual fitness reduction (Gill, Norris, & Sutherland, 2001), we demonstrate that the passage of a single motorized boat in a tidal wetland caused behavioral responses in significant fractions of small waterbird populations. More frequent boat passage may also lead to increased disturbance frequency and could potentially impact waterbird fitness and survival (Gill, 2007). For example, Madsen (1998) found that Eurasian wigeon individuals flushed by hunters on a non-motorized mobile punt initially responded by ceasing to forage for an average of 46 min following disturbance. However, following a second disturbance by the same stimulus, those same individuals disrupted foraging for an average of 168 min. Increased time and energy costs associated with frequent disturbance may even be fatal in stressful conditions, such as during periods of bad weather, low prey availability, and pre-migratory fattening (Goss-Custard, Triplet, Sueur, & West, 2006). During the winter season of 2006–2007, Herrera et al. (2008) recorded an average of 6.4 boats navigating through the Treto and Ano channels within SMNP at any given time during the four central hours of low tide. The large majority of these boats were artisanal shellfishing boats (59%) or recreational fishing boats (33%). Non-systematic observations suggest that artisanal shellfishing and recreational fishing boats elicit similar waterbird disturbance responses as birding tour boats on a per boat basis (Herrera, Navedo, Torralbo, Gonzalez-Pardo, & Alcántara, 2008). Although in the current study we did not measure waterbird disturbance events associated with the passage of other boats in SMNP, given their likely similar effects on wintering waterbirds, we recommend managers take a precautionary approach (Cooney, 2004) to minimizing boat disturbances, starting with those derived from recreational activities.

To minimize boat disturbance to SMNP waterbirds, we recommend an overall buffer zone of 100 m. While a 100 m buffer zone would likely prevent most disturbance events, managers may be advised to implement larger species-specific buffer zones for species of conservation concern, such as velvet scoter, which is classified as vulnerable by the IUCN and displayed the greatest FIDs. Our observed FIDs (mean: 27 m, range: 15–48 m), which were used to calculate buffer zones, are comparable to those reported by other studies in which similar waterbird species were approached by motorized boats (mean: 39 m, range 23–58; Rogers & Schwikert, 2002) and non-motorized canoes (mean: 33 m, range: 7–72 m; Glover, Guay, & Weston, 2015). For some species, such as Eurasian curlew, our FIDs are smaller than those previously reported for closely related species (Weston et al., 2012). These discrepancies are likely due to methodological differences in the disturbance stimulus (direct approach by single walker vs. indirect approach by motorized boat), which make strict comparisons across studies challenging. The large majority of birds disturbed (87%) and disturbance events (75%) occurred in sectors 2 or 5, which are the narrowest sections of the channels through which the tour boat operated, and have maximum respective widths of 110 m and 194 m. In either case, if a boat were to travel down the center of the channel, the distance between the boat and the shore would always be less than the recommended overall buffer zone of 100 m, increasing the likelihood that any bird present would flush. The high number of disturbance events and birds disturbed in channels under 200 m wide, as well as the much lower numbers recorded in sectors with maximum widths ≥290 m, support the validity of FID-based buffer zones, and suggest that our recommended 100 m buffer zone could substantially reduce boat related disturbance among SMNP waterbirds.

In addition to implementing buffer zones, managers may reduce the impacts of boat disturbance locally through careful route planning and awareness of current conditions. We did not observe any changes in FID related to tidal amplitude, temperature, or date in winter, suggesting these factors do not substantially affect waterbird responses to recreational boat disturbance at SNMP. However, it is important to note that our surveys were never performed in inclement weather (high winds or measureable precipitation), which may elicit different disturbance responses. In the current study, most disturbance events involving common scoter, the most affected species at the population level, occurred in sector 5. Boat operators may thus be advised to avoid or minimize time spent in this sector. Disturbance events in sector 2 predominately involved wading birds or shallow water foraging waterbirds, which require specific water depths to effectively forage. These species, such as Eurasian wigeon, are more likely to return to foraging grounds following disturbance if the disturbance occurs early in their feeding cycle (Fox, Bell, & Mudge, 1993). As such, in areas where the flushing of birds is unavoidable, the effects of disturbance may be substantially reduced if boats pass through these areas while the tide is still receding, as opposed to rising, allowing birds more time to return and resume foraging. Finally, boat operators may be advised to give large flocks extra berth given the observed positive relationship between flock size and FID, which is consistent with trends reported elsewhere in the literature (e.g. Fernández-Juricic, Jiménez, & Lucas, 2002; Weston et al., 2012).

