



# Understanding the impact of recreational disturbance caused by motor vehicles on waterbirds: a case study from the Bundala Wetland, Sri Lanka

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## Abstract

Promotion of recreational access is an important strategy that helps to impart conservation values to wetlands and aids in fostering sustainable employment for local communities who live in close proximity to wildlife habitats. Unregulated recreational vehicles in coastal wetlands can cause detrimental impacts on coastal avifauna. There is a dearth of information especially in the South Asian context on the impact of recreational disturbance to waterbirds that can inform the management of wetland destinations. This study examined the response of selected water birds to motor vehicles using multispecies experimental disturbance trials conducted at Bundala National Park, Sri Lanka; a Ramsar-listed wetland of global importance. The selected species had significantly different sensitivities to disturbance caused by motor vehicles (log-rank test,  $\chi^2 = 51.7$ ,  $P < 0.05$ ). The probability of a bird responding to a moving vehicle parallel to the bird at a distance of 75 m was greater than 0.6 for all selected species (*Calidris minuta*, *Charadrius alexandrinus*, *Himantopus himantopus*, *Limosa limosa*, *Platalea leucorodia* and *Mycteria leucocephala*) except *Hydroprogne caspia*. Resting birds appeared to be more affected by recreational disturbance when compared to foraging birds. Larger birds (height of adult bird: 80–105 cm) were more sensitive to recreational stimuli, compared to smaller birds (10–20 cm). In general, responses of birds for recreational stimuli, were prominent up to 100 m from the source. Selected waterbirds showed longer response distances in habitats exposed to high vehicle traffic activity suggesting possible habituation of birds to recurring disturbance. Our findings suggest a minimal setback buffer of 100 m needs to be employed to manage recreational disturbance from motor vehicles at Bundala National Park.

**Keywords** Agitation distance · Recreation · Off-road driving · Vehicle traffic · Habituation

## Introduction

Nature-based tourism in coastal environments is a very popular phenomenon in contemporary tourism settings (Tang 2015; Kurniawan et al. 2016; Schuhmann et al. 2016; de

Andrés et al. 2018; Marasinghe et al. 2021). As a result, the proportion of coastal habitats including coastal wetlands that are exposed to tourism activities is on the rise (Badalamenti et al. 2000). Birds in coastal habitats are a major attraction in wildlife tourism based on coastal environments, and recent literature suggests that birdwatching in coastal areas is a recreational activity of global significance (Moss 2009; Hardiman and Burgin 2010; Velando and Munilla 2011; Muttaqien et al. 2015; Kjølørød 2019; Marasinghe et al. 2020, 2021). Accordingly, in many countries due to the increasing popularity of bird watching, coastal habitats are more likely to attract visitors during times when migratory shorebirds are present and during the breeding season of resident bird species (Glover et al. 2011). However, not all human recreational activities are compatible with the conservation of coastal environments (Orams 2003; Davenport and Davenport 2006).

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A disruption to normal behavioral and physiological activities or states caused by the response of a bird to the presence of a stimulus is described as a ‘disturbance’ in the literature (Fox and Madsen 1997; Weston et al. 2012; Weston 2019). A diverse range of natural and anthropogenic stimuli can disturb birds. Typical behavioral responses by birds to such external stimuli include vigilance (i.e. the bird stopping its current activity to monitor its surrounding) and flight responses (Fernández-Juricic et al. 2001; Glover et al. 2011; Weston et al. 2012; Chatwin et al. 2013). Tourism in natural areas is known to cause such disturbance to birds (Alwis et al. 2016; Radkovic et al. 2019; Slater et al. 2019), with shorebirds especially vulnerable to human disturbance because of their size, behaviors, and attraction for birders (Muttaqien et al. 2015; Kutzner 2019; Newsome and Simpson 2020). It has been argued that birds perceive humans or moving vehicles as predators and this elicits behavioral responses that can have detrimental consequences (McLeod et al. 2013; Guay et al. 2014; Bernard et al. 2018).

Recreational disturbance in coastal environments causes birds to leave their habitats temporarily or permanently potentially resulting in significant negative impacts at the individual, population, and community level (Fernández-Juricic and Tellería 2000; Mallord et al. 2007; Newsome et al. 2013; Alwis et al. 2016). Critical issues documented include alteration (reduction) of foraging behavior and habitat use (Moore 2014; Martín et al. 2015; Stigner et al. 2016; Monti et al. 2018). A systematic review by Marasinghe et al. (2020) identified the presence of humans/foot traffic, exercising pet dogs, operation of motor vehicles, and recreational boating as the most commonly reported sources of disturbance to shorebirds in tropical Asia. Numerous studies have reported a significant correlation between higher vehicle traffic and reduced species richness and abundance of birds in coastal habitats (Marcum 2006; Tarr et al. 2010; Steven et al. 2011; Schlacher et al. 2013a; Ramli and Norazlimi 2017). The movement and sound of motor vehicles can induce vigilance and escape behaviors in birds and cause displacement of birds from their preferred feeding and roosting sites, forcing them to spend considerable amounts of their energy budget avoiding human recreational disturbance (Meager et al. 2012; Ortega 2012; Helldin et al. 2013; Palia 2018).

Vehicular access can cause direct mortality of birds as a result of crushing/trampling nests of beach-dwelling bird species (Hockin et al. 1992; Williams et al. 2004; Kearvell 2011; Weston et al. 2012; Schulte and Simons 2015), eggs (Melvin et al. 1994; Weston et al. 2012), chicks (McGowan 2004; Williams et al. 2004; McGowan and Simons 2006; Weston et al. 2012; Schulte and Simons 2015) and adult birds due to collisions with vehicles (Tarr et al. 2010; Schlacher et al. 2013b). Motor vehicular traffic may also negatively affect the nesting success of shorebirds (McGowan and Simons 2006; Tarr et al. 2010; van Polanen Petel and

Bunce 2012; Maslo et al. 2018). Nonetheless, different bird species show differential responses to recreational disturbance and certain avian species are capable of tolerating greater degrees of disturbance (Marcum 2006; Gill 2007; Cardoni et al. 2008; Weston et al. 2012). The nature or type of disturbance and the distance from the source of disturbance to the bird have been reported as important determinants of birds’ response to human recreational disturbance (Pease et al. 2005; Ruddock and Whitfield 2007; Jorgensen et al. 2016; French et al. 2019). Hence, an in-depth understanding of such phenomena has essential implications in the management of recreation in coastal habitats (Weston et al. 2012; Guay et al. 2016).

In theory, well-managed ecotourism may involve setting scientifically based operational guidelines such as defining visitor access zones and set-back distances to reduce negative impacts on the environment and wildlife and to manage recreational disturbance (Guay et al. 2019). Stakeholder consultation is also important, encouraging involvement in management, educational programs and interpretation to create experiences that inculcate positive environmental attitudes and human behaviors (Newsome et al. 2013; Chatwin et al. 2013). For ecotourism operations in coastal habitats, especially those based on birdwatching, to be sustainable, it is important that key biodiversity features (i.e. the bird populations inhabiting coastal environments) are maintained. Hence, managing recreational disturbance to birds should be prioritized in any coastal habitat management agenda. Previous studies suggest a variety of management actions such as limiting vehicle access (Yosef 2000; Yasué and Dearden 2006; Borneman et al. 2016), limiting access points (Meager et al. 2012), temporal and spatial zoning/creation of spatial refuges (Schlacher et al. 2013a, b; DeRose-Wilson et al. 2018), temporary/seasonal closure during important periods for birds such as the breeding season (Pease et al. 2005; Weston et al. 2014) and educating drivers about the impact of vehicles on birds (Petch et al. 2018). Among those, establishing set-back distances or buffers is one of the widely accepted and successful approaches to minimize the impacts of motor vehicles on birds in coastal habitats (Defeo et al. 2009; Borgmann 2010; Glover et al. 2011; Schlacher et al. 2013b; Choi et al. 2015; Hillman et al. 2015; Coetzer and Bouwman 2017).

Although the response of forest birds to various anthropogenic disturbance has been examined by previous research (Goodale et al. 2014, 2015; Alwis et al. 2016; Perera et al. 2017), no studies have attempted to understand the response of wetland birds to recurring recreational disturbances in the Sri Lankan context. Hence, the main objective of this study was to determine the responses of selected waterbirds to recreational disturbance from motor vehicles at the Bundala National Park in the south coast of Sri Lanka; a globally important Ramsar wetland and a highly popular destination for birdwatching. Specifically, we wanted to determine the

agitation distance (the distance at which a vigilance response is initiated) of selected wetland birds to approaching motor vehicles under different circumstances, such as during different bird behavioral conditions (feeding and resting), vehicle speeds, degree of motor traffic, and body size of birds. Given that tourist/recreational access at BNP is only via vehicular access, our intention was to provide further data to assist management in the setting of appropriate management actions to reduce vehicular recreational impacts on wetland birds at an important conservation reserve and tourism site in Sri Lanka.

## Methodology

### Study location

This study was carried out at the Bundala National Park (BNP), a premier wildlife tourism destination for bird-watching. BNP, which is 6216 ha in extent (DWC 2008), is located on the coast of Hambantota District in Southern Province, Sri Lanka (Fig. 1). BNP and the Wilmenna Sanctuary (3333 ha) bordering the northern boundary of the BNP together form a unique ecosystem comprising of coastal wetland habitats, which are important for migratory and native avifauna (DWC 2008). As such, BNP has been recognized as a Wetland of International Importance as defined by the Ramsar Convention for the conservation and sustainable use of wetlands (DWC 2008). Three topographic zones can be identified within BNP, (1) beach and sand dunes, (2) outer coastal plains with lagoons, and (3) inner coastal plains (DWC 2008). BNP lies in the dry zone, with a mean annual temperature of 27<sup>0</sup> C and mean annual rainfall ranging between 900 and 1300 mm (DWC 2008). BNP has rich biodiversity comprising of 185 plant species, 29 mammal species, 26 reptile species, 29 fish species, 13 amphibian species, and 52 butterfly species (Bambaradeniya et al. 2002; DWC 2008). However, avifaunal diversity is the key biodiversity feature of tourism importance. Approximately 50% of Sri Lanka's 240 breeding resident bird species and 21% of 213 migratory bird species are recorded in the BNP and sanctuary (DWC 2008; MOE 2012). Out of these, nearly 50% of the total bird species are aquatic or aquatic associates, making BNP and the sanctuary one of the critically important sites for aquatic bird conservation in Sri Lanka.

### Selection of sampling locations

Field observations were carried out at six sampling locations inside the BNP (Fig. 1). Sampling locations were selected based on the abundance of waterbirds and proximity to designated access trails used by motor vehicles. Visibility was a key factor considered in selecting the sampling locations and the observation points were selected to have

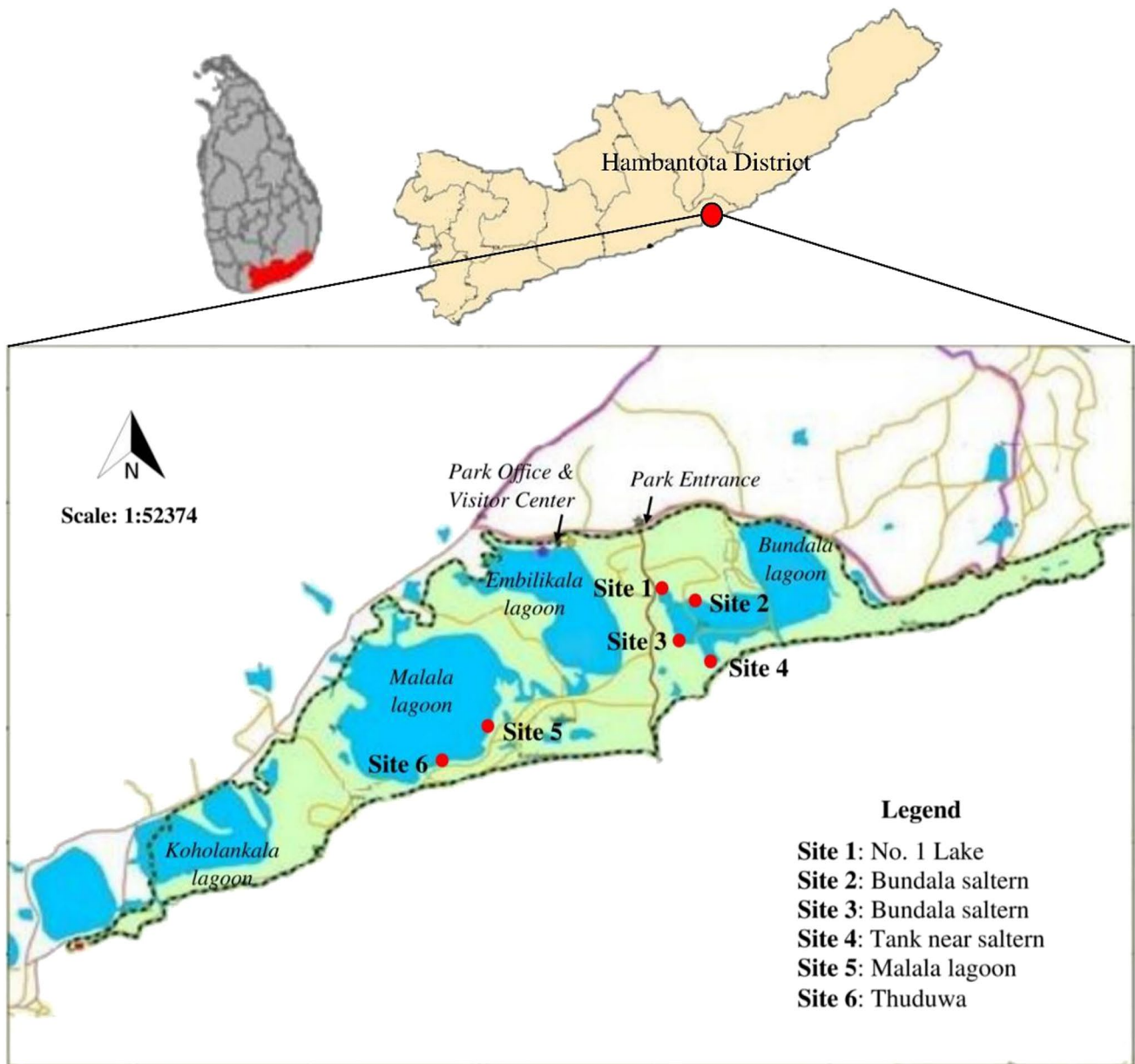
a clear horizontal visual range exceeding 200 m. At each visual horizontal landscape, the boundaries of main habitats were identified (i.e. terrestrial, terrestrial-aquatic interface, and aquatic). Natural landmarks (such as trees and rocks/boulders on the ground) and wooden pegs placed at 25 m intervals from the edge of the trail were used as distance indicators from the trail to the target bird to aid the estimation and verification of horizontal distance measurements.

