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Human Activity and Habitat Characteristics Influence Shorebird Habitat Use and Behavior at a Vancouver Island Migratory Stopover Site

Colleen R. Murchison[1,2] · Yuri Zharikov[3] · Erica Nol[4]

Abstract Pacific Rim National Park Reserve on Vancouver Island, British Columbia, Canada, has 16 km of coastal beaches that attract many thousands of people and shorebirds (S.O. Charadrii) every year. To identify locations where shorebirds concentrate and to determine the impact of human activity and habitat characteristics on shorebirds, we conducted shorebird and visitor surveys at 20 beach sectors (across 20 total km of beach) during fall migration in 2011–2014 and spring migration in 2012 and 2013. Using zero-inflated negative binomial regression and a model selection approach, we found that beach width and number of people influenced shorebird use of beach sectors (Bayesian information criterion weight of top model = 0.69). Shorebird absence from beaches was associated with increasing number of people (parameter estimate from top model: 0.38; 95 % CI 0.19, 0.57) and decreasing beach width (parameter estimate: −0.32; 95 % CI −0.47, −0.17). Shorebirds spent more time at wider beaches (parameter estimate: 0.68; 95 % CI 0.49, 0.87). Close proximity to people increased the proportion of time shorebirds spent moving, while shorebirds spent more time moving and less time foraging on wider beaches than on narrower ones. Shorebird disturbance increased with proximity of people, activity speed, and presence of dogs. Based on our findings, management options, for reducing shorebird disturbance at Pacific Rim National Park Reserve and similar shorebird stopover areas, include mandatory buffer distances between people and shorebirds, restrictions on fast-moving activities (e.g., running, biking), prohibiting dogs, and seasonal closures of wide beach sections.

Introduction

Recent estimates suggest that 61 % of North American shorebird populations have declined in the last 30 years and 42 % of these populations exhibited downward trends in the last 10 years (Andres et al. 2012). These negative population trends illustrate the continued need to better understand and mitigate the factors contributing to shorebird decline. The quality of migratory staging and stopover areas, including their ability to provide adequate nutrients for refueling, continuing migration and survival to reproduce, has received much attention (e.g., Baker et al. 2004). To make informed decisions for shorebird management at stopover and staging sites, we first need to determine the factors that influence the quality of a particular site.

Food is an essential habitat component and aggregative response in many shorebirds to their preferred prey occurs at various wintering and stopover grounds (Goss-Custard 1970; Colwell and Landrum 1993; Rose and Nol 2010). While prey densities may explain broad patterns of shorebird distributions during migration and at wintering

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sites (Butler et al. 2001), the risk of predation can also be important in explaining shorebird use of a particular site (Pomeroy 2006; Yasué 2006). At a landscape scale, the width of a site (e.g., distance from low water mark to high water mark for beaches) and prey abundance correctly predicted western sandpiper use at 14 out of 17 potential stopover sites (Pomeroy et al. 2008). Site width is thought to reflect risk because shorebird predators, including merlin (*Falco columbarius*) and peregrine falcons (*Falco peregrinus*), are more successful at ambushing shorebirds closer to vegetative cover (Whitfield 2003). In general, proximity to cover that conceals predators from their prey correlates with the distribution of shorebirds at a local scale (Pomeroy 2006; Yasué 2006; Zharikov et al. 2009). Finally, at sites with high levels of human activity, disturbances by humans and their pets can become additional factors impacting shorebird habitat use (Pfister et al. 1992; Tarr et al. 2010). Shorebird behavior can also be impacted by human disturbance through reductions in time devoted to foraging and roosting (Burger and Gochfeld 1991; Yasué 2005; Schlacher et al. 2013b). These behavioral modifications may significantly lower shorebird fitness especially when food is limited (Goss-Custard et al. 2006).

Although many recent studies examine how prey density, risk of predation, or human activity affect shorebird habitat selection and behavior at migratory stopover areas, few assess all three factors and their possible interactive effects on shorebirds simultaneously (Yasué 2006). To address this question, a site that is frequented by people and migratory shorebirds and has heterogeneous habitat, variable in resource availability and predator concealment is required. Pacific Rim National Park Reserve (PRNPR) in coastal British Columbia, Canada, is a stopover area for many shorebird species, including thousands of sanderling (*Calidris alba*) and western sandpipers (*Calidris mauri*), the latter of which has a declining population (Andres et al. 2012). The Long Beach Unit of PRNPR consists of distinct sections of coastal beach that vary in width and other habitat attributes, and is annually visited by over 800,000 visitors, mostly during the start of fall migration in July and August (Edwards 2005).

We quantified shorebird use of the beaches along the Long Beach Unit of PRNPR. We hypothesized that shorebird behavior and use of the PRNPR beaches would serve to maximize uninterrupted prey consumption and roosting and minimize (perceived) predation risk. We predicted that shorebirds would (1) spend more time at wider beaches with more macroinvertebrates and avoid or spend less time at beaches as the number of people and dogs at the beach increased and (2) devote a greater proportion of time to: foraging, at beaches with more macroinvertebrates; vigilant behavior at narrower beaches;

and vigilant behavior and locomotion, when in the presence of nearby people and/or dogs. Our second objective was to quantify current levels of disturbance experienced by shorebirds at PRNPR and discuss how this impact might be reduced. Consistent with previous research on disturbance and shorebirds, we predicted that: (1) the likelihood of shorebird disturbance would increase with increasing proximity of people or dogs to shorebirds (Schlacher et al. 2013b) and (2) fast-moving humans and all dogs would be more likely to cause shorebirds to fly or be displaced from feeding areas than slow-moving or stationary humans (Thomas et al. 2003; Burger et al. 2007; Schlacher et al. 2013b).