The ability of some birds to habituate (*sensu* Bejder et al., 2009) to repeated disturbance stimuli may allow managers greater flexibility in reducing the impacts of recreational activities on wildlife. We observed increased tolerance (i.e. reduced FID) to boat passage between 2006-2008 and 2012-2015 among both Eurasian wigeon and common scoter, suggesting that these species may be able to habituate somewhat to recreational boat disturbance. However, it is important to distinguish between true habituation and changes in behavior or flock composition which may affect tolerance to disturbance. Observed increases in tolerance may be due to a variety of factors, including the relocation of less tolerant individuals to other sites within SMNP in response to repeated disturbance, changes in habitat quality and/or body condition which may influence individual decision making (Bejder et al., 2009), or changes in flock size, which may influence FID (Weston et al., 2012). We noted that Eurasian wigeon foraged in smaller flocks in sector 2 during 2012–2015 than during 2006–2008, and that larger numbers of the species foraged instead in a less trafficked channel outside of the tour route. Further research tracking disturbance responses by marked individuals is warranted to determine if the observed decrease in FID is a result of habituation, or other factors, such as changes in flock size or the relocation of less tolerant individuals to sites with fewer disturbance stimuli.

In regions where we lack detailed information on waterbird responses to disturbance stimuli, managers may be able to use species-specific traits (i.e. wing loading or body mass) to infer best management practices *a priori* (Samia et al., 2015). Contrary to previous studies (e.g. Blumstein 2006; Weston et al., 2012), we did not observe any correlation between body mass and FID. This lack of finding may be due to mass-related differences in tolerance, since large birds are more likely than small birds to develop tolerance in areas of high human disturbance (Samia et al., 2015). Unlike previous studies, we used an indirect boat approach in a highly trafficked wetland, so SMNP birds may have developed some tolerance to such boat passage. We did however find a marginally significant relationship between wing loading and distance flying. Birds with higher wing loading may fly further in response to disturbance because they require a longer period of flapping flight to gain altitude, or because they generally fly at greater speeds than birds with lower wing loading (Rayner, 1988). Birds with higher wing loading are also likely to experience greater energetic costs associated with taking flight (Rayner, 1995). Given that high wing loading species flew further following disturbance, and that these species also experience greater energetic costs associated with taking flight, it is likely that the impacts of disturbance on individual fitness are much greater for species with high wing loading than for those with low wing loading.

5. Conclusions and management implications

Birding is a popular and growing recreational activity in coastal wetlands, yet few studies have addressed the effects of this particular form of recreation on waterbirds (Sekercioglu, 2002). We demonstrate that the passage of a single motorized birding tour boat in a tidal wetland caused behavioral responses in measurable fractions of small waterbird populations, but had minor effects on species with large populations. More frequent boat passage may also lead to repeated disturbance and increased impacts on both rare and abundant species. Impacts on target bird species may be more pronounced if boats physically approach species of interest. Our results suggest that managers may substantially minimize boat disturbance to waterbirds through careful tour route planning and the implementation of FID-based buffer zones. The empirically derived species-specific and overall buffer zones recommended here (Table 1) provide a starting point for managers looking to minimize motorized boat disturbance in similar tidal wetlands, especially where site-specific disturbance data is lacking. When developing plans to manage recreational boat disturbance in wetlands, we urge caution in allowing passage through waterways ≤200 m in width during low tide, and in particular where operators cannot effectively maintain a 100 m buffer zone between their boat and waterbirds.