Visitors use either safari jeeps or private vehicles that are suitable for use inside the park for birdwatching and wildlife observation. Descriptors for the intensity and impact of recreational disturbances caused by motor vehicles are known to vary (Monz et al. 2016; Spaul and Heath 2017; Marasinghe et al. 2020). In this study, we defined recreational disturbance in terms of the speed of vehicles and the degree of traffic (frequency of disturbance). Accordingly, the six sample sites were categorized as low traffic (< 2 motor vehicles per hour; Sites 5 and 6), moderate traffic (2–5 motor vehicles per hour; Sites 3 and 4), and high traffic (5 > motor vehicles per hour; Site 1 and 2) based on baseline data/observations made during a pilot study conducted at same sites prior to experimental studies.

### Field techniques

During the period between April 2017 and April 2019, waterbirds at the sampling sites were experimentally disturbed by moving a single off-road motor vehicle at different speeds to record responses of waterbirds. We conducted experimental trials instead of observing the responses of waterbirds to regular vehicle movements in the park to standardize the conditions (e.g. eliminate possible bias due to varying noise levels, colour and size of the vehicle) under which the observations were made, and to ensure consistency and accuracy of observations (Bellefleur et al. 2009; Chatwin et al. 2013). The disturbance vehicle traveled along the designated road to emulate regular vehicle movement in the park instead of driving the vehicle towards birds to induce a response.

The distance at which a bird shows a visible vigilance response to a disturbance is synonymously referred to as Alarm Initiation Distance, Alert Distance or Agitation Distance (Dandenong Valley Authority 1979; Chatwin et al. 2013; Weston 2019). Accordingly, the distance that the first bird in the group or an individual 'targeted' bird showed a visible response to the approaching vehicle (Agitation Distance: AD) was measured using a Nikon Forestry Pro (Nikon Corporation, Tokyo, Japan) laser rangefinder. Activities that differed from normal foraging and resting behaviors such as alertness, standing up more erect, lifting head, scanning around, vocalizing, move away from the point, leaving the area, were characterized as visual responses for the recreational disturbance (Chatwin et al. 2013). When any of these responses occurred, the vehicle was stopped and the distance



**Fig. 1** Location map of Bundala National Park

to the agitated bird was measured by the observer in the vehicle. During the pilot trials, the observers were trained to take measurements using a laser range finder as well as estimating the distance to a bird (eye estimation within  $\pm 10$  m accuracy) (Schlacher et al. 2013b), as measuring distance with a laser range finder was not always feasible when a large group of birds were present. Observations were made for approximately eight hours per day from 6.00 to 10.00 h and 14.00 to 18.00 h, when birds were more abundant in the sampling locations. Experimental disturbances were carried out under 3-speed regimes at each location: the vehicle moving at a speed of 10 km/h, 20 km/h, and 30 km/h parallel to the bird from a starting distance of 200 m. Experimental

disturbance trials were carried out when no other vehicles were present at the selected sites.

We targeted selected waterbird species in both single species flocks and mixed species flocks (Linley et al. 2020). We considered only the events of experimental disturbance caused by the vehicle. Events, where the target bird/group of birds were disturbed by other external stimuli such as natural environmental factors (e.g. strong winds and rain), behaviors of a neighboring bird, over flight of a bird of prey (e.g. Brahminy kite - *Haliastur indus*; White-bellied sea eagle - *Haliaeetus leucogaster*, Grey-headed fish eagle - *Ichthyophaga ichthyaeetus*) or approach of other potential predators (e.g. Golden jackal - *Canis aureus*, Saltwater crocodile - *Crocodylus*

porous), were not considered. In such cases, the disturbance vehicle left the scene and returned after a minimum interval of 30 min to allow the birds to resume their normal activities. The targeted birds were not disturbed more than once per day to minimize habituation to the recreational disturbance.

### Data analysis

In our study, the response to a disturbance was considered as the discrete event of interest. The agitation distance (AD) was measured from the source of disturbance to a focal bird/group of birds. Note that AD is positive-valued and may not be fully observable (i.e. censored or incomplete observations). Hence, Survival Analysis techniques were utilized to analyze the data related to AD since Survival Analysis techniques are required to handle censored or incomplete data (e.g. see Cox 1972). Hence, using Survival Analysis techniques, we investigated the survival function, the probability of responding at a distance beyond d, denoted by S(d) (ref. Eq. (2)), hazard of responding at distance d denoted by h(d) (ref. Eq. (3)) and how different covariates considered affect these functions through various survival models.

To estimate the survival function, a nonparametric approach was followed as it does not make any distributional assumptions. Hence, the Kaplan Meier (KM) estimator (Kaplan and Meier 1958) was utilized to determine the probability of response of waterbirds beyond a certain distance from the source of disturbance under different scenarios. This technique has been widely used in recreational disturbance studies to model the time or distance to a discrete event when there are events of no response (Lawless 2002; Collop 2017; Scarton 2020). KM Survival curves for AD were plotted and investigated for birds who are experiencing different levels of disturbance.

### Hazard rate

Suppose that the main random variable of interest, the agitation distance (AD) is denoted by D. Then, by definition the probability density function of D is

$$f(d) = \lim_{\Delta d \rightarrow 0} \frac{P(\text{Responding within}(d, d + \Delta d)\text{distance})}{\Delta d} \quad (1)$$

where  $\Delta d$  is the next delta distance and  $d \in [0, \infty)$ . The survival function of AD is defined as the complement of the cumulative distribution function  $F(d) = P(D \leq d)$  and hence:

$$S(d) = P(\text{responding after distance } d) = P(D > d) = 1 - F(d). \quad (2)$$

The hazard function of AD, i.e. the hazard of responding, can be defined as follows (e.g. see Lee and Wang 2003):

$$h(d) = \frac{f(d)}{s(d)} = \lim_{\Delta d \rightarrow 0} \frac{P(\text{Responding within}(d, d + \Delta d)\text{ distance given that the bird has not responded by distance } d)}{\Delta d} \quad (3)$$

where  $\Delta d$  is the next delta distance and  $d \in [0, \infty)$ .

### Cox proportional hazards (Cox PH) model

We used Cox PH model (Cox 1972) to investigate the AD of selected waterbird species depending on different covariates (e.g. species, type of behaviour, traffic level, body size of the birds and speed of the approaching vehicles). This is a non-parametric model which does not assume any distribution for the time-to-event random variable concerned (AD).

Model formula:

$$h(d|X) = h_0(d) \exp\left(\sum_{i=1}^p b_i X_i\right) \quad (4)$$

where  $X_i$  for  $i = 1, \dots, p$  are the covariates (and/or associated indicator variables) in the model,  $b_i$  for  $i = 1, \dots, p$  are their coefficients,  $h(d|X)$  is the hazard rate in the presence of covariates in the model and  $h_0(d)$  is the baseline hazard rate; i.e. the hazard rate when all the covariates in the model are in their reference category in this study. Hence, coefficient of a dichotomous/polychotomous r.v. (ordinal or nominal r.v. with k levels/categories) can be interpreted as follows, when the other variables are held constant:

- If  $\exp(b_i) > 1$ , then the hazard of responding for a bird belonging to the  $i^{\text{th}}$  category is  $\exp(b_i)$  times greater than the hazard of responding for a bird belonging to the reference category.
- If  $\exp(b_i) < 1$ , then the hazard of responding for a bird belonging to the  $i^{\text{th}}$  category is  $\exp(b_i)$  times the hazard of responding of a bird belonging to the reference category. Hence, the hazard of responding for a bird belonging to the  $i^{\text{th}}$  category is  $(1 - \exp(b_i))100\%$  lower than the hazard of responding for a bird belonging to the reference category.
- If  $\exp(b_i) \cong 1$ , then the hazard of responding for a bird belonging to the  $i^{\text{th}}$  category is approximately equal to the hazard of responding for a bird belonging to the reference category. Such coefficients will be shown as insignificant (p-value of the corresponding Wald's test > the level of significance considered).

We made two assumptions in fitting Cox PH model:

- (1) Proportional hazards assumption: Hazard functions of different birds are assumed to be proportional and independent of distance; i.e. ratio of hazard functions

of two birds with different covariate values is constant (does not vary with distance). Validity of the assumption is tested through a Schoenfeld residual analysis.

- (2) Each covariate makes a linear contribution to the model; i.e. Log hazard and the quantitative covariates are in a linear relationship. Validity is tested through a martingale residual analysis.

In our study we do not have any quantitative covariates. Hence, the second assumption has not been made and hence not required to be tested. The analysis was primarily conducted using RStudio (RStudio Team 2020) and IBM® SPSS® Statistics 20 software.

### Stratified Cox PH (SCox PH) model

As a remedy for the violation of proportional hazards assumption for some covariates in some models, stratified Cox PH models were fitted. This resulted in a set of models with significantly better goodness of fit which was evaluated through Akaike Information Criterion (AIC). The lower the AIC, the higher the goodness of fit of a model.

The Cox PH model assumed that the ratio of the response hazard functions of any two birds with different covariate values is constant. Cox's model can be generalized using the concept of stratification (Kalbfleisch and Prentice 1980) when this assumption is not met. It adjusts the model parameters considering the fact that different hazard functions exist for different levels in the stratifying variable. For example, if the stratifying variable consists of  $k$  number of levels then the model can be written as follows:

Model formula:

$$h_j(d|X) = h_{j0}(d) \exp\left(\sum_{i=1}^p b_i X_i\right) \quad (5)$$

where  $j = 1, \dots, k$ ,  $X_i$  for  $i = 1, \dots, p$  are the covariates (and/or associated indicator variables) in the model,  $b_i$  for  $i = 1, \dots, p$  are their coefficients,  $h_j(d|X)$  is the hazard function of the  $j$ th category of the stratifying variable in the presence of covariates in the model and  $h_{j0}(d)$  is the baseline hazard rate function of the  $j$ th category of the stratifying variable when all the other covariates in the model are in their reference category.

### The sensitivity of species to recreational disturbance from motor vehicles

Species sensitivity was analyzed by using AD as the response variable for the waterbird species with sufficient observations. Accordingly, agitation distances of foraging and resting birds: Little stint (*Calidris minuta*), Kentish plover (*Charadrius alexandrinus*), Black-winged stilt (*Himantopus himantopus*),

Black-tailed godwit (*Limosa limosa*), Eurasian spoon-bill (*Platalea leucorodia*), and Painted stork (*Mycteria leucocephala*) to a vehicle moving at a speed of 10 km/h, were analyzed. Only the disturbance events of resting Caspian tern (*Hydroprogne caspia*) were considered for the analysis, since foraging activities of this species couldn't be captured by using our methods, as it is an aerial forager.

### Agitation probability and the frequency of recreational disturbances in the habitat

Since response of birds could possibly depend on the previous exposure to human disturbances (Livezey et al. 2016; De Blocq Van Scheltinga 2017), Kaplan-Meier analysis was performed for agitation distances of selected waterbird species in high, medium, and low vehicle traffic habitats/sampling sites. Only the disturbance events by a vehicle moving at 10 km/hour were considered in the analysis as the sample size of disturbance trials conducted by a vehicle moving at 20 km/h and 30 km/h speeds were less than the minimum sample size requirements for reliable Kaplan-Meier estimate (Akbar et al. 2009; Che 2014).

### Effect of body size of birds on agitation

It is suggested in the literature that there is a positive correlation between body size and response/flight initiation distance of bird species (Fernández-Juricic et al. 2002; Blumstein 2006; Weston et al. 2012). To investigate the differential responses of bird species of different body sizes, the birds subjected to recreational disturbances were categorized into three body size classes based on the height of adult birds i.e. small (10–20 cm), medium (35–45 cm), and large (80–105 cm) (Harrison 2011). Pooled data under three body-size categories were then analyzed to determine the probability of agitation of birds of each body size class with the distance from the source of the disturbance. Only the disturbance events at the vehicle moving at 10 km/hour were used due to insufficient sample sizes according to 20 km/h and 30 km/h speeds. Since the focus of the work is also on the management of recreational disturbance on waterbirds, phylogenetically controlled analyses were not attempted (Slater et al. 2019).

### Effect of speed of vehicles on agitation

The response distance of birds of the three body-size classes was examined for disturbance events made under vehicles moving at 10 km/h, 20 km/h and 30 km/h speeds. Data analyses were carried out using IBM® SPSS® Statistics 20 software and R Studio.