Methods

Study Area and General Management

The Long Beach Unit of PRNPR is a 16 km stretch of coastal beaches and rocky outcrops on the west coast of Vancouver Island, BC (Heathfield and Walker 2011). The beaches are situated close to the Tofino Wah-nah-jus Hilth-hoo-is Mudflats, a recently designated Western Hemisphere Shorebird Reserve Network site of regional importance (WHSRN 2013). In addition to being an important stopover area for shorebirds, the Long Beach Unit beaches are also popular, largely seasonal tourist destinations, with visitor attendance peaking in July and August, during fall migration. Popular beach activities include walking with and without dogs (that are required to be on-leash while in the park), surfing, biking, and sunbathing. Recreational vehicles are prohibited on beaches.

Along the Long Beach Unit, between Schooner Cove in the northwest and Florencia Bay in the southeast (Fig. 1), 20 beach sectors were selected systematically for shorebird monitoring to reflect the range of beach width and human activity level within the Long Beach Unit. Beach sectors were spaced approximately 500 m apart. Sectors consisted of 100-m-wide sections of beach and included all areas from the waterline to the vegetation line, this distance (hereafter total beach width) was measured at the same tidal height for all beach sectors. Total beach width varied among sectors ranging from 70 m at Wickaninnish Beach to 245 m at Long Beach. Spatial scales in the range of 100's of m^2 are thought to reflect localized habitat selection (Yasué 2006), compared to regional habitat selection, typically examined at spatial scales >1 km^2 (Pomeroy et al. 2008). At low tide, all of the study beaches (but not sectors) were continuous, with the exception of Florencia Bay which was separated from Wickaninnish Beach by ∼2.5 km of rocky outcrops.
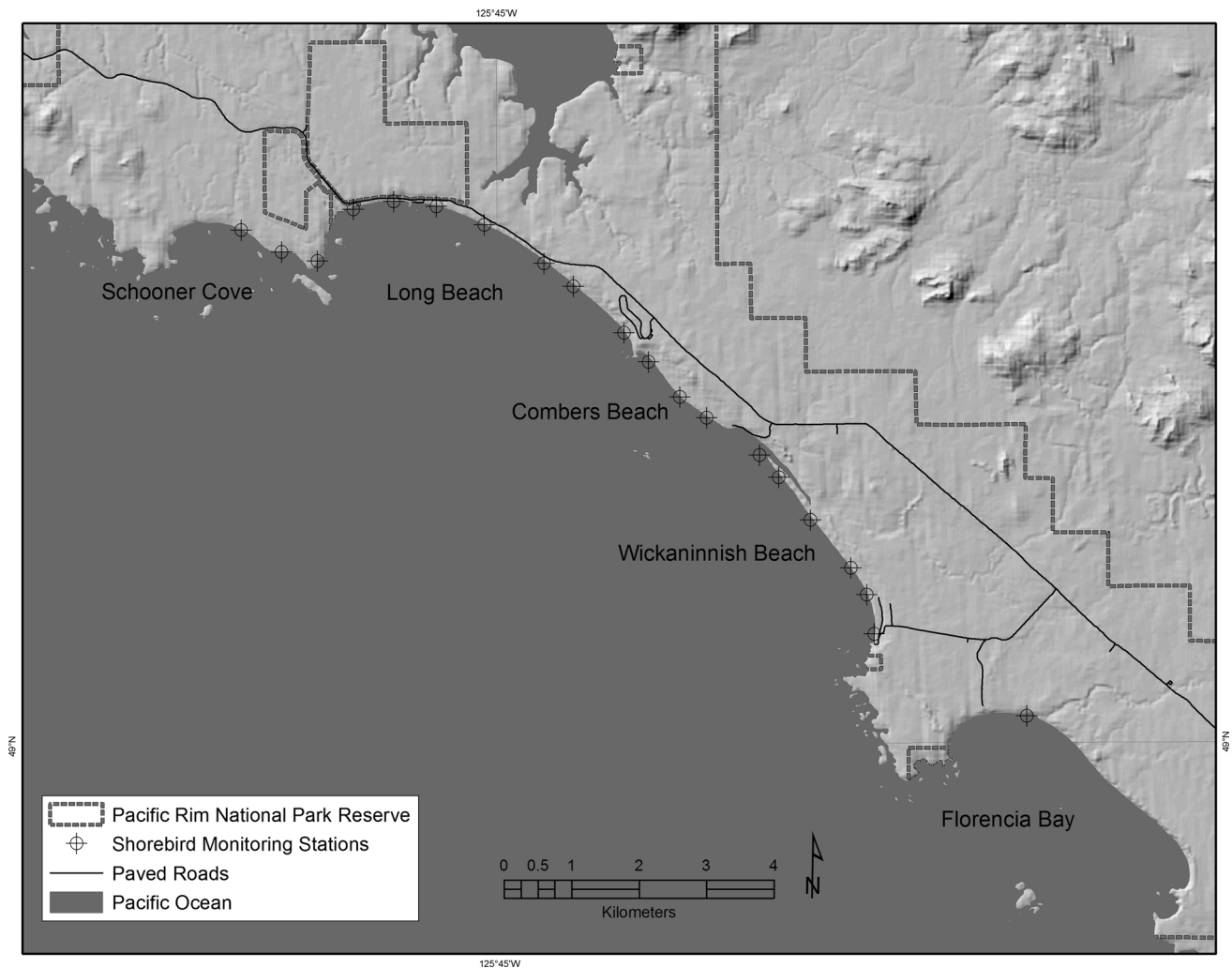
Fig. 1 Shorebird observation stations centered in 100 m sectors, within the Long Beach Unit of Pacific Rim National Park Reserve, Vancouver Island, BC