Acknowledgments

This manuscript is dedicated to the memory of our late friend Francisco Romero, major warden of the Santoña Marshes Natural Park. We thank M. Alcántara for drawing Fig. 1. We are grateful to F. Belén, D. Briz, C. Gómez, L. Torralbo and D. Arranz, who piloted the 'Cofre' during this 10-year study. We also thank O. Carazo, A. Chocarro, J.A. López-Constante, Á. Ruiz, D. Álvarez, X. Valeiras, E. Abad, Ó. Llama, D. García, L. López-Areal, G. Pérez and J. Aizcorbe, who participated in the boat tours and certified that field data was collected in accordance with stated protocols. This study was conducted with permissions from the Organismo Autónomo Parques Nacionales (belonging to the former Spanish Ministry of the Environment) and the Dirección General del Medio Natural, Gobierno de Cantabria. JGN was supported during writing by FONDECYT grant #1161224.

References

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P. G. P., & Hellgren, O. (2007). Flight speeds among bird species: Allometric and phylogenetic effects. *PLoS Biology, 5*, e197.

Bechet, A., Giroux, J. F., & Gauthier, G. (2004). The effects of disturbance on behaviour: Habitat use and energy of spring staging snow geese. *Journal of Applied Ecology, 41*, 689–700.

Bejder, L., Samuels, A., Whitehead, H., Finn, H., & Allen, S. (2009). Impact assessment research: Use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. *Marine Ecology Progress Series, 395*, 177–185.

Bellefleur, D., Lee, P., & Ronconi, R. A. (2009). The impact of recreational boat traffic on Marbled Murrelets (*Brachyramphus marmoratus*). *Journal of Environmental Management, 90*, 531–538.

Blumstein, D. T., Anthony, L. L., Harcourt, R., & Ross, G. (2003). Testing a key assumption of wildlife buffer zones: Is flight initiation distance a species-specific trait? *Biological Conservation, 110*, 97–100.

Blumstein, D. T. (2006). Developing an evolutionary ecology of fear: How life history and natural history traits affect disturbance tolerance in birds. *Animal Behavior, 71*, 389–399.

Brown, S. C., Hickey, C., Harrington, B., & Gill, R. (2001). *The U.S. shorebird conservation plan* (2nd ed.). Manomet, Massachusetts: Manomet Center for Conservation Sciences.

Burger, J. (1986). The effect of human activity on shorebirds in two coastal bays in northeastern United States. *Environmental Conservation, 13*, 123–130.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach* (2nd ed.). New York: Springer.

Burton, N. H. K., Evans, P. R., & Robinson, M. A. (1996). Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artificial island at Hartlepool, Cleveland. *Biological Conservation, 77*, 193–201.

Cardoni, D. A., Favero, M., & Isacch, J. P. (2008). Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: Implications for waterbird conservation. *Biological Conservation, 141*, 797–806.

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

Colwell, M. A. (2010). *Shorebird ecology, conservation, and management* (1st ed.). University of California Press.

Cooney, R. (2004). *The precautionary principle in biodiversity conservation and natural resource management: An issues paper for policy-makers, researchers and practitioners.* Gland, Switzerland and Cambridge: UK: IUCN.

Cordell, H. K. (2012). *Outdoor recreation trends and futures: A technical document supporting the forest service 2010 RPA assessment.* Ashville, North Carolina: U. S. Forest Services, Southern Research Center.

Drewitt, A. L. (2007). Birds and recreational disturbance. *Ibis, 149*, 1–2.

Durell, S. E. L. V. D., Stillman, R. A., Triplet, P., Aulert, C., dit Biot, D. O., Bouchet, A., et al. (2005). Modelling the efficacy of proposed mitigation areas for shorebirds: A case study on the Seine Estuary, France. *Biological Conservation, 123*, 67–77.