## Results

A total of 1627 disturbance trials were completed during the study period. Out of these, 1259 disturbance trials were performed by a vehicle moving at 10 km/h speed while 209 and 159 trials were completed by a vehicle moving at 20 km/h and 30 km/h speeds respectively.

### Agitation distances of selected waterbird species

Kentish plover (*Charadrius alexandrinus*) showed the shortest AD (17 m), followed by Little stint (*Calidris minuta*) (21 m). Eurasian spoonbill (*Platalea leucorodia*) showed the longest AD (51 m) while Painted stork (*Mycteria leucocephala*), Black-tailed godwit (*Limosa limosa*), Black-winged stilt (*Himantopus himantopus*) and Caspian tern (*Hydroprogne caspia*) showed AD of 32 m, 36 m, 37 and 39 m respectively.

### Agitation probability of foraging vs. resting birds to recreational disturbance from motor vehicles

Agitation probability curves of the selected species under foraging and resting, obtained from Kaplan-Meier Survival Analysis, are depicted in Fig. 2. All agitation probability curves under foraging and resting events converged to 0 at the distance of 200 m except for Caspian tern (*Hydroprogne caspia*). The agitation probability curves of Little stint (*Calidris minuta*), Kentish plover (*Charadrius alexandrinus*), Black-tailed godwit (*Limosa limosa*), Eurasian spoonbill (*Platalea leucorodia*), and Painted stork (*Mycteria leucocephala*) showed a clear drop at 100 m from the source of disturbance under both foraging and resting events. A similar drop in agitation probability curves was observed for Black-winged stilt (*Himantopus himantopus*) and Caspian tern (*Hydroprogne caspia*), at a 150 m distance (Fig. 2). Resting Caspian terns (*Hydroprogne caspia*) showed an agitation probability of 0.02 (2%) at a 200 m distance. However, log-rank test results indicated no statistically significant differences in survival distributions of species when disturbed while foraging and resting, except for Black-winged stilt (*Himantopus himantopus*) (Table 1).

### Agitation of birds in habitats that have different baseline levels of vehicular disturbance

Log-rank testing to determine the differences in the agitation response distributions for waterbirds occupying wetland habitats subjected to different intensities of recreational disturbances (defined based on the baseline vehicle traffic conditions under normal wildlife tourism operations) indicated

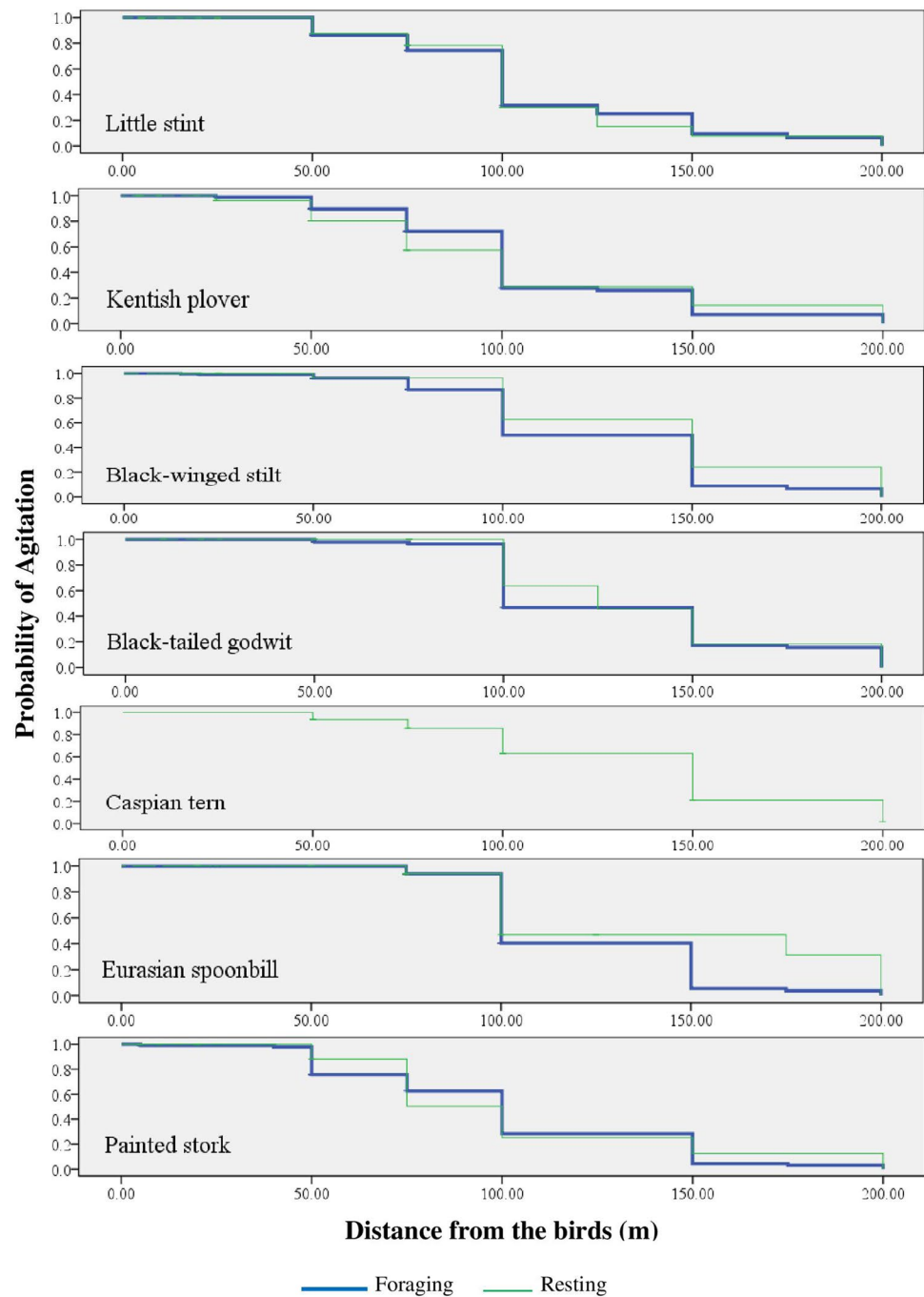
statistically significant differences among the high, moderate, and low traffic habitats ( $\chi^2 = 7.54$ ,  $P < 0.05$ ). Agitation probability curves for the selected species occupying habitats under different intensities of disturbance are indicated in Fig. 3. For all the seven species, the agitation probability curves converged to 0 at the distance of 200 m. In general, agitation probabilities of the seven species were highest in low baseline traffic habitats at all approach distances, while comparatively low agitation probabilities have been observed under high traffic environments (Fig. 3). In high and moderate traffic environments, the agitation probability curves of Little stint (*Calidris minuta*), Kentish plover (*Charadrius alexandrinus*), Black-tailed godwit (*Limosa limosa*), Eurasian spoonbill (*Platalea leucorodia*), and Painted stork (*Mycteria leucocephala*) showed a substantial drop at 100 m from the source of disturbance, while a decline in agitation probability curves were evident at 150 m distance for Black-winged stilt (*Himantopus himantopus*), Caspian tern (*Hydroprogne caspia*). In low traffic environments, the agitation probability curves of Kentish plover (*Charadrius alexandrinus*), Eurasian spoonbill (*Platalea leucorodia*), and Painted stork (*Mycteria leucocephala*) showed a visible drop at 100 m and further at 150 m distance from the source of the disturbance. For the Little stint (*Calidris minuta*), Black-winged stilt (*Himantopus himantopus*), Black-tailed godwit (*Limosa limosa*) and Caspian tern (*Hydroprogne caspia*), the drop in agitation probability curves were visible at 150 m distance (Fig. 3).

The log-rank tests further indicated statistically significant differences in agitation response distributions of Kentish plover (*Charadrius alexandrinus*), Black-winged stilt (*Himantopus himantopus*), Eurasian spoonbill (*Platalea leucorodia*), and Painted stork (*Mycteria leucocephala*) under different intensities of recreational disturbances. Mantel-Cox pairwise comparisons further indicated significant differences in survival distributions between low and high traffic habitats for Kentish plover (*Charadrius alexandrinus*), Black-winged stilt (*Himantopus himantopus*), and Painted stork (*Mycteria leucocephala*) (Table 2).

### The body size of birds and agitation probability

Waterbirds belonging to the three body-size categories showed significant differences in their survival distributions under recreational disturbance caused by a vehicle moving at a speed of 10 km/h. As indicated in Fig. 4, waterbirds with a medium-sized body (35–45 cm) exhibited the highest probability of agitation, while small birds (10–20 cm) reported the lowest probability compared to other body size categories. The agitation probabilities of all three body sizes declined with the distance from the source of disturbance and converged to 0 at the distance of 200 m (Fig. 4). The largest decline in the probability of

**Fig. 2** Plots of agitation proportions with the distance, for foraging and resting Little stint (*Calidris minuta*), Kentish plover (*Charadrius alexandrinus*), Black-winged stilt (*Himantopus himantopus*), Black-tailed godwit (*Limosa limosa*), Eurasian spoonbill (*Platalea leucorodia*), Painted stork (*Mycteria leucocephala*), and resting Caspian tern (*Hydroprogne caspia*)



agitation was observed at 100 m for birds with small and large body sizes. For medium-sized birds, equally large drops in agitation probability were observed at 100 and 150 m (Fig. 4). Mantel-Cox pairwise comparisons further indicated significant differences in survival distributions between birds of small and medium ( $\chi^2 = 48.921$ ,  $P < 0.05$ ), medium and large ( $\chi^2 = 12.691$ ,  $P < 0.05$ ) and small and large ( $\chi^2 = 13.697$ ,  $P < 0.05$ ) body size categories.

### Effect of speed of vehicles on agitation probability for different body size categories

Responses of waterbirds to three different speed levels (e.g. 10 km/h, 20 km/h, and 30 km/h) were pooled under three body-size categories and the effect of speed of the vehicle on agitation was further analyzed. Small (log-rank test,  $\chi^2 = 92.075$ ,  $P < 0.05$ ), medium (log-rank test,  $\chi^2 = 55.759$ ,  $P < 0.05$ ) and large (log-rank test,  $\chi^2 = 90.540$ ,  $P < 0.05$ )



**Table 1** Log-rank test results for differences in survival distributions of species when disturbed while foraging and resting

Species	$\chi^2$	<i>p</i> value
Little stint	0.002	0.968
Kentish plover	0.226	0.635
Black-winged stilt	4.178	0.041*
Black-tailed godwit	0.076	0.782
Eurasian spoonbill	2.173	0.143
Painted stork	0.132	0.716

\*Statistical significance at  $\alpha=0.05$  significance level

birds showed a significant difference in sensitivity to different speed levels. The probability of agitation of waterbirds of all three body size categories increased with the increasing speed of the vehicle (Fig. 5). The agitation probability of small, medium and large birds substantially declined beyond 100 m distance for disturbances caused by a vehicle moving at a speed of 10 km/h while comparatively higher agitation probabilities were observed for vehicles moving at 20 and 30 km/h speeds even at 150–200 m distances. Both medium and large birds showed higher probabilities of agitation at greater distances away from the source of disturbance for vehicles moving at 20 and 30 km/h speeds compared to birds of smaller body size (Fig. 5).

### Cox PH models and Stratified Cox PH models for response of selected waterbirds to disturbance from recreational motor vehicles

A total number of 7 models were fitted depending on different covariates considered for the analysis (e.g. species, behavior of bird before disturbance, traffic level, body size of the birds and speed of the recreational vehicle) as described below.

#### Model 1: All birds with species, behaviour and traffic as covariates

According to the fitted Cox PH model, when holding the other covariates constant, the ‘hazard of responding’ of a Painted stork is 1.43 times greater than of a Black-tailed godwit ( $P < 0.05$ ), which was considered as the reference level. Furthermore, Little stint showed a 1.51 times greater ‘hazard of responding’ ( $P < 0.001$ ) while it is 1.46 times greater for Kentish plover ( $P < 0.001$ ), compared to Black-tailed godwit. When considering the type of behaviour of targeted waterbirds, a resting bird showed a ‘hazard of responding’, which is 1.60 times greater than of a foraging bird. The ‘hazard of responding’ of a bird when the traffic is ‘high’ is 35% less than the ‘hazard of responding’ of a bird when the traffic is ‘low’ (Table 3).

The Schoenfeld residual analysis revealed that proportional hazard assumption is not valid for the covariate ‘behaviour’. Hence, a stratified Cox PH (SCox PH) was fitted with behaviour as the stratifying variable. According to SCox PH, the ‘hazard of responding’ of Painted stork, Little stint and Kentish plover are greater than Black-tailed godwit by 1.48 ( $P < 0.001$ ), 1.48 ( $P < 0.001$ ) and 1.40 ( $P < 0.05$ ) times respectively. Interestingly, the ‘hazard of responding’ of a bird when the traffic is ‘high/moderate’ is not statistically significantly different to the ‘hazard of responding’ of a bird when the traffic is ‘low’ (Table 4).

#### Model 2: All birds with body size, behaviour and traffic as covariates

As revealed by the fitted Cox PH model, when holding the other covariates constant, the ‘hazard of responding’ of a medium sized bird is 34% less ( $P < 0.001$ ) than the ‘hazard of responding’ of a small bird, which was considered as the reference level for the body size. A resting bird showed 1.569 times greater ‘hazard of responding’ ( $P < 0.001$ ) compared to a foraging bird (reference level). Moreover, the ‘hazard of responding’ of a bird when the traffic is ‘high’ is 37% less ( $P < 0.001$ ) than the ‘hazard of responding’ of when the traffic is ‘low’ (reference level) (Table 3).