Shorebird and Visitor Surveys

We performed shorebird and visitor surveys from late April until the end of May, 2012–2013, and from July through October, in 2011–2014 to capture spring and fall migrations, respectively. We conducted the surveys at randomly generated times between 06:00 and 19:00 on a daily basis, at 1–7 beach sectors per day. Each survey lasted 60 min (2011) or 30 min (2012–2014) per sector. We changed the duration of the surveys in later years to survey more sectors more frequently. We recorded the tidal height at the middle of each survey. Data from http://www.waterlevels.gc.ca were used to quantify tidal height.

During surveys, we used binoculars and a 20× spotting scope. We maximized detection of shorebirds by observing from locations that allowed the entire sector to be seen but at the same time avoiding direct disturbance of the birds. We postponed surveys when visibility was poor due to weather conditions. For all groups of shorebirds that entered the sector over the survey period, we recorded the time of entry and exit, species, group size, and behavioral state (flying, foraging, or roosting). We classified shorebirds as foraging when they were pecking and moving (e.g., with the tide) or roosting if they remained stationary and did not peck. If the group's behavioral state changed during the course of the survey, the time of the change was recorded to determine the duration in each state. We calculated shorebird minutes spent on the beach (rounded to the nearest whole minute) by summing the duration of time all shorebirds spent on the beach (i.e., not flying) per survey. For a subset of the surveys ($n = 297$), we recorded the beach zone of foraging and roosting shorebirds as either: swash zone (i.e., where waves were actively washing up onto the beach), intertidal zone (i.e., the area between the swash zone and upper beach), upper beach (i.e., the area from the wrack line, where debris

from previous high tides had washed up, to the vegetation line at the upper edge of the beach), or rocky outcrop. Although we recorded all observations of avian predators, observations were too infrequent to include these data in our statistical analyses.

For all groups of human visitors encountered over the survey period, we recorded time of entry and exit, activity (walking, jogging, surfing), and distance from shorebirds (estimated from the observer's vantage point) and whether they disturbed shorebirds. The speed (m/s) at which people moved was calculated by dividing the elapsed time a group of visitors spent in the sector by the sector width (i.e., 100 m). When visitors had a dog(s), we recorded the number of dogs, whether they were on leash, and their activity (walking, running, playing, sitting). If the activity of the visitor(s) or their dog(s) changed during the course of the survey (e.g., walking to sitting), we noted the time of the change to determine the amount of time spent participating in each activity. Any event where a shorebird's (or group of shorebirds') behavioral state changed from a foraging or roosting state to a flying or running state was classified as a disturbance event if shorebird(s) moved away from the visitors or dogs following their behavioral state change. To reduce subjectivity in attributing shorebird behavioral changes to human and canine activity, we considered only events where people or dogs were within 100 m of birds as potential disturbance events because mean flight initiation distances, resulting from human approach, ranging from 23 to 90 m have been reported previously (Glover et al. 2011) for shorebird species. These flight initiation distances are comparable to those that we observed.

In 2013, in addition to the regular shorebird surveys, we monitored shorebird behavior via focal-switch sampling to obtain time-activity budgets (Altmann 1974; Losito et al. 1989). Whenever shorebirds were on the beach during the shorebird and visitor surveys, we randomly selected and observed one individual for a minimum of 30 s and maximum of 5 min after which we selected a new individual (Altmann 1974; Rose and Nol 2010). We classified behavior into four behavioral states: foraging, roosting, locomotion (including general locomotion and flush/escape locomotion), and vigilance behavior (alert, with head raised) (Schlacher et al. 2013a). We used a stopwatch to time the focal individual and determine the proportion of time allocated to each behavioral category. To obtain sufficient data to analyze different species separately, we limited focal-switch sampling to the three most commonly observed species: western sandpipers, sanderlings, and semipalmated plovers (*Charadrius semipalmatus*). One observer conducted all focal-switch sampling to limit potential bias in determining shorebird behavioral states.

Macroinvertebrate Sampling

We sampled macroinvertebrates at each shorebird monitoring sector on 2–3 occasions between May and August 2013. All sampling was conducted within 2 h of low tide. During each sampling period, we collected 30 macroinvertebrate samples per sector. This included 10 samples that were collected haphazardly from each of three beach zones within each sector: the wrack line, the swash zone, and the intertidal zone. We chose these zones according to where shorebirds were most commonly observed foraging during shorebird surveys conducted in 2011 and 2012. We used 3″ (7.62 cm) diameter beveled-edge PVC pipes, driven to a depth of 10 cm to capture burrowing invertebrates (VanDusen et al. 2012). Samples were rinsed once through a 2-mm mesh sieve and sorted in seawater on white trays. We identified macroinvertebrates from each sample using a hand lens, identification keys, and reference specimens collected at a prior date. Following identification and enumeration, we returned all macroinvertebrates to the substrate.