Fernández-Juricic, E., Jimenez, M. D., & Lucas, E. (2002). Factors affecting intra- and inter-specific variations in the difference between alert distance and flight distances for birds in forested habitats. *Canadian Journal of Zoology, 80*, 1212–1220.

Fernández-Juricic, E., Blumstein, D. T., Abrica, G., Manriquez, L., Adams, L. B., Adams, R., et al. (2006). Relationships of anti-predator escape and post-escape responses with body mass and morphology: A comparative avian study. *Evolutionary Ecology Research, 8*, 731–752.

Fitzpatrick, S., & Bouchez, B. (1998). Effects of recreational disturbance on the foraging behaviour of waders on a rocky beach. *Bird Study, 45*, 157–171.

Fowler, G. S. (1999). Behavioral and hormonal responses of Magellanic penguins (*Spheniscus magellanicus*) to tourism and nest site visitation. *Biological Conservation, 90*, 143–149.

Fox, A. D., Bell, D. V., & Mudge, G. P. (1993). A preliminary study of the effects of disturbance on feeding wigeon grazing on eelgrass Zostera. *Wader Study Group Bulletin, 68*, 67–71.

Gill, J. A., Norris, K., & Sutherland, W. J. (2001). Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation, 97*, 265–268.

Gill, J. A. (2007). Approaches to measuring the effects of human disturbance on birds. *Ibis, 149*, 9–14.

Glover, H. K., Guay, P. J., & Weston, M. A. (2015). Up the creek with a paddle; avian flight distances from canoes versus walkers. *Wetlands Ecology and Management, 23*, 775–778.

Goss-Custard, J. D., Triplet, P., Sueur, F., & West, A. D. (2006). Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation, 127*, 88–97.

Harrington, B. A. (2003). Shorebird management during the non-breeding season − An overview of needs, opportunities, and management concepts. *Wader Study Group Bulletin, 100*, 59–66.

Herrera, A. G., Navedo, J. G., Torralbo, L., Gonzalez-Pardo, J., & Alcántara, M. A. (2008). *Efectos del tránsito de una embarcación turística ligera sobre las poblaciones de aves acuáticas invernantes en el estuario del Asón*, *Vol. 5*, Locustella: Anuario de la Naturaleza Cantabria80–87.

Higginbottom, K. (2004). *Wildlife tourism: Impacts, management and planning.* Melbourne: Common Ground Publishing.

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

Klein, M. L. (1995). Effects of ecotourism on distribution of waterbirds on a wildlife refuge. *Conservation Biology, 9*, 1454–1465.

Koch, S. L., & Paton, P. W. C. (2014). Assessing anthropogenic disturbances to develop buffer zones for shorebirds using a stopover site. *The Journal of Wildlife Management, 78*, 58–67.

Madsen, J. (1998). Experimental refuges for migratory waterfowl in Danish wetlands. I. Baseline assessment of the disturbance of recreational activities. *Journal of Applied Ecology, 35*, 386–397.

McLeod, E. M., Guay, P. J., Taysom, A. J., Robinson, R. W., & Weston, M. A. (2013). Buses, cars, bicycles and walkers: The influence of the type of human transport on the flight responses of waterbirds. *Public Library Of Science, 8*, e82008.

Montero, J. A. (2005). *Dónde ver aves en España. Los 100 mejores lugares.* Barcelona, Spain: Lynx Editions.

Mullner, A., Linsenmair, K. E., & Wikelski, M. (2004). Exposure to ecotourism reduces survival and affects stress response in hoatzin chicks (*Opisthocomus hoazin*). *Biological Conservation, 118*, 549–558.

Myers, J., Morrison, R., Antas, P. Z., Harrington, B. A., Lovejoy, T. E., Sallaberry, M., et al. (1987). Conservation strategy for migrating species. *American Scientist, 75*, 18–26.

Navedo, J. G., & Herrera, A. G. (2012). Effects of recreational disturbance on tidal wetlands: Supporting the importance of undisturbed roosting sites for waterbird conservation. *Journal of Coastal Conservation, 16*, 373–381.