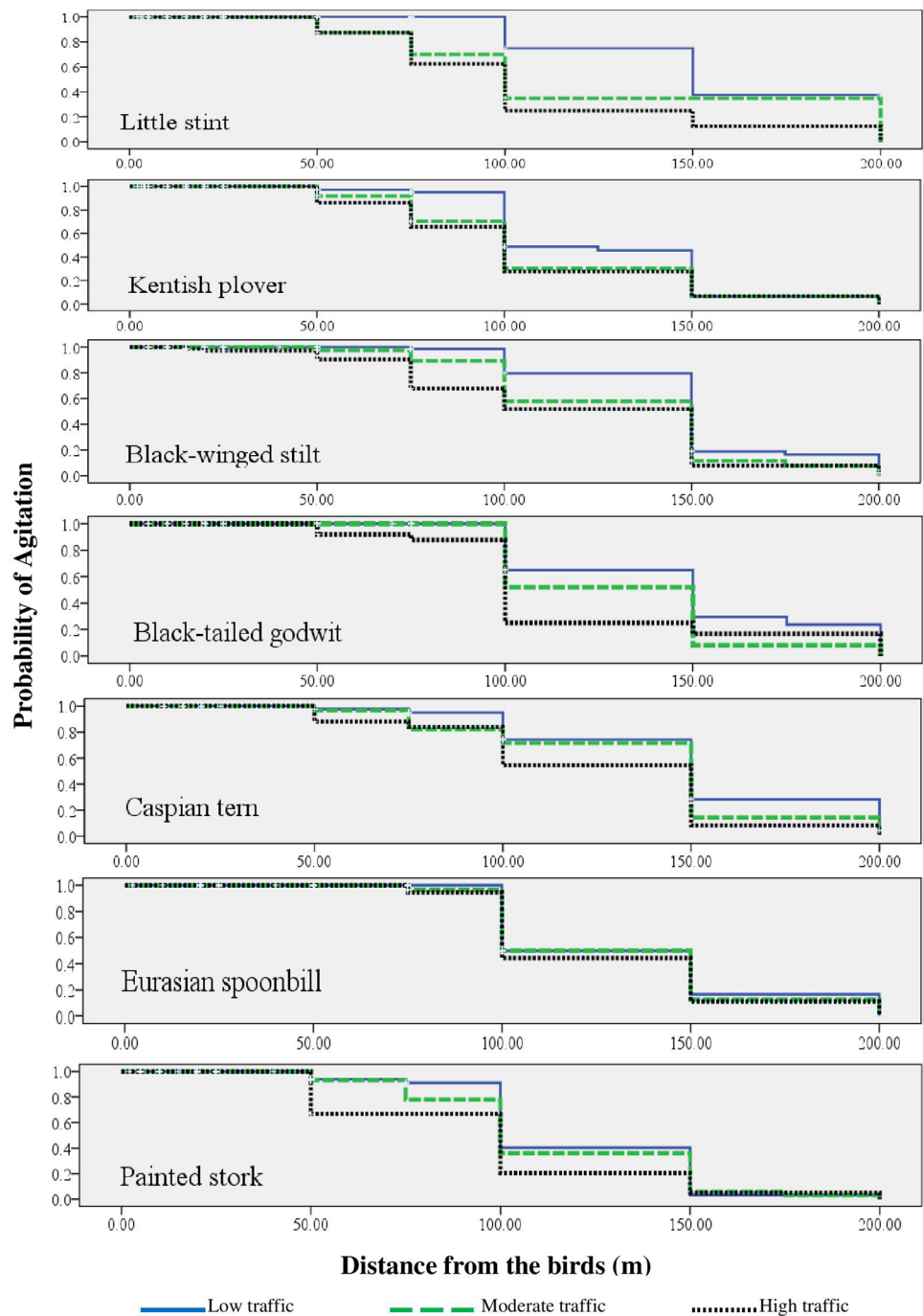
A stratified Cox PH was fitted with ‘behaviour’, as Schoenfeld residual analysis revealed that proportional hazard assumption is not valid for that covariate. When SCox PH adjusted for behaviour of selected waterbirds, ‘hazard of responding’ of a bird who has a medium body size is 23% less ( $P < 0.05$ ) than the ‘hazard of responding’ of a bird who has a small body size (Table 4).

#### Model 3: Foraging birds with body size and traffic as covariates

According to Cox PH model, when holding the other covariates constant, the ‘hazard of responding’ of a foraging bird who has a medium body size is 33% less ( $P < 0.001$ ) than the ‘hazard of responding’ of a foraging bird who has a small body size (reference level). When considering the level of traffic, ‘hazard of responding’ of a foraging bird, when the traffic is ‘moderate’ and ‘high’, is greater than of a bird experiencing a the ‘low’ level of traffic (reference level) by 1.435 times ( $P < 0.001$ ) and 1.613 times ( $P < 0.001$ ) respectively (Table 3).

The Schoenfeld residual analysis revealed that proportional hazard assumption is not valid for the covariate ‘traffic’. Hence, a SCox PH was fitted with that as the stratifying variable. When SCox PH adjusted for the level of traffic that the foraging birds are experiencing, the ‘hazard of responding’ of a foraging bird who has a medium body size is 34%

**Fig. 3** Plots of agitation proportions (under low, moderate, and high vehicle traffic conditions) with the distance, for Little stint (*Calidris minuta*), Kentish plover (*Charadrius alexandrinus*), Black-winged stilt (*Himantopus himantopus*), Black-tailed godwit (*Limosa limosa*), Caspian tern (*Hydroprogne caspia*), Eurasian spoonbill (*Platalea leucorodia*) and Painted stork (*Mycteria leucocephala*) when disturbed by a moving vehicle at 10 km/h speed



less ( $P < 0.001$ ) than that of a foraging bird who has a small body size (reference level) (Table 4).

#### Model 4: Resting birds with body size and traffic as covariates

When holding the other covariates constant in the Cox PH, the ‘hazard of responding’ of a resting bird who has a medium body size is 65% less ( $P < 0.001$ ) than the ‘hazard of responding’ of a resting bird who has a small body size

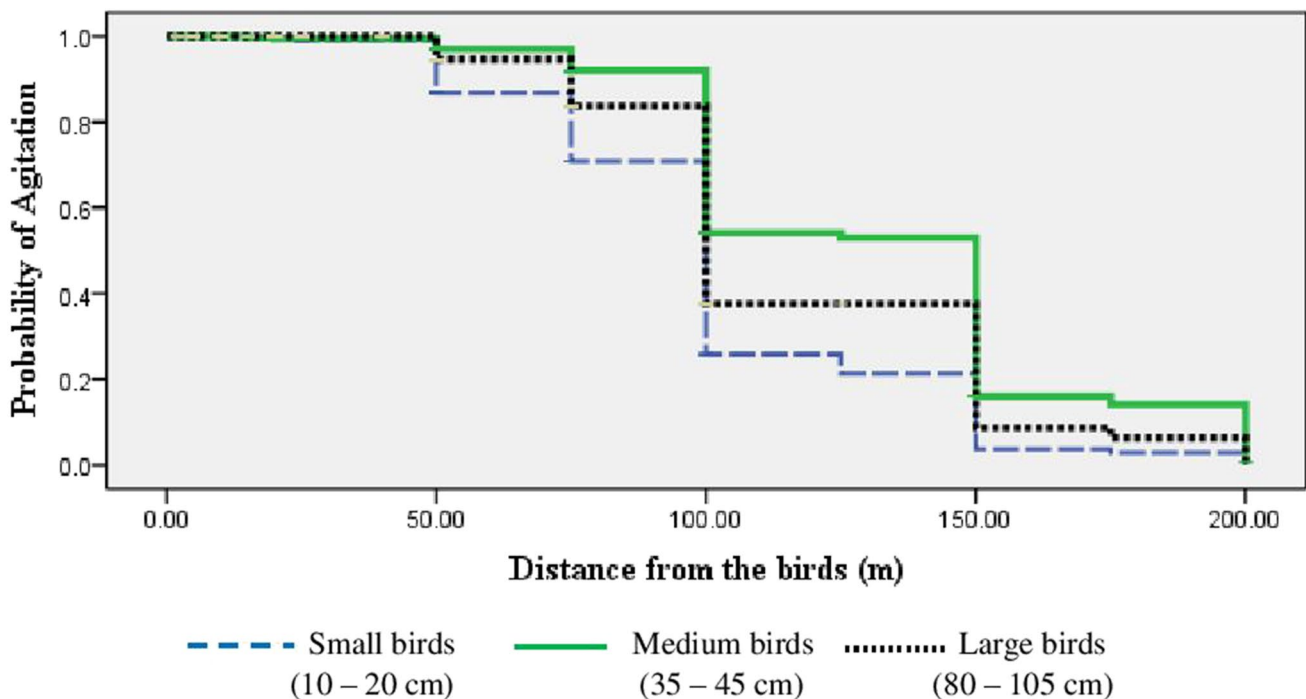
(reference level). On the other hand, the ‘hazard of responding’ of a resting bird, is 41% less ( $P < 0.001$ ) when the traffic is ‘moderate’ while it is 77% less ( $P < 0.001$ ) when the traffic is ‘high’, compared to ‘hazard of responding’ of a resting bird when the traffic is ‘low’ (reference level) (Table 3).

As revealed by the Schoenfeld residual analysis, proportional hazard assumption is not valid for the covariate ‘traffic’. Hence, a SCox PH was fitted with that as the stratifying variable. When SCox PH adjusted for the level of traffic that the resting birds are experiencing, the ‘hazard of responding’

**Table 2** Mantel-Cox pairwise comparisons for differences in survival distributions under disturbances between low and high traffic habitats

Species	Low vs. Moderate		Low vs. High		Moderate vs. High	
	$\chi^2$	<i>p</i> value	$\chi^2$	<i>p</i> value	$\chi^2$	<i>p</i> value
Little stint	2.502	0.114	2.518	0.113	3.304	0.069
Kentish plover	6.153	0.013*	18.523	0.000*	11.623	0.001*
Black-winged stilt	0.007	0.933	43.973	0.000*	44.826	0.000*
Black-tailed godwit	2.285	0.131	0.546	0.460	0.596	0.440
Caspian tern	0.068	0.794	2.438	0.118	2.327	0.127
Eurasian spoonbill	6.573	0.010*	0.319	0.572	9.780	0.002*
Painted stork	0.060	0.807	12.907	0.000*	13.813	0.000*

\*Statistical significance at  $\alpha=0.05$  significance level



**Fig. 4** Plots of agitation proportions with the distance for small (10–20 cm), medium (35–45 cm), and large birds (80–105 cm)

of a resting bird who has a medium body size is 62% less ( $P < 0.001$ ) than that of a resting bird who has a small body size (reference level) (Table 4).

**Model 5: Speed analysis; birds with body size and speed as covariates**

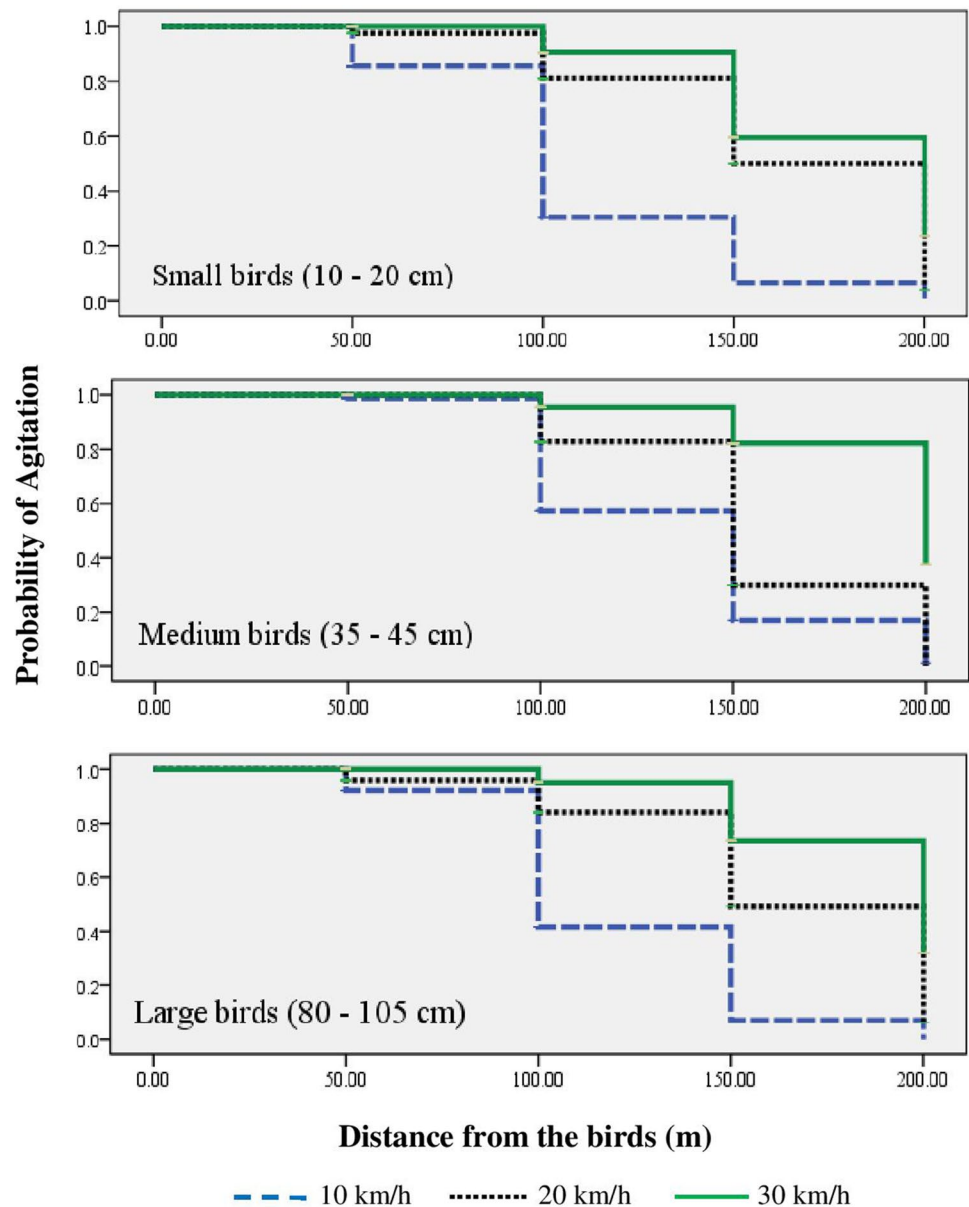
According to Cox PH, when holding the other covariates constant, the ‘hazard of responding’ of a bird who has a medium body size is 1.267 times ( $P < 0.1$ ) than that of a bird who has a small body size (reference level), under 90% CI level. When considering the effect of the speed of the recreational motor vehicle, the ‘hazard of responding’ of a bird when the speed is 30 km/h is 1.675 times ( $P < 0.001$ )

than the ‘hazard of responding’ of a bird when the speed is 10 km/h (reference level), under 95% CI level (Table 3).