Statistical Analysis

We used zero-inflated negative binomial (ZINB) regression (Greene 1994) to simultaneously model shorebird presence/absence and shorebird minutes spent on the beach because in addition to containing excess zeros (Vuong non-nested hypothesis test-statistic: $Z = 5.30$, ZINB model > negative binomial model, $P < 0.0001$), data were overdispersed (Martin et al. 2005). As the zero component models the probability of absence, the interpretation of the signs of the estimates for the zero component is opposite that of typical binary models. Both the count and zero components of the global model included number of people, total beach width, total beach width × tidal height, and season as explanatory variables explaining shorebird absence and minutes spent on the beach. We used 'number of people per survey' as an index of human and canine activity. Total beach width × tide represented the beach width at the time of the survey (i.e., functional beach width). We included functional beach width because avian predators have limited success at capturing shorebirds beyond 30 m away from the predator-concealing forest edges (Cresswell et al. 2010). Therefore, as tidal height increases, the perceived risk shorebirds associate with narrow beach sectors may increase at a greater rate than with wide beach sectors. We included season because shorebird use of migratory stopover areas can differ during spring and fall migration (Davis and Smith 1998). Prior to model analysis, we standardized the predictor variables by their means and standard deviations, as independent variables were measured in different units (Schielzeth 2010),

and tested all predictor variables for collinearity. Also, we divided human and shorebird counts from surveys that were conducted in 2011 by two, to account for the 1 h surveys conducted in that year. To assess the effect of prey availability on shorebird beach use, we included invertebrate abundance (total invertebrate abundance at a sector at the most recent sampling date) in a simplified version of the ZINB analysis that used data from 2013 only. We fit the ZINB models using the 'zeroinfl' function in the R package 'pscl' (Zeileis et al. 2008).

We modeled the effect of human/canine proximity and activity speed on the likelihood of shorebird disturbance via multiple logistic regression. To fit the model, we used the 'glm' function (family = binomial) in the R package 'stats' (R Core Team 2013). We used model selection and averaging to generate average models from all plausible models for the ZINB and multiple logistic regression procedures. We calculated the Bayesian information criterion (BIC) (Schwarz 1978) for all possible candidate models and used the weights from all models with substantial support ($\Delta BIC < 2$) to compose the average models (Grueber et al. 2011) that we report here. We used BIC rather than Akaike's information criterion (AIC) because BIC tends to select simpler models with less variance, compared to AIC, which may increase the applicability of our results to shorebird management issues outside of PRNPR (Geman et al. 1992; Posada and Buckley 2004). To accomplish model selection and averaging, we used the 'dredge' and 'model.avg' functions in the R package 'MuMIn' (Bartoń 2013).

Data on the proportions of the behavior of shorebirds, derived from focal observations, were analyzed using permutational MANCOVA analyses ('adonis' function in the R package 'vegan', Oksanen et al. 2013). We used 'whether people were within 100 m of shorebirds' as the factor in the analysis and functional beach width, shorebird group size, and invertebrate abundance as the covariates. If the effect of a covariate was not significant, we dropped it from the analysis. If permutational MANCOVA results were significant, we performed permutational ANCOVAs (also using the 'adonis' function) on the proportion of time the focal shorebird species spent in the four behavioral states: foraging, roosting, locomotive, and vigilant. We analyzed semi-palmated plover observations separately from western sandpipers and sanderlings because plovers exhibit foraging strategies distinct from the Calidrine sandpipers (Nol 1986). We generated least-squares means, accounting for covariates when significant, using the 'lsmeans' function in the R package 'lsmeans' (Lenth 2014).

To assess whether invertebrate abundance varied significantly among sectors, we first used ANOVA ('aov' function in the R package 'stats'), with beach sector as the factor and invertebrate sector abundance per sampling period as the dependent variable. Data met assumptions of homogeneity of variances. We calculated average invertebrate abundance beach zone^{-1} sector^{-1} by averaging the invertebrate abundance in each beach zone of each sector collected during the three sampling periods. Average invertebrate abundance beach zone^{-1} sector^{-1} data did not meet assumptions of homogeneity of variances and sphericity, so we used the Friedman rank sum test ('friedman.test' function in the R package 'stats'), to assess spatial trends in within-sector invertebrate abundance. Beach zone was the factor, beach sector was the subject, and average invertebrate abundance beach zone^{-1} sector^{-1} was the dependent variable.

Results

During spring and fall migration from 2011 to 2014, we recorded 27,741 shorebirds of 20 species during 906 surveys totaling 524 h (Table 6 in "Appendix"). More than 90 % of all observations were of western sandpipers, sanderlings, and semipalmated plovers (Table 6 in "Appendix"). Flock size (i.e., number of individuals that entered a sector at the same time) ranged from 1 to 307, with an average of 16 shorebirds per flock. Multi-species flocks were common (>20 % flocks consisted of 2 or more species upon entry to sector). Shorebirds spent 85, 11, and 4 % of time in foraging, roosting, and flying states, respectively. Foraging and roosting shorebirds primarily occupied the intertidal zone (80 %), followed by the swash zone (17 %), upper beach (3 %), and rocky outcrops (<1 %). The number of shorebirds varied greatly between years and seasons, with more in spring than in fall of the same year and more in 2014 than in previous years (Table 1).