Navedo, J. G., & Masero, J. A. (2007). Measuring potential negative effects of traditional harvesting on shorebirds: A case study with migrating curlews *Numenius arquata*. *Animal Conservation, 10*, 88–94.

Navedo, J. G. (2006). *Efectos del marisqueo tradicional sobre la alimentación de las aves limícolas en areas intermareales: Aplicaciones para la gestión de los estuarios cantábricos Dissertation.* Santander, Spain: Universidad de Cantabria.

Navedo, J. G., Masero, J. A., & Juanes, J. A. (2007). Updating waterbird population estimates within the East Atlantic Flyway: Status and trends of migratory waterbirds in Santoña Marshes. *Ardeola, 54*, 237–249.

Nudds, R. L., Dyke, G. J., & Rayner, J. (2006). Avian brachial index and wing kinematics: Putting movement back into bones. *Journal of Zoology, 272*, 218–226.

Peters, K. A., & Otis, D. L. (2006). Wading bird response to recreational boat traffic: Does flushing translate into avoidance? *Wildlife Society Bulletin, 34*, 1383–1391.

Rayner, J. M. V. (1988). Form and function in avian flight. In R. F. Johnston (Ed.). *Current Oornithology* (pp. 1–66). New York: Springer.

Rayner, J. M. V. (1995). Flight mechanics and constraints on flight performance. *Israel Journal of Zoology, 43*, 321–342.

Recio, M., Ondiviela, B., Puente, A., Galván, C., Gómez, A. G., & Juanes, J. A. (2013). A management approach for the ecological integrity of NE Atlantic estuaries. *Estuaries and Coasts, 36*, 997–1005.

Rogers, J. A., & Schwikert, S. T. (2002). Buffer-zone distances to protect foraging and loafing waterbirds from disturbance by personal watercraft and outboard-powered boats. *Conservation Biology, 6*, 216–224.

Robinson, J. A., & Pollitt, M. S. (2002). Sources and extent of human disturbance to waterbirds in the UK: An analysis of Wetland Bird Survey data, 1995/96 to 1998/99. *Bird Study, 49*, 05–211.

Ronconi, R. A., & St Clair, C. C. (2002). Management options to reduce boat disturbance on foraging black guillemots (Cepphus grille) in the Bay of Fundy. *Biological Conservation, 108*, 265–271.

Samia, D. S. M., Nakagawa, S., Nomura, F., Rangel, T. F., & Blumstein, D. T. (2015). Increased tolerance to humans among disturbed wildlife. *Nature Communications, 6*, 8877.

Sekercioglu, C. H. (2002). Impacts of birdwatching on human and avian communities. *Environmental Conservation, 29*, 282–289.

Steven, R., Pickering, C., & Castley, J. G. (2011). A review of the impacts of nature based recreation on birds. *Journal of Environmental Management, 92*, 2287–2294.

Stillman, R. A., West, A. D., Caldow, R. W. G., & Durell, S. E. A. L. V. (2007). Predicting the effect of disturbance on coastal birds. *Ibis, 149*, 73–81.

Thomas, K., Kvitek, R. G., & Bretz, C. (2003). Effects of human activity on the foraging behavior of sanderling. *Calidris alba. Conservation Biology, 109*, 67–71.

Weston, M. A., McLeod, E. M., Blumstein, D. T., & Guay, P. J. (2012). A review of flight-initiation distances and their application to managing disturbance to Australian birds. *Emu, 112*, 269–286.

Wetlands International (2012). *Waterbird population estimates* (5th ed.). Wageningen: Wetlands International.

Wiersma, P., & Piersma, T. (1994). Effects of microhabitat, flocking, climate and migratory goal on energy-expenditure in the annual cycle of Red Knots. *Condor, 96*, 257–279.

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). *Mixed effects models and extensions in ecology with R.* New York: Springer.