**Model 6: Foraging birds with species and traffic as covariates**

When other covariates are constant in Cox PH, the ‘hazard of responding’ of a foraging Painted stork (1.634 times greater,  $P < 0.01$ ), foraging Little stint (1.558 times greater,  $P < 0.05$ ) and foraging Kentish plover (1.489 times greater,  $P < 0.05$ ) is greater than the ‘hazard of responding’ of a foraging Black-tailed godwit, which was considered as the reference level for the species. Furthermore, when the traffic is ‘moderate’, ‘hazard of responding’ of a foraging bird is 1.424 times greater ( $P < 0.001$ )

**Fig. 5** Plots of agitation proportions for small (10–20 cm), medium (35–45 cm), and large birds (80–105 cm), with the distance under different speed levels of vehicles



and when the traffic is ‘high’, that of a foraging bird is 1.667 times greater ( $P < 0.001$ ), compared to the reference level (‘low’ traffic) (Table 3).

The Schoenfeld residual analysis revealed that proportional hazard assumption is not valid for the covariate ‘traffic’. Hence, a SCox PH was fitted with that as the stratifying variable. When SCox PH adjusted for the level of traffic, the ‘hazard of responding’ of a foraging Painted stork (1.625 times greater,  $P < 0.01$ ), foraging Little stint (1.565 times greater,  $P < 0.05$ ) and foraging Kentish plover (1.495 times greater,  $P < 0.05$ ) is greater than the ‘hazard of responding’ of a foraging Black-tailed godwit (reference level) (Table 4).

#### Model 7: Resting birds with species and traffic as covariates

When holding the other covariates constant in Cox PH, the ‘hazard of responding’ of a resting Little stint (2.231 times greater,  $P < 0.05$ ), resting Eurasian spoonbill (1.987 times greater,  $P < 0.05$ ) and resting Kentish plover (1.964 times greater,  $P < 0.05$ ) is greater than the ‘hazard of responding’ of a resting Black-tailed godwit (reference level). Under ‘moderate’ traffic, ‘hazard of responding’ of a resting bird is 41% less ( $P < 0.001$ ) and under the ‘high’ traffic, that of a resting bird is 79% less ( $P < 0.001$ ), than

**Table 3** Summary of Cox PH models

Covariate	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.
Species (reference level – BTG)														
BWS	0.843	0.210	-	-	-	-	-	-	-	-	1.022	0.883	0.886	0.724
PS	1.433	0.014*	-	-	-	-	-	-	-	-	1.634	0.003**	1.747	0.101
CT	-	-	-	-	-	-	-	-	-	-	-	-	0.676	0.172
LS	1.512	0.006**	-	-	-	-	-	-	-	-	1.558	0.012*	2.231	0.010*
ESB	1.257	0.112	-	-	-	-	-	-	-	-	1.038	0.819	1.987	0.031*
KP	1.465	0.008**	-	-	-	-	-	-	-	-	1.489	0.013*	1.964	0.049*
Body Size (reference level - Small)														
Medium	-	0.664	3.07e-05***	0.669	0.000***	0.353	1.01e-09***	1.267	0.066.	-	-	-	-	-
Large	-	0.019	0.857	0.840	0.116	0.884	0.511	1.138	0.327	-	-	-	-	-
Behaviour (reference level - Foraging)														
Resting	1.599	4.79e-06***	1.569	1.03e-05***	-	-	-	-	-	-	-	-	-	-
Traffic (reference level - Low)														
Moderate	1.102	0.266	1.112	0.229	1.435	0.000***	0.592	0.000***	-	-	1.424	0.000***	0.592	0.001***
High	0.650	9.77e-05***	0.628	2.24e-05***	1.613	2.58e-05***	0.226	6.56e-16***	-	-	1.667	9.52e-06***	0.214	5.56e-16***
Speed (reference level – 10 km/h)														
20 km/h	-	-	-	-	-	-	-	-	0.966	0.800	-	-	-	-
30 km/h	-	-	-	-	-	-	-	-	1.675	2.18e-05***	-	-	-	-
AIC	8026.661		8028.372		5734.655		2264.589		4618.682		5732.067		2269.756	

\*\*\*significant at 0.001 level, \*\*significant at 0.01 level, \* significant at 0.05 level, .significant at 0.1 level

BTG- Black-tailed godwit, BWS- Black-winged stilt, PS- Painted stork, CT- Caspian tern, LS- Little stint, ESB- Eurasian spoonbill, KP- Kentish plover

**Table 4** Summary of the final models (Models 1–4, 6–7 are Stratified Cox PH models. Model 5 is a Cox PH and is same as in Table 1)

Covariate	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.	Exp (coef)	Sig.
Species (reference level – BTG)														
BWS	0.902	0.451	-	-	-	-	-	-	-	-	0.999	0.997	0.764	0.439
PS	1.478	0.008**	-	-	-	-	-	-	-	-	1.625	0.003**	1.651	0.145
CT	-	-	-	-	-	-	-	-	-	-	-	-	0.676	0.177
LS	1.476	0.00**	-	-	-	-	-	-	-	-	1.565	0.011*	2.129	0.016*
ESB	1.123	0.420	-	-	-	-	-	-	-	-	1.047	0.777	1.799	0.067.
KP	1.402	0.019*	-	-	-	-	-	-	-	-	1.495	0.012*	1.683	0.133
Body Size (reference level - Small)														
Medium	-	-	0.777	0.011*	0.656	6.98e-05***	0.376	9.58e-09***	1.267	0.066.	-	-	-	-
Large	-	-	1.087	0.419	0.839	0.113	0.889	0.536	1.138	0.327	-	-	-	-
Behaviour (reference level - Foraging)														
Resting	Stratifying variable	Stratifying variable	-	-	-	-	-	-	-	-	-	-	-	-
Traffic (reference level - Low)														
Moderate	1.118	0.205	1.139	0.138	Stratifying variable	Stratifying variable	Stratifying variable	-	-	-	Stratifying variable	Stratifying variable	Stratifying variable	Stratifying variable
High	0.914	0.394	0.894	0.284	-	-	-	-	-	-	-	-	-	-
Speed (reference level – 10 km/h)														
20 km/h	-	-	-	-	-	-	-	-	0.966	0.800	-	-	-	-
30 km/h	-	-	-	-	-	-	-	-	1.675	2.18e-05***	-	-	-	-
AIC	7269.331	-	7275.793	-	4577.843	-	1792.999	-	4618.682	-	4575.779	-	1798.458	-

\*\*\*significant at 0.001 level, \*\*significant at 0.01 level, \*significant at 0.05 level, .significant at 0.1 level

BTG- Black-tailed godwit, BWS- Black-winged stilt, PS- Painted stork, CT- Caspian tern, LS- Little stint, ESB- Eurasian spoonbill, KP- Kentish plover

‘hazard of responding’ of resting bird under the reference level (‘low’ traffic) (Table 3).

According to the Schoenfeld residual analysis, proportional hazard assumption is not valid for the covariate ‘traffic’. Hence, a SCox PH was fitted with that as the stratifying variable. When SCox PH adjusted for the level of traffic, with 95% confidence we can say that the ‘hazard of responding’ of a resting Little stint is 2.129 times greater ( $P < 0.05$ ) than the ‘hazard of responding’ of a resting Black-tailed godwit. With 90% confidence we can say that the ‘hazard of responding’ of a resting Eurasian spoonbill is 1.799 times greater ( $P < 0.1$ ) than that of a resting Black-tailed godwit (Table 4).

## Discussion

The lack of published data on the impact of recreation on shorebirds at migratory stopovers in the Asia–Pacific region calls for sound baseline information (Nebel 2007; Guay et al. 2016; Marasinghe et al. 2020). This experimental work revealed the trends in probability of the response of various waterbirds at Bundala National Park, Sri Lanka, to motorized recreational disturbance. Responses were measured according to different approach speeds by off-road vehicles under different established baseline disturbance scenarios. As waterbirds, especially waders, inhabit a variety of coastal habitats and wetlands, the findings of this study are useful in managing recreational disturbance from vehicle traffic at similar recreational sites. The results suggest, the selected bird species displayed significantly different sensitivities to experimental disturbance. Our data is consistent with the findings in literature where agitation responses and response distance of birds to recreational disturbance has been found to be complex and reported to vary among bird species (Blumstein et al. 2003; Rodgers and Schwikert 2003; Beale 2007; Chatwin et al. 2013).

A variety of factors can affect the response of birds to recreational disturbance. Disturbance stimuli include foot traffic, pet animals, motorized vehicles, and boats (Murchison et al. 2016; Coetzer and Bouwman 2017; McFadden et al. 2017; DeRose-Wilson et al. 2018; Marasinghe et al. 2020) and the speed and noise of motor vehicles (Tarr et al. 2010; Maslo et al. 2012; Chatwin et al. 2013; Schlacher et al. 2013a; Weston et al. 2014; DeVault et al. 2014, 2015; Murchison et al. 2016). Previous exposure or the degree of habituation of birds to recreational disturbance (Chatwin et al. 2013; De Blocq Van Scheltinga 2017; Ramli and Norazlimi 2017; Gómez-Serrano 2020) also plays a role in the response of a particular species. However, some studies suggest that individual birds of a species show differential responses (within-species variation) for a stimuli (Weston et al. 2012). Body size of the bird is also a consideration (Fernández-Juricic et al. 2001; Blumstein et al. 2005; O’Neal Campbell

2006). The experimental design employed in this study quantified the impact of recreational disturbance under the following scenarios.

### Whether the bird was foraging or resting

Results of this study revealed that foraging and resting events of birds are affected differently by moving motor vehicles and the birds show varying responses to such disturbance. Fitted Cox PH model with species, behaviour and traffic as covariates, indicate that resting birds are more vulnerable to disturbance from recreational motor vehicles. Similar observations have been reported elsewhere (Chatwin et al. 2013), though some studies suggest foraging birds are more sensitive to recreational disturbance from vehicles (McGarigal et al. 1991; De Blocq Van Scheltinga 2017). However, log-rank test results indicated no statistically significant differences in agitation probability distributions of species when disturbed while foraging and resting, except for Black-winged stilt (*Himantopus himantopus*). As suggested by the results, both foraging and resting birds were sensitive to recreational disturbance from slow-moving motor vehicles for up to a distance of 50m from the source (vehicle). However, there were some exceptions where foraging birds did not appear to show any noticeable response. For instance, during very active feeding events, birds were less inclined to leave the foraging site even under closer encounters with passing motor vehicles. This may be explained by the ‘disturbance-risk hypothesis’, which is described as an animal making decisions about whether to move away from a disturbed area, based on the relationship between the benefits and costs of staying versus fleeing (Gill et al. 2001; Frid and Dill 2002).

### Previous exposure and habituation

According to log-rank test results, previous exposure to similar disturbance (i.e. birds inhabiting already well-established high vehicular traffic habitats) had an impact on the probability of waterbird agitation. The highest agitation probability for the selected species (at all approach distances) was recorded at habitats with already established low recreational vehicle traffic while the lowest agitation probabilities were recorded in areas with high and moderate recreational vehicle traffic. This is probably due to the habituation of birds to disturbance from regular and on-going vehicular access associated with tourism at the study site (for example, see Stolen 2003; Chatwin et al. 2013). However, according to fitted SCox model with behaviour as the stratifying variable, there is no significant difference in ‘hazard of responding’ of birds experiencing moderate and high traffic levels compared to birds experiencing a low traffic.

Habituation of birds is the gradual dampening of alert and flight responses to ensure that unnecessary time and

energy is not expended by reacting to a benign stimulus (Burger et al. 1995; Nisbet 2000). Exposure to recurring disturbance from motor vehicles can result in birds no longer perceiving recreational vehicles as threats or predation risk (as discussed by Bejder et al. 2009; Chatwin et al. 2013; DeVault et al. 2017). Habituation can have both beneficial and negative effects on birds inhabiting recreational environments. For instance, Nisbet (2000) argued that habituation in waterbird colonies could be beneficial in bird conservation under controlled conditions and could promote beneficial educational and recreational uses. Conversely, several other studies suggest that habituation has negative consequences as it renders wildlife more susceptible to intra-specific aggression and predation by associated habituated species as well as to vehicular collisions (Higginbottom 2004; Newsome et al. 2005).