We recorded 7466 people and 565 dogs during the surveys. The average number of people observed was twice as great during fall migration than during spring migration (Table 1). Visitor attendance was higher on weekends than on weekdays (weekdays: 6.44 ± 0.38 SE people 100 m sector^{-1} half hour^{-1}; weekends: 9.03 ± 1.20 SE). Compliance with the dog on-leash regulation was higher during fall migration with rates of 38.9, 49.6, 56.4, and 37.1 % in 2011, 2012, 2013 and 2014, respectively, compared to rates of 18.5 and 29.0 % during spring migration in 2012 and 2013.

Food Abundance

Five classes and more than eight families of invertebrates were recorded, with a total abundance of 3326 invertebrates (Table 7 in "Appendix"). The most abundant taxa of invertebrates sampled were *Euzonus* spp. (48 % of

Table 1 Average (±SE) and maximum number of people and shorebirds plus number of surveys (*n*) per 100-m-wide beach sector observed at the Long Beach Unit of Pacific Rim National Park Reserve (survey length = 30 min) during spring and fall migration

Year	Spring					Fall				
	n	People		Shorebirds		*n*	People		Shorebirds	
		Average	Max	Average	Max		Average	Max	Average	Max
2011	–	–	–	–	–	142	8.59 ± 1.02	76	8.76 ± 1.79	133
2012	100	2.63 ± 0.39	18	24.61 ± 8.08	530	183	8.44 ± 0.97	74	14.02 ± 2.92	227
2013	119	3.82 ± 1.06	116	13.69 ± 3.01	201	203	7.69 ± 0.83	55	8.41 ± 2.35	269
2014	–	–	–	–	–	159	7.47 ± 0.81	57	33.5 ± 7.90	660

invertebrates), followed by *Megalorchestia californiana* (20 %), and *Cirolanidae* spp. (11 %). Invertebrate abundance did not differ significantly among the 20 beach sectors [one-way ANOVA: $F_{(18,152)} = 0.84$, $P = 0.65$]. There was strong evidence of zonation within sectors (Friedman rank sum test: $\chi^2_{(2)} = 22.8$, $P < 0.0001$) with mean invertebrate abundance (±SE) decreasing from $35.05 ± 4.83$, to $15.47 ± 2.96$, to $5.53 ± 0.67$ invertebrates per 4.56×10^{-3} m^3 in the wrack line, intertidal zone, and swash zone, respectively.

Habitat Use

Using data from all years, the top model suggested that shorebird minutes spent on the beach was explained by beach width while shorebird absence was explained by beach width and number of people (Table 2). Shorebirds spent more time on wider beaches (beach width parameter estimate derived from the top model: 0.68; 95 % CI 0.49, 0.87). The probability of shorebird absence increased with decreasing beach width (parameter estimate: −0.32; 95 % CI −0.47, −0.17) and increasing number of people at a sector (parameter estimate: 0.38; 95 % CI 0.19, 0.57). Models containing season and functional beach width received little support (ΔBIC > 2; Table 2).

Beach width was the only variable included in the top model when the analysis was limited to 2013, when invertebrate abundance data were available (Table 3). Here again, shorebirds spent more time in wider beach sectors (beach width parameter estimate derived from the top model: 0.57; 95 % CI 0.21, 0.94). The importance of the number of people was greatly reduced compared to when data from all years were considered as no models with substantial support contained that variable (ΔBIC > 2; Table 3). Models containing invertebrate abundance explained little of the variation in shorebird beach use ($w < 0.06$; Table 3).

Behavior

The presence of people and functional beach width affected western sandpiper and sanderling behavior [$F_{people(1,33)} = 6.94$, $P = 0.006$, $R^2 = 0.14$; $F_{beach\ width(1,33)} = 4.80$, $P = 0.02$, $R^2 = 0.10$] but did not significantly affect semipalmated plover behavior [$F_{people(1,23)} = 2.97$, $P = 0.056$, $R^2 = 0.08$; $F_{beach\ width(1,23)} = 3.32$, $P = 0.053$, $R^2 = 0.09$]. After controlling for functional beach width, the presence of people increased the proportion of time sanderlings and western sandpipers spent moving from 0.028 of total time (95 % CI −0.006, 0.062) when people were not within 100 m

Table 2 Zero-inflated regression models where the count component explains shorebird minutes spent on the beach and the zero-inflation component explains the probability of shorebird absence during 906 beach surveys at the Long Beach Unit of Pacific Rim National Park Reserve during fall migration in 2011–2014 and spring migration in 2012 and 2013

Model factors		*df*	BIC	ΔBIC	*w*
Count	Zero				
Beach width	Beach width + number of people	6	4867.7	0	0.693
Beach width	Beach width + number of people + season	7	4870.8	3.07	0.149
Beach width + functional beach width	Beach width + number of people	7	4873.6	5.87	0.037
Beach width + season	Beach width + number of people	7	4874.2	6.43	0.028
Beach width	Beach width + number of people + functional beach width	7	4874.4	6.67	0.025
Beach width + number of people	Beach width + number of people	7	4874.5	6.75	0.024

Models with BIC weights <0.01 were excluded

df is the model degrees of freedom, *BIC* is the model Bayesian information criterion score, *ΔBIC* is the difference in BIC score from the top model, and *w* is the model weight

Table 3 Zero-inflated regression models where the count component explains shorebird minutes spent on the beach and the zero-inflation component explains the probability of shorebird absence during 306 beach surveys at the Long Beach Unit of Pacific Rim National Park Reserve during spring and fall migration in 2013

Model factors		df	BIC	ΔBIC	w
Count	Zero				
Beach width		4	1358.3	0	0.416
		3	1360.9	2.62	0.112
Beach width	Number of people	5	1361.5	3.20	0.084
Beach width + number of people		5	1361.7	3.42	0.075
Beach width	Beach width	5	1362.2	3.88	0.060
Beach width + invertebrate abundance + number of people	Beach width + invertebrate abundance + number of people	9	1378.2	19.84	0.00

Models with ΔBIC >4 were excluded

df is the model degrees of freedom, BIC is the model Bayesian information criterion score, ΔBIC is the difference in BIC score from the top model, and w is the model weight

of shorebirds to nearly a quarter of their time (0.24; 95 % CI 0.18, 0.29) when they were (Table 4). The proportion of time western sandpipers and sanderlings spent in foraging and roosting states decreased accordingly when people were present (Fig. 2a), although these decreases were not statistically significant [$F_{\text{foraging}(1,37)} = 1.93$, $P = 0.17$, $R^2 = 0.04$; $F_{\text{roosting}(1,37)} = 1.59$, $P = 0.23$, $R^2 = 0.04$]. Functional beach width appeared to have minimal effects on the proportion of time western sandpipers and sanderlings spent moving, when people were not present, and appeared to have a positive effect, when people were present within 100 m of shorebirds (Fig. 2b). The proportion of time that western sandpipers and sanderlings spent in a foraging state decreased with increasing functional beach width (Fig. 2b; Table 4). Vigilance behavior in western sandpipers and sanderlings was not affected by the presence of people [$F_{(1,37)} = 1.55$,

$P = 0.28$, $R^2 = 0.04$] or functional beach width [$F_{(1,37)} = 2.56$, $P = 0.10$, $R^2 = 0.06$]. Trends in semipalmated plover behavior, although not significant, were similar to results for western sandpipers and sanderlings (with the exception of vigilance behavior) with a greater proportion of time spent foraging and roosting and lesser proportion of time spent in a locomotive state in the absence of people than when people were within 100 m of shorebirds (Fig. 3).

Disturbance Events

Shorebirds were disturbed (changed from a foraging or roosting state to a running or flying state and moved in the opposite direction from people or dogs) on 160 of 308 (52 %) occasions when people and/or their dogs were within 100 m of shorebirds. The nearest distance that

Table 4 Permutational ANCOVAs of the effect of the presence of people within 100 m of shorebirds and functional beach width on the proportion of time western sandpipers and sanderlings spent in locomotive and foraging behavioral states (n = 41)

	df	F	R²	P
Locomotive				
People within 100 m	**1**	**63.865**	**0.502**	**0.001**
Functional beach width	**1**	**6.851**	**0.054**	**0.010**
People within 100 m: functional beach width	**1**	**19.475**	**0.153**	**0.001**
Residuals	37		0.291	
Foraging				
People within 100 m	1	1.925	0.043	0.165
Functional beach width	**1**	**5.189**	**0.117**	**0.028**
People within 100 m: functional beach width	1	0.423	0.010	0.544
Residuals	37		0.831	

Variables of interest with P values <0.05 are bolded

df indicates the degrees of freedom of the factor, F the value of the statistic, R² the percentage of variance explained by the factor, and P the P value associated with the factor
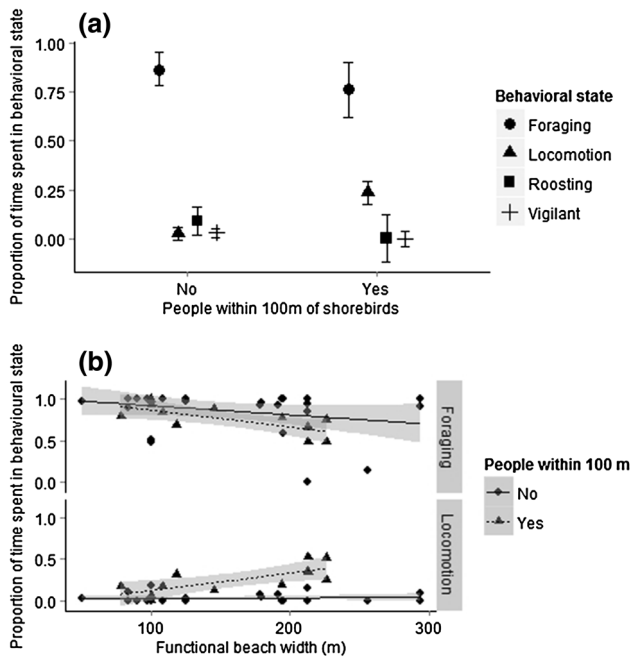
Fig. 2 a Least-squares mean proportion of time (accounting for the covariate beach width when significant in ANCOVA analyses) western sandpipers and sanderlings spent in foraging, locomotive, roosting, and vigilant states, b proportion of time western sandpipers and sanderlings spent in foraging and locomotive states according to functional beach width when people were within 100 m of shorebirds ($n = 11$) and absent ($n = 30$). *Error bars* represent 95 % confidence interval, *lines and shading represent lines* of best fit and 95 % confidence regions