### Body size of the bird and their response to disturbance

The literature reports that agitation probability and agitation/response distance tend to vary among species, depending on the body size of the bird (Kiltie 2000; Collop et al. 2016; Mikula et al. 2018). Our results suggest that all birds at areas with different baseline traffic conditions, are more responsive to recreational disturbances up to 100m from the source, irrespective of their body size. According to Mantel-Cox pairwise comparisons, large and medium-sized birds showed greater response distances compared to smaller bird species. Interestingly, as revealed by fitted Cox PH model with body size and speed of the disturbance vehicle as covariates, medium-sized waterbirds (35–45 cm) exhibited a significantly greater ‘hazard of responding’ compared to that of small birds, but this may be due to an insufficient number of disturbance trials conducted for birds of different body-size categories, various species and under different speed levels. Our findings are largely consistent with the literature where it has been reported that larger bird species have greater agitation distances compared to small bird species (Fernández-Juricic et al. 2001; Blumstein et al. 2005; O’Neal Campbell 2006). Larger birds have higher visual activity and greater perceptual ranges, thus allowing them to perceive more landscape elements as compared to smaller birds (Lima and Zollner 1996; Kiltie 2000). Moreover, larger birds have slower escape responses because of their size (Glover et al. 2011). On the other hand, it has been suggested that smaller birds have more tolerance towards a disturbance due to higher energy expenditure associated with greater area/body mass ratios compared to large birds (Holmes et al. 1993). However, according to Scox PH adjusted for behaviour of selected waterbirds, ‘hazard of responding’ of a medium-sized bird is significantly less than that of a small bird. Similarly, when SCox PH model adjusted for

traffic, hazard of responding’ of a medium-sized foraging/resting bird is significantly less than that of a small foraging/resting bird.

### Speed of disturbance vehicles

Birds were less responsive to disturbance caused by slow-moving motorized vehicles beyond 100 m distance from the source. Fitted Cox PH model with body size and speed of the disturbance vehicle as covariates, also revealed that, ‘hazard of responding’ of a bird when the speed is 30 km/h is significantly higher than that of a bird when the speed is 10 km/h. Our observations are consistent with findings in the literature where a response distance of 25 m to vehicles, has been reported for many shorebird species (e.g. Schlacher et al. 2013b). According to our field observations, the most frequent response at less than 50 m is flushing (McLeod et al. 2013; Schlacher et al. 2013b). Vigilance and locomotion (moving a few meters away from the disturbance) were the common behavioral responses shown by birds between 50 and 100 m distances from the source. At distances beyond 100 m from the source, birds showed vigilance behavior or no response. As suggested by Maslo et al. (2012), birds perceive motorized vehicles as a threat according to several factors such as size, speed, and noise. The speed of vehicles particularly affects the general behavior of the birds (Blackwell et al. 2009; Fernández-Juricic et al. 2011; Schlacher et al. 2013a, b; DeVault et al. 2014, 2015; Weston et al. 2014) as well as the response of birds to the disturbance (e.g. increased vigilance, agitation, flushing) (Bellefleur et al. 2009; Tarr et al. 2010). Birds of different body sizes have different sensitivities to different speed levels, but higher vehicle speeds induce greater agitation responses of birds (Blumstein and Fernández-Juricic 2010; Glover et al. 2011; Weston et al. 2012; Schlacher et al. 2014). However, some studies suggest that, birds are less responsive to vehicles than humans on foot, thus closer observation of birds is possible on vehicles (Pease et al. 2005; Schlacher et al. 2013b).

In this study, conducting disturbance trials in a manner to ensure more or less equal sample sizes under each speed levels was impractical due to numerous regulatory and environmental conditions. In the studied BNP, the maximum permissible speed limit for vehicles is 20 km/h. The change of physical condition of the access trails during the course of the study (i.e. rising water levels in the rainy season severely affecting the vehicle movements at desired speeds) further restricted performing equal disturbance trials under each speed level. Nonetheless, it has been shown that the Kaplan-Meier estimator gives reliable results under low censoring rates and large sample sizes i.e. samples greater than 100 (Akbar et al. 2009; Che 2014). In our study, since all three samples can be considered as large samples with low censoring rates, the Kaplan-Meier estimator can be expected to



perform well, thus the unequal sample sizes will not affect the reliability of our results.

### Implications for management

This study suggests that motorized vehicles in coastal wetland protected areas can be a significant source of disturbance for waterbirds. Hence, protected area managers should pay attention to manage disturbance from vehicle traffic to waterbirds. Limiting vehicle access (Yasué and Dearden 2006; Borneman et al. 2016), temporal and spatial zoning and designation of spatial refuges (DeRose-Wilson et al. 2018), temporary/seasonal closure of areas during the breeding season of birds (Pease et al. 2005; Weston et al. 2014) and establishing setbacks or buffers (Hillman et al. 2015; Guay et al. 2016; Coetzer and Bouwman 2017) have been employed elsewhere. In the Sri Lankan context, recreation and wildlife viewing is allowed by mandate in protected areas and in most cases tourist access is only via jeeps and tour buses. As such, establishing setback distances can be a viable management option to reduce the disturbance to birds from motor vehicles (Defeo et al. 2009; Borgmann 2010; Glover et al. 2011; Schlacher et al. 2013b; Choi et al. 2015; Hillman et al. 2015; Coetzer and Bouwman 2017).

The aim of establishing setbacks is to separate threatening stimuli (e.g. human recreational activities) from wildlife. Hence, set-back distances rely on the diminishing wildlife responses with increasing distance between stimuli and wildlife (Pfister et al. 1992; Lafferty 2001; Whitfield et al. 2008). Furthermore, set-back distances depend on environmental conditions and biological context and vary according to different bird species (Fernández-Juricic et al. 2005). Smaller birds appear to require smaller setbacks, while larger birds need much greater distances from the source of disturbance (Coetzer and Bouwman 2017). Set-back distances can reduce impacts on wildlife when they are carefully designed and are most effective when the distance is based on empirical data from stimulus-response experiments (Rodgers and Schwikert 2003; Weston et al. 2012). Therefore, the outcomes of this multispecies experimental study can be used as baseline information in designing setbacks for waterbirds in coastal wetlands under varying baseline traffic conditions in Sri Lanka.

Since the selected species for our studies often co-occur at BNP, consideration must be given to species that are most sensitive to disturbance, and species that are of management concern (such as threatened and migratory birds). Hence, site-specific setbacks can be established considering the agitation distances of highly sensitive species such as Caspian tern (*Hydroprogne caspia*), Black-winged stilt (*Himantopus himantopus*), and Black-tailed godwit (*Limosa limosa*). The resting grounds of Caspian tern (*Hydroprogne caspia*) may be of special importance for establishing setbacks since

the birds are resting and recovering following migration. According to the trends in the variation of agitation probabilities observed in this study, a minimal setback buffer of 100 m would suffice to negate recreational disturbance from motor vehicles. However, physical barriers (e.g. symbolic fencing at the edge of colonies and signboards) can be used as tools to establish setback distances (Yasué and Dearden 2006; Antos et al. 2007; Devney and Congdon 2009; Webber et al. 2013; Hillman et al. 2015; Maguire et al. 2015).

### Conclusions

Waterbirds in coastal wetlands exhibit differential responses to recreational disturbance caused by motorized vehicles. Resting birds are more vulnerable to disturbance than foraging birds. Black-winged stilt and resting Caspian terns appeared to be more sensitive to vehicular disturbance. Waterbirds inhabiting environments that are subject to frequent and recurring recreational disturbance by motor vehicles are less likely to become agitated or respond to disturbance, probably due to higher levels of habituation. Birds with larger body sizes were more responsive to disturbance compared to smaller birds. In general, responses of birds for vehicular recreational disturbance were prominent up to 100 m from the source. However, the response distance of birds extended beyond 100 m from the source when they were disturbed by vehicles moving at higher speeds. The findings of this study provide valuable baseline data for informed decision-making in establishing set-back distances and maximum allowable speed limits at coastal wetlands in Sri Lanka. Given that tourist/recreational access at BNP is sanctioned only via vehicular access this work provides useful data for managers in their goal of achieving the dual mandate of waterbird conservation and providing recreational opportunities for visitors.

### References

- Akbar A, Pasha GR, Naqvi SFH (2009) Properties of Kaplan-Meier estimator: group comparison of survival curves. *Eur J Sci Res* 32(3):391–397
- Alwis NS, Perera P, Dayawansa NP (2016) The response of tropical avifauna to visitor recreational disturbances: a case study from the Sinharaja World Heritage Forest, Sri Lanka. *Avian Res* 7(1):15. <https://doi.org/10.1186/s40657-016-0050-5>
- Antos MJ, Ehmke GC, Tzaros CL, Weston MA (2007) Unauthorized human use of an urban coastal wetland sanctuary: current and future patterns. *Landsc Urban Plan* 80(1–2):173–183. <https://doi.org/10.1016/j.landurbplan.2006.07.005>
- Badalamenti F, Ramos AA, Voultziadou E, Lizaso JS, D'anna G, Pipitone C, Riggio S (2000) Cultural and socio-economic impacts of Mediterranean marine protected areas. *Environ Conserv* :110–125. <https://doi.org/10.1017/s0376892900000163>

- Bambaradeniya CNB, Ekanayake SP, Fernando RHSS, Perera WPN, Somaweera R (2002) A biodiversity status profile of Bundala National Park-A Ramsar wetland in Sri Lanka. Occasional Paper of IUCN Sri Lanka (2)
- Beale CM (2007) Managing visitor access to seabird colonies: a spatial simulation and empirical observations. *Ibis* 149:102–111
- Bejder L, Samuels A, Whitehead H, Finn H, Allen S (2009) Impact assessment research: use and misuse of habituation, sensitization and tolerance in describing wildlife responses to anthropogenic stimuli. *Mar Ecol Prog Ser* 395:177–185. <https://doi.org/10.3354/meps07979>
- Bellefleur D, Lee P, Ronconi RA (2009) The impact of recreational boat traffic on Marbled Murrelets (*Brachyramphus marmoratus*). *J Environ Manage* 90(1):531–538. <https://doi.org/10.1016/j.jenvman.2007.12.002>
- Bernard GE, van Dongen WF, Guay PJ, Symonds MR, Robinson RW, Weston MA (2018) Bicycles evoke longer flight-initiation distances and higher intensity escape behaviour of some birds in parks compared with pedestrians. *Landsc Urban Plan* 178:276–280. <https://doi.org/10.1016/j.landurbplan.2018.06.006>
- Blackwell BF, Fernandez-Juricic E, Seamans TW, Dolan T (2009) Avian visual system configuration and behavioral response to object approach. *Anim Behav* 77(3):673–684. <https://doi.org/10.1016/j.anbehav.2008.11.017>
- Blumstein DT (2006) Developing an evolutionary ecology of fear: how life history and natural history traits affect disturbance tolerance in birds. *Anim Behav* 71(2):389–399. <https://doi.org/10.1016/j.anbehav.2005.05.010>
- Blumstein DT, Anthony LL, Harcourt R, Ross G (2003) Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait? *Biol Conserv* 110(1):97–100. [https://doi.org/10.1016/s0006-3207\(02\)00180-5](https://doi.org/10.1016/s0006-3207(02)00180-5)
- Blumstein DT, Esteban F-J, Zollner PA, Garity SC (2005) Interspecific variation in avian responses to human disturbance. *J Appl Ecol* 42(5):943–953. <https://doi.org/10.1111/j.1365-2664.2005.01071.x>
- Blumstein DT, Fernández-Juricic E (2010) A primer of conservation behavior. Sinauer Associates, Sunderland, p 224
- Borgmann KL (2010) A review of human disturbance impacts on waterbirds. *Audubon Calif* 376:1–23
- Borneman TE, Rose ET, Simons TR (2016) Off-road vehicles affect nesting behaviour and reproductive success of American Oystercatchers *Haematopus palliatus*. *Ibis* 158(2):261–278. <https://doi.org/10.1111/ibi.12358>
- Burger J, Gochfeld M, Niles LJ (1995) Ecotourism and birds in coastal New Jersey: contrasting responses of birds, tourists, and managers. *Environ Conserv* 22(1):56–65. <https://doi.org/10.1017/s0376892900034081>
- Cardoni DA, Favero M, Isacch JP (2008) Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: implications for waterbird conservation. *Biol Conserv* 141(3):797–806
- Chatwin TA, Joy R, Burger AE (2013) Set-back distances to protect nesting and roosting seabirds off Vancouver Island from boat disturbance. *Waterbirds* 36(1):43–52. <https://doi.org/10.1675/063.036.0108>
- Che H (2014) Cutoff sample size estimation for survival data: a simulation study. Uppsala University, Uppsala
- Choi CY, Nam HY, Lee WS (2015) Behavioural responses of wintering black-faced spoonbills (*Platalea minor*) to disturbance. *Wildl Res* 41(6):465–472. <https://doi.org/10.1071/wr14150>
- Coetzer C, Bouwman H (2017) Waterbird flight initiation distances at Barberspan Bird Sanctuary, South Africa. *Koedoe* 59(1):1–8. <https://doi.org/10.4102/koedoe.v59i1.1419>
- Collop C (2017) Impact of human disturbance on coastal birds: population consequences derived from behavioural responses. Doctoral Dissertation, Bournemouth University
- Collop C, Stillman RA, Garbutt A, Yates MG, Rispin E, Yates T (2016) Variability in the area, energy and time costs of wintering waders responding to disturbance. *Ibis* 158(4):711–725. <https://doi.org/10.1111/ibi.12399>
- Cox DR (1972) Regression models and life-tables. *J R Stat Soc Ser B (Methodological)*, 34(2):187–202. [https://doi.org/10.1007/978-1-4612-4380-9\\_37](https://doi.org/10.1007/978-1-4612-4380-9_37)
- Dandenong Valley Authority (1979) Edithvale Wetlands buffer area analysis. Environmental Report 2. Dandenong Valley Authority, Melbourne
- Davenport J, Davenport JL (2006) The impact of tourism and personal leisure transport on coastal environments: a review. *Estuar Coast Shelf Sci* 67(1–2):280–292. <https://doi.org/10.1016/j.ecss.2005.11.026>
- Devney CA, Congdon BC (2009) Testing the efficacy of a boundary fence at an important tropical seabird breeding colony and key tourist destination. *Wildl Res* 36(4):353–360. <https://doi.org/10.1071/wr08143>
- de Andrés M, Barragán JM, Scherer M (2018) Urban centres and coastal zone definition: Which area should we manage? *Land use policy* 71:121–128. <https://doi.org/10.1016/j.landusepol.2017.11.038>
- De Scheltinga B (2017) A Disturbance effects of boat-based tourism on waterbirds at the Ramsar-designated De Hoop Vlei, Western Cape, Southfrica. Doctoral Dissertation, University of Cape Town
- Defeo O, McLachlan A, Schoeman DS, Schlacher TA, Dugan J, Jones A, Scapini F (2009) Threats to sandy beach ecosystems: a review. *Estuar Coast Shelf Sci* 81(1):1–12. <https://doi.org/10.1016/j.landusepol.2017.11.038>
- DeRose-Wilson AL, Hunt KL, Monk JD, Catlin DH, Karpanty SM, Fraser JD (2018) Piping Plover chick survival negatively correlated with beach recreation. *J Wildl Manage* 82(8):1608–1616. <https://doi.org/10.1002/jwmg.21552>
- DeVault TL, Blackwell BF, Seamans TW, Lima SL, Fernández-Juricic E (2014) Effects of vehicle speed on flight initiation by turkey vultures: implications for bird-vehicle collisions. *PLoS ONE* 9(2):e87944. <https://doi.org/10.1371/journal.pone.0087944>
- DeVault TL, Blackwell BF, Seamans TW, Lima SL, Fernández-Juricic E (2015) Speed kills: ineffective avian escape responses to oncoming vehicles. *Proc Royal Soc B* 282(1801):20142188. <https://doi.org/10.1098/rspb.2014.2188>
- DeVault TL, Seamans TW, Blackwell BF, Lima SL, Martinez MA, Fernández-Juricic E (2017) Can experience reduce collisions between birds and vehicles? *J Zool* 301(1):17–22. <https://doi.org/10.1111/jzo.12385>
- DWC (2008) Biodiversity Baseline Survey: Bundala National Park. Consultancy Services Report prepared by Green, MJB (ed.), De Alwis SMDAU, Dayawansa PN, How R, Padmalal UKGK, Singhakumara BMP, Weerakoon D, Wijesinghe MR. Infotechs IDEAS in association with GREENTECH Consultants. Sri Lanka Protected Areas Management and Wildlife Conservation Project (PAMandWCP/CONSULT/02/BDBS), Department of Wildlife Conservation, Ministry of Environment and Natural Resources, Colombo. 46 pp
- Esteban F-J, Tellería JL (2000) Effects of human disturbance on spatial and temporal feeding patterns of Blackbird *Turdus merula* in urban parks in Madrid, Spain. *Bird Study* 47(1):13–21. <https://doi.org/10.1080/00063650009461156>
- Esteban F-J, Jimenez MD, Lucas E (2001) Alert distance as an alternative measure of bird tolerance to human disturbance: implications for park design. *Environ Conserv* 263–269. <https://doi.org/10.1017/s0376892901000273>