Fig. 3 Least-squares mean proportion of time semipalmated plovers spent in foraging, locomotive, roosting, and vigilant states when people were within 100 m of shorebirds ($n = 7$) and absent ($n = 24$). *Error bars* represent 95 % confidence interval

people and/or dogs were to shorebirds and the speed at which people were moving affected the chances of shorebirds being disturbed as both variables were present in the top two models (Table 5). With every 1 m increase in distance from the shorebirds, the probability that shorebirds

were disturbed decreased by 8 % (OR 0.92; 95 % CI 0.90, 0.94; Fig. 4a). The risk of disturbance was particularly great when people or dogs were <50 m from shorebirds, as shorebirds were disturbed on 152 of 210 (72 %) of these occasions. In addition, the faster people moved through a sector, the more likely they were to disturb shorebirds (OR 2.49; 95 % CI 1.55, 4.15; Fig. 4b). Group type (with or without a dog) also influenced shorebird disturbance as group type was present in the top model (Table 5), and shorebirds were 77 % less likely to be disturbed when only people were within 100 m of shorebirds than when people and dogs were within 100 m of shorebirds (OR 0.23; 95 % CI 0.07, 0.65; Fig. 4a).

Discussion

As predicted, beach width and human activity impacted shorebird habitat use and behavior within PRNPR. Shorebirds spent less time at narrower beaches and were less likely to use beaches as the number people on the beach increased. Western sandpipers and sanderlings spent significantly more time in a locomotive state when people were present than when there were no people in the vicinity of shorebirds. There was also a tendency for shorebirds to spend less time in foraging and roosting states when people were present. Beach width also significantly affected the time-activity budgets of two of the focal shorebird species in a direction opposite to our prediction. Western sandpipers and sanderlings spent less time foraging and more time moving with increasing functional beach width. Vigilance behavior in western sandpipers, sanderlings, and semipalmated plovers was unaffected by functional beach width. Contrary to our hypothesis and to prior research, invertebrate abundance was not associated with shorebird habitat use or behavior at the sector scale. The risk of shorebird disturbance decreased with increasing distance between people and shorebirds, decreasing speed of human activity, and groups where only people were present compared to groups with people and dogs.

Shorebird Habitat Use

Total beach width was a key determinant of time shorebirds spent on the beach and, to a lesser extent, occurrence as shorebirds were more likely to be absent from narrower beaches than wider ones. These results are consistent with previous studies that describe site width as an important predictor of shorebird use of potential stopover sites on a landscape scale and that, on a more localized scale, shorebirds at stopover and wintering grounds concentrate on wide sections of beach, far from vegetative cover

Table 5 Multiple logistic regression models explaining whether shorebirds were disturbed when people only (n = 259) or people and dogs (n = 44) were within 100 m of shorebirds during surveys conducted at the Long Beach Unit of Pacific Rim National Park Reserve during fall migration in 2011–2014 and spring migration in 2012 and 2013

Model	df	BIC	ΔBIC	w
Distance to shorebirds + speed + group type	4	270.4	0	0.763
Distance to shorebirds + speed	3	272.8	2.42	0.227
Distance to shorebirds + group type	3	279.3	8.91	0.009
Distance to shorebirds	2	283.2	12.79	0.001
Speed	2	419.4	149.08	0
Speed + group type	3	423.1	152.75	0
	1	425.6	155.24	0
Group type	2	428.1	157.70	0

Speed refers to the speed (in m/s) at which people moved across a 100 m beach sector. Group type was with or without a dog(s)

df is the model degrees of freedom, BIC is the model Bayesian information criterion score, ΔBIC is the difference in BIC score from the top model, and w is the model weight
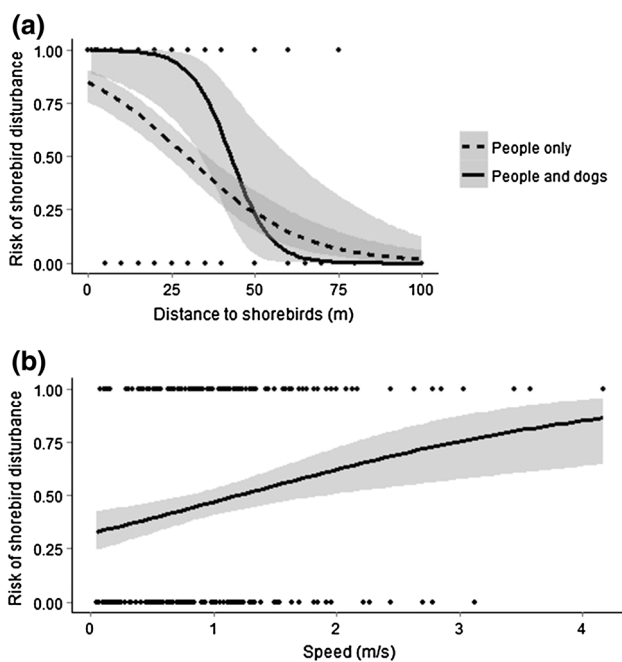

Fig. 4 Risk of shorebird disturbance in relation to **a** the distance that people and/or dogs got within shorebirds when people only (n = 259) or people and dogs (n = 44) were within 100 m of shorebirds, **b** the speed that people were moving when they were within 100 m of shorebirds (n = 256). Shading represents 95 % confidence region

(Pomeroy 2006; Yasué 2006). Perceived predation risk is a proposed explanation for shorebirds' preferential use of wide, open areas (Ydenberg et al. 2002) and is supported by observations of more shorebird predation at sites closer to the vegetative cover of the shoreline (Whitfield 2003; Cresswell et al. 2010). However, as we were unable to measure predation risk directly at PRNPR, it is possible that preferential use of wider sectors by shorebirds is due to one or more factors other than (or in addition to) perceived predation risk (e.g., area of available foraging habitat).