- Fernández-Juricic E, Jimenez MD, Lucas E (2002) Factors affecting intra- and inter-specific variations in the difference between alert distances and flight distances for birds in forested habitats. *Can J Zool* 80(7):1212–1220. <https://doi.org/10.1139/z02-104>
- Fernández-Juricic E, Smith R, Kacelnik A (2005) Increasing the costs of conspecific scanning in socially foraging starlings affects vigilance and foraging behaviour. *Anim Behav* 69(1):73–81. <https://doi.org/10.1016/j.anbehav.2004.01.019>
- Fernández-Juricic E, Beauchamp G, Treminio R, Hoover M (2011) Making heads turn: association between head movements during vigilance and perceived predation risk in brown-headed cowbird flocks. *Anim Behav* 82(3):573–577. <https://doi.org/10.1016/j.anbehav.2011.06.014>
- Fox AD, Madsen J (1997) Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. *J Appl Ecol* 1–13. <https://doi.org/10.2307/2404842>
- French RK, Muller CG, Chilvers BL, Battley PF (2019) Behavioural consequences of human disturbance on subantarctic Yellow-eyed Penguins *Megadyptes antipodes*. *Bird Conserv Int* 29(2):277–290. <https://doi.org/10.1017/s0959270918000096>
- Frid A, Dill L (2002) Human-caused disturbance stimuli as a form of predation risk. *Conserv Ecol* 6(1). <https://doi.org/10.5751/es-00404-060111>
- Gill JA (2007) Approaches to measuring the effects of human disturbance on birds. *Ibis* 149:9–14. <https://doi.org/10.1111/j.1474-919x.2007.00642.x>
- Gill JA, Norris K, Potts PM, Gunnarsson TG, Atkinson PW, Sutherland WJ (2001) The buffer effect and large-scale population regulation in migratory birds. *Nature* 412(6845):436–438. <https://doi.org/10.1038/35086568>
- Glover HK, Weston MA, Maguire GS, Miller KK, Christie BA (2011) Towards ecologically meaningful and socially acceptable buffers: response distances of shorebirds in Victoria, Australia, to human disturbance. *Landsc Urban Plan* 103(3–4):326–334. <https://doi.org/10.1016/j.landurbplan.2011.08.006>
- Gómez-Serrano M (2020) Four-legged foes: dogs disturb nesting plovers more than people do on tourist beaches. *Ibis*. <https://doi.org/10.1111/ibi.12879>
- Goodale E, Kotagama SW, Raman TS, Sidhu S, Goodale U, Parker S, Chen J (2014) The response of birds and mixed-species bird flocks to human-modified landscapes in Sri Lanka and southern India. *Ecol Manag* 329:384–392. <https://doi.org/10.1016/j.foreco.2013.08.022>
- Goodale E, Ding P, Liu X, Martínez A, Si X, Walters M, Robinson SK (2015) The structure of mixed-species bird flocks, and their response to anthropogenic disturbance, with special reference to East Asia. *Avian Res* 6(1):14. <https://doi.org/10.1186/s40657-015-0023-0>
- Guay PJ, McLeod EM, Taysom AJ, Weston MA (2014) Are vehicles ‘mobile bird hides’? A test of the hypothesis that ‘cars cause less disturbance’. *Vic Nat* 131(4):150–156
- Guay PJ, van Dongen WF, Robinson RW, Blumstein DT, Weston MA (2016) AvianBuffer: An interactive tool for characterising and managing wildlife fear responses. *Ambio* 45(7):841–851. <https://doi.org/10.1007/s13280-016-0779-4>
- Guay PJ, Van Dongen WF, McLeod EM, Whisson DA, Vu HQ, Wang H, Weston MA (2019) Does zonation and accessibility of wetlands influence human presence and mediate wildlife disturbance? *J Environ Plan Manag* 62(8):1306–1320. <https://doi.org/10.1080/09640568.2018.1495066>
- Hardiman N, Burgin S (2010) Recreational impacts on the fauna of Australian coastal marine ecosystems. *J Environ Manag* 91(11):2096–2108. <https://doi.org/10.1016/j.jenvman.2010.06.012>
- Harrison J (2011) A field guide to the birds of Sri Lanka. Oxford University Press, Oxford
- Helldin JO, Collinder P, Bengtsson D, Asking J (2013) Assessment of traffic noise impact in important bird sites in Sweden—a practical method for the regional scale. *Oecol Aust* 17(1):48–62. <https://doi.org/10.4257/oeco.2013.1701.05>
- Higginbottom K (ed) (2004) Wildlife tourism: Impacts, management and planning. Common Ground Publishing, Champaign
- Hillman MD, Karpanty SM, Fraser JD, Derose-Wilson A (2015) Effects of aircraft and recreation on colonial waterbird nesting behavior. *J Wildl Manag* 79(7):1192–1198. <https://doi.org/10.1002/jwmg.925>
- Hockin D, Ounsted M, Gorman M, Hill D, Keller V, Barker MA (1992) Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. *J Environ Manag* 36(4):253–286. [https://doi.org/10.1016/0006-3207\(93\)90159-x](https://doi.org/10.1016/0006-3207(93)90159-x)
- Holmes TL, Knight RL, Stegall L, Craig GR (1993) Responses of wintering grassland raptors to human disturbance. *Wildl Soc Bull* 21:461–468
- Jorgensen JG, Dinan LR, Brown MB (2016) Flight initiation distances of nesting Piping Plovers (*Charadrius melodus*) in response to human disturbance. *Avian Conserv Ecol* 11(1):5. <https://doi.org/10.5751/ace-00826-110105>
- Kalbfleisch JD, Prentice RL (1980) The statistical analysis of failure time data. Wiley, New York
- Kaplan EL, Meier P (1958) Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 53(282):457–481. [https://doi.org/10.1007/978-1-4612-4380-9\\_25](https://doi.org/10.1007/978-1-4612-4380-9_25)
- Kearvell JC (2011) Causes of breeding failure in banded dotterel (*Charadrius bicinctus*) breeding on Ashley Spit, North Canterbury, New Zealand. *Notornis* 58:43–45
- Kiltie RA (2000) Scaling of visual acuity with body size in mammals and birds. *Funct Ecol* 14:226–234. <https://doi.org/10.1046/j.1365-2435.2000.00404.x>
- Kjølørød L (2019) You can really start birdwatching in your backyard, and from there the sky’s the limit. Leisure as Source of Knowledge, Social Resilience and Public Commitment. Palgrave Macmillan, London, pp 145–168
- Kurniawan F, Adrianto L, Bengen DG, Prasetyo LB (2016) Vulnerability assessment of small islands to tourism: The case of the Marine Tourism Park of the Gili Matra Islands, Indonesia. *Glob Ecol Conserv* 6:308–326. <https://doi.org/10.1016/j.gecco.2016.04.001>
- Kutzner D (2019) Environmental change, resilience, and adaptation in nature-based tourism: conceptualizing the social-ecological resilience of birdwatching tour operations. *J Sustain Tour* 27(8):1142–1166. <https://doi.org/10.1080/09669582.2019.1601730>
- Lafferty KD (2001) Disturbance to wintering western snowy plovers. *Biol Conserv* 101(3):315–325. [https://doi.org/10.1016/s0006-3207\(01\)00075-1](https://doi.org/10.1016/s0006-3207(01)00075-1)
- Lawless JF (2002) Statistical models for lifetime data. Wiley, Toronto
- Lee ET, Wang J (2003) Statistical methods for survival data analysis, vol 476. Wiley, Hoboken
- Lima SL, Zollner PA (1996) Towards a behavioural ecology of ecological landscapes. *Trends Ecol Evol* 11:131–135. [https://doi.org/10.1016/0169-5347\(96\)81094-9](https://doi.org/10.1016/0169-5347(96)81094-9)
- Linley GD, Guay PJ, Weston MA (2020) Are disturbance separation distances derived from single species applicable to mixed-species shorebird flocks? *Wildl Res* 46(8):719–723. <https://doi.org/10.1071/wr18198>
- Livezey KB, Fernández-Juricic E, Blumstein DT (2016) Database of bird flight initiation distances to assist in estimating effects from human disturbance and delineating buffer areas. *J Fish Wildl Manag* 7(1):181–191. <https://doi.org/10.3996/082015-jfwm-078>

- Maguire GS, Rimmer JM, Weston MA (2015) Stakeholder knowledge of threatened coastal species; the case of beach-goers and the Hooded Plover *Thinornis rubricollis*. *J Coast Conserv* 19(1):73–77. <https://doi.org/10.1007/s11852-014-0361-9>
- Mallord JW, Dolman PM, Brown AF, Sutherland WJ (2007) Linking recreational disturbance to population size in a ground-nesting passerine. *J Appl Ecol* 44(1):185–195. <https://doi.org/10.1111/j.1365-2664.2006.01242.x>
- Marasinghe S, Simpson GD, Newsome D, Perera P (2020) Scoping recreational disturbance of shorebirds to inform the agenda for research and management in Tropical Asia. *Trop Life Sci Res* 31(2):51. <https://doi.org/10.21315/tlsr2020.31.2.4>
- Marasinghe S, Perera P, Simpson GD, Newsome D (2021) Nature-based tourism development in coastal wetlands of Sri Lanka: An Importance–Performance analysis at Maduganga Mangrove Estuary. *J Outdoor Recreat Tour* 33:100345. <https://doi.org/10.1016/j.jort.2020.100345>
- Marcum HA (2006) The effects of human disturbance on birds in Bastrop State Park. Doctoral Dissertation, Texas A and M University
- Martín B, Delgado S, De La Cruz A, Tirado S, Ferrer M (2015) Effects of human presence on the long-term trends of migrant and resident shorebirds: evidence of local population declines. *Anim Conserv* 18(1):73–81. <https://doi.org/10.1111/acv.12139>
- Maslo B, Burger J, Handel SN (2012) Modeling foraging behavior of piping plovers to evaluate habitat restoration success. *J Wildl Manag* 76(1):181–188. <https://doi.org/10.1002/jwmg.210>
- Maslo B, Leu K, Pover T, Weston MA, Schlacher TA (2018) Managing birds of conservation concern on sandy shores: How much room for future conservation actions is there? *Ecol Evol* 8(22):10976–10988. <https://doi.org/10.1002/ece3.4564>
- McFadden TN, Herrera AG, Navedo JG (2017) Waterbird responses to regular passage of a birdwatching tour boat: Implications for wetland management. *J Nat Conserv* 40:42–48. <https://doi.org/10.1016/j.jnc.2017.09.004>
- McGarigal K, Anthony RG, Isaacs FB (1991) Interactions of humans and bald eagles on the Columbia River estuary. *Wildl Monogr* 115:1–47
- McGowan CP (2004) Factors affecting nesting success of American Oystercatchers (*Haematopus pallitus*) in North Carolina. Dissertation, North Carolina State University
- McGowan CP, Simons TR (2006) Effects of human recreation on the incubation behavior of American Oystercatchers. *Wilson J Ornithol* 118(4):485–493. <https://doi.org/10.1676/05-084.1>
- McLeod EM, Guay PJ, Taysom AJ, Robinson RW, Weston MA (2013) Buses, cars, bicycles and walkers: the influence of the type of human transport on the flight responses of waterbirds. *PLoS ONE* 8(12):e82008. <https://doi.org/10.1371/journal.pone.0082008>
- Meager JJ, Schlacher TA, Nielsen T (2012) Humans alter habitat selection of birds on ocean-exposed sandy beaches. *Divers Distrib* 18(3):294–306. <https://doi.org/10.1111/j.1472-4642.2011.00873.x>
- Melvin SM, Hecht A, Griffin CR (1994) Piping plover mortalities caused by off-road vehicles on Atlantic coast beaches. *Wildl Soc Bull* (1973–2006) 22(3):409–414
- Mikula P, Díaz M, Möller AP, Albrecht T, Tryjanowski P, Hromada M (2018) Migratory and resident waders differ in risk taking on the wintering grounds. *Behav Process* 157:309–314. <https://doi.org/10.1016/j.beproc.2018.07.020>
- MOE (2012) The National Red List 2012 of Sri Lanka; Conservation Status of the Fauna and Flora. Ministry of Environment, Colombo
- Monti F, Duriez O, Dominici JM, Sforzi A, Robert A, Fusani L, Grémillet D (2018) The price of success: integrative long-term study reveals ecotourism impacts on a flagship species at a UNESCO site. *Anim Conserv* 21(6):448–458. <https://doi.org/10.1111/acv.12407>
- Monz C, D’Antonio A, Lawson S, Barber J, Newman P (2016) The ecological implications of visitor transportation in parks and protected areas: Examples from research in US National Parks. *J Transp Geogr* 51:27–35. <https://doi.org/10.1016/j.jtrangeo.2015.11.003>
- Moore AA (2014) The impact of human disturbance on the foraging ecology of green herons (*Butorides Virescens*). Dissertation, Texas State University
- Moss S (2009) Birding past, present and future – a global view. In: del Hoyo J, Elliot A, Christie DA (eds) *Handbook of the Birds of the World*, vol 14. Bush-shrikes to Old World Sparrows. Lynx Ediciones, Barcelona
- Murchison CR, Zharikov Y, Nol E (2016) Human activity and habitat characteristics influence shorebird habitat use and behavior at a Vancouver Island migratory stopover site. *Environ Manage* 58(3):386–398. <https://doi.org/10.1007/s00267-016-0727-x>
- Muttaqien HZ, Hakim L, Leksono AS (2015) Analysis of bird diversity for supporting ecotourism development in Rajegwesi, Meru Betiri National Park. *J Indones Tour Dev Stud* 3(3):105–110. <https://doi.org/10.21776/ub.jitode.2015.003.03.03>
- Nebel S (2007) Differential migration of shorebirds in the East Asian—Australasian Flyway. *Emu-Austral Ornithol* 107(1):14–18. <https://doi.org/10.1071/mu06006>
- Newsome D, Dowling RK, Moore SA (2005) *Wildlife tourism*, vol 24. Channel View Publications, Bristol, UK
- Newsome D, Moore SA, Dowling RK (2013) *Natural area tourism: Ecology, impacts and management*, vol 58. Channel View Publications, Bristol
- Newsome D, Simpson G (2020) *Green cities as bird watching destinations*. Routledge. <https://doi.org/10.4324/9780429244605-17>
- Nisbet IC (2000) Disturbance, habituation, and management of waterbird colonies. *Waterbirds: The International Journal of Waterbird Biology* 3(2):312–332
- O’Neal Campbell M (2006) Urban parks as shared spaces? The utility of alert distances as indicators of avian tolerance of humans in Stirling. *Scotl Area* 38(3):301–311. <https://doi.org/10.1111/j.1475-4762.2006.00695.x>
- Orams MB (2003) Sandy beaches as a tourism attraction: a management challenge for the 21st century. *J Coast Res* 35:74–84
- Ortega CP (2012) Chap. 2: Effects of noise pollution on birds: A brief review of our knowledge. *Ornithol Monogr* 74(1):6–22. <https://doi.org/10.1525/om.2012.74.1.6>
- Palia S (2018) Effects of Traffic Noise on Foraging, Vigilance, and Aggression of the Zebra Finch (*Taeniopygia guttata*). Dissertation, The College of William & Mary
- Pease ML, Rose RK, Butler MJ (2005) Effects of human disturbances on the behavior of wintering ducks. *Wildl Soc Bull* 33(1):103–112. [https://doi.org/10.2193/0091-7648\(2005\)33\[103:eohdot\]2.0.co;2](https://doi.org/10.2193/0091-7648(2005)33[103:eohdot]2.0.co;2)
- Perera P, Wijesinghe S, Dayawansa N, Marasinghe S, Wickramarachchi C (2017) Response of tropical birds to habitat modifications in fragmented forest patches: A case from a tropical lowland rainforest in south-west Sri Lanka. *Community Ecol* 18(2):175–183. <https://doi.org/10.1556/168.2017.18.2.7>
- Petch N, Maguire GS, Schlacher TA, Weston MA (2018) Motivations and behavior of off-road drivers on sandy beaches. *Ocean Coast Manag* 163:82–91. <https://doi.org/10.1016/j.ocecoaman.2018.05.021>
- Pfister C, Harrington BA, Lavine M (1992) The impact of human disturbance on shorebirds at a migration staging area. *Biol Conserv* 60(2):115–126. [https://doi.org/10.1016/0006-3207\(92\)91162-1](https://doi.org/10.1016/0006-3207(92)91162-1)
- Radkovic AZ, Van Dongen WF, Kirao L, Guay PJ, Weston MA (2019) Birdwatchers evoke longer escape distances than pedestrians in

- some African birds. *J Ecotourism* 18(1):100–106. <https://doi.org/10.1080/14724049.2017.1372765>
- Ramli ROSLI, Norazlimi NA (2017) The effects of disturbance on the abundance and foraging behaviour of shorebirds and waterbirds in the tropical mudflat areas. *Sains Malays* 46(3):365–372. <https://doi.org/10.17576/jsm-2017-4603-02>
- Rodgers JA, Schwikert ST (2003) Buffer zone distances to protect foraging and loafing waterbirds from disturbance by airboats in Florida. *Waterbirds* 26(4):437–443. [https://doi.org/10.1675/1524-4695\(2003\)026\[0437:bzdtpf\]2.0.co;2](https://doi.org/10.1675/1524-4695(2003)026[0437:bzdtpf]2.0.co;2)
- RStudio Team (2020) RStudio: Integrated Development for R. RStudio, PBC, Boston
- Ruddock M, Whitfield DP (2007) A review of disturbance distances in selected bird species. A report from Natural Research (Projects) Ltd to Scottish Natural Heritage 181
- Scarton F (2020) Could we assess the hatching success of Pied Avocets (*Recurvirostra avosetta* Linnaeus, 1758) by drone monitoring? A pilot study. *Lavori - Società Veneziana di Scienze Naturali* 45:139–142
- Schlacher TA, Nielsen T, Weston MA (2013a) Human recreation alters behaviour profiles of non-breeding birds on open-coast sandy shores. *Estuar Coast Shelf Sci* 118:31–42. <https://doi.org/10.1016/j.ecss.2012.12.016>
- Schlacher TA, Weston MA, Lynn D, Connolly RM (2013b) Setback distances as a conservation tool in wildlife-human interactions: testing their efficacy for birds affected by vehicles on open-coast sandy beaches. *PLoS ONE* 8(9):e71200. <https://doi.org/10.1371/journal.pone.0071200>
- Schlacher TA, Meager JJ, Nielsen T (2014) Habitat selection in birds feeding on ocean shores: landscape effects are important in the choice of foraging sites by oystercatchers. *Mar Ecol* 35(1):67–76. <https://doi.org/10.1111/maec.12055>
- Schuhmann PW, Bass BE, Casey JF, Gill DA (2016) Visitor preferences and willingness to pay for coastal attributes in Barbados. *Ocean Coast Manag* 134:240–250. <https://doi.org/10.1016/j.ocecoaman.2016.09.020>
- Schulte SA, Simons TR (2015) Factors affecting the reproductive success of American Oystercatchers *Haematopus palliatus* on the Outer Banks of North Carolina. *Mar Ornithol* 43:37–47
- Slater C, Cam G, Qi Y, Liu Y, Guay PJ, Weston MA (2019) Camera shy? Motivations, attitudes and beliefs of bird photographers and species-specific avian responses to their activities. *Biol Conserv* 237:327–337. <https://doi.org/10.1016/j.biocon.2019.07.016>
- Spaul RJ, Heath JA (2017) Flushing responses of Golden Eagles (*Aquila chrysaetos*) in response to recreation. *Wilson J Ornithol* 129(4):834–845. <https://doi.org/10.1676/16-165.1>
- Steven R, Pickering C, Castley JG (2011) A review of the impacts of nature based recreation on birds. *J Environ Manage* 92(10):2287–2294. <https://doi.org/10.1016/j.jenvman.2011.05.005>
- Stolen ED (2003) The effects of vehicle passage on foraging behavior of wading birds. *Waterbirds* 26(4):429–436. [https://doi.org/10.1675/1524-4695\(2003\)026\[0429:teovpo\]2.0.co;2](https://doi.org/10.1675/1524-4695(2003)026[0429:teovpo]2.0.co;2)
- Stigner MG, Beyer HL, Klein CJ, Fuller RA (2016) Reconciling recreational use and conservation values in a coastal protected area. *J Appl Ecol* 53(4):1206–1214. <https://doi.org/10.1111/1365-2664.12662>
- Tang Z (2015) An integrated approach to evaluating the coupling coordination between tourism and the environment. *Tour Manag* 46:11–19. <https://doi.org/10.1016/j.tourman.2014.06.001>
- Tarr NM, Simons TR, Pollock KH (2010) An experimental assessment of vehicle disturbance effects on migratory shorebirds. *J Wildl Manag* 74(8):1776–1783. <https://doi.org/10.2193/2009-105>
- van Polanen Petel T, Bunce A (2012) Understanding beach users' behavior, awareness, and attitudes to shorebird conservation in central Queensland: tools for effective shorebird conservation. *Coast Manag* 40(5):501–509. <https://doi.org/10.1080/08920753.2012.709464>
- Velando A, Munilla I (2011) Disturbance to a foraging seabird by sea-based tourism: Implications for reserve management in marine protected areas. *Biol Conserv* 144(3):1167–1174. <https://doi.org/10.1016/j.biocon.2011.01.004>
- Webber AF, Heath JA, Fischer RA (2013) Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during the breeding season. *Ecol Evol* 3(4):853–863. <https://doi.org/10.1002/ece3.511>
- Weston MA (2019) Chapter Eleven. Human Disturbance. *Studies in Avian Biology* no. 52 Colwell and Haig
- Weston MA, McLeod EM, Blumstein DT, Guay PJ (2012) A review of flight-initiation distances and their application to managing disturbance to Australian birds. *Emu-Austral Ornithol* 112(4):269–286. <https://doi.org/10.1071/mu12026>
- Weston MA, Schlacher TA, Lynn D (2014) Pro-environmental beach driving is uncommon and ineffective in reducing disturbance to beach-dwelling birds. *Environ Manage* 53(5):999–1004. <https://doi.org/10.1007/s00267-014-0256-4>
- Whitfield DP, Ruddock M, Bullman R (2008) Expert opinion as a tool for quantifying bird tolerance to human disturbance. *Biol Conserv* 141(11):2708–2717. <https://doi.org/10.1016/j.biocon.2008.08.007>
- Williams AJ, Ward VL, Underhill LG (2004) Waders respond quickly and positively to the banning of off-road vehicles from beaches in South Africa. *Bulletin-Wader Study Group* 104:79–81
- Yasué M, Dearden P (2006) The potential impact of tourism development on habitat availability and productivity of Malaysian plovers *Charadrius peronii*. *J Appl Ecol* 43(5):978–989. <https://doi.org/10.1111/j.1365-2664.2006.01204.x>
- Yosef R (2000) Individual distances among Greater Flamingos as indicators of tourism pressure. *Waterbirds* :26–31. <https://doi.org/10.2307/152214>

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