Shorebirds were also more likely to be absent from beaches as the number of people at the beach increased, indicating that human activity was displacing shorebirds from the Long Beach Unit beaches. Similarly, at Plymouth Beach, a staging area in Massachusetts, USA, shorebird species that preferred front beach habitat were displaced to back-beach habitat with increasing human activity (Pfister et al. 1992). The strength of both the effect of human activity and beach width on shorebird habitat use was reduced when we limited the analysis to 2013 indicating reduced power of the analysis of the data subset. However, the reduction in the importance of beach width, with the more limited data, was not as much as the reduction in the effect of human activity suggesting that the risk shorebirds associated with narrow beaches may have been greater than the risk they associated with beaches with many people. Frid and Dill (2002) hypothesized that the level at which an animal responds to a potential threat should correspond to the risk they associate with the threat (a.k.a. the risk-disturbance hypothesis). A potential explanation for stronger effects of beach width than human presence is that avian predators are a direct source of shorebird mortality, whereas human activity is not, at least on this part of the shorebird journey (shorebird hunting by humans does occur in Central and South America, Morrison et al. 2012).

Shorebird occurrence was not associated with invertebrate abundance at the spatial scale of our study. In highly dynamic and high-energy environments such as open Pacific Ocean beaches, a lack of correlation between shorebird habitat use and prey density has been attributed to less predictable prey availability, compared to more stable environments (Colwell 1993; Schlacher et al. 2014). In other words, predictable patches of habitat yielding

sustainable and high intake may be limited in this environment. While we currently have no data on the stopover lengths of birds at this site, if migratory shorebirds are only using PRNPR beaches for brief stopovers, they may be less able to track prey (Piersma et al. 1993; Kraan et al. 2009). Similar to what we observed at the sector scale, within-sector beach use by shorebirds did not match prey abundance that we measured as most shorebirds were observed in the intertidal and swash zones, whereas invertebrate abundance was greatest at the wrack line. Preferential use of wet habitat (i.e., swash and intertidal zone vs. drier wrack line and upper beach) has been exhibited previously by migrating shorebirds using ocean-facing beaches in New Jersey (Burger et al. 1977). Increased prey availability and accessibility in the wet habitats of the intertidal and swash zones aids tactile foragers like western sandpipers and sanderlings, in prey detection and capture (Gerritsen and Meiboom 1985).

Shorebird Behavior

As in our study, human and canine activity reduced time spent foraging by sanderlings in Florida, USA (Burger and Gochfeld 1991). At a coastal stopover site in Pachena Beach, British Columbia, Canada, human activity negatively impacted swallowing rates of semipalmated plover (Yasué 2005). We observed slightly, but not significantly lower proportions of time spent foraging in semipalmated plovers, and the differences in the response variable measured could explain the inconsistencies between the results of these two studies.

Functional beach width affected shorebird behavior, although not in the way that we anticipated, as shorebirds moved more and foraged less with increasing functional beach width, especially in the presence of people. The effect of functional beach width on the proportion of time western sandpipers and sanderlings spent in a locomotive state was dependent on the presence of people. The increasing proportion of time spent in a locomotive state with increasing functional beach width when people were present, could be because shorebirds were reluctant to abandon the wider and preferred beach sectors.

As with the total time spent on the beach, the proportion of time focal shorebirds allocated to foraging was unaffected by prey abundance. Similarly, the lack of an effect of prey abundance on foraging time may be due to the absence of significant variation in invertebrate abundance among the Long Beach Unit beach sectors, and therefore the lack of patchiness, compared to the gradient in food supply among habitats observed elsewhere (e.g., Rose and Nol 2010; Kraan et al. 2009). Differences in the profitability of our study sectors for shorebirds may thus be limited as well.

Disturbance Events

Although the effects of human activity on shorebird habitat use and behavior may be variable, one consistent result from our study and others is that in areas where humans and shorebirds overlap, shorebirds are disturbed frequently (Lafferty 2001; Thomas et al. 2003; Schlacher et al. 2013a). Similar to Schlacher et al. (2013b), we found that whether shorebirds were disturbed was determined by proximity and speed of human activity. Shorebirds were also more likely to be disturbed when dogs were present than when they were absent, a result consistent with other studies (Burger et al. 2007; Lafferty 2001).

Management Implications

Human activity on PRNPR beaches caused increases in time shorebirds devoted to flying, reductions in time devoted to feeding and roosting, and displacement from potential foraging and roosting areas. To date, the fitness consequences for shorebirds that can result from these disturbance-induced behavioral alterations have only been demonstrated using modeling (Goss-Custard et al. 2006; Rogers et al. 2006). Although many challenges for measuring the energetic costs of disturbance in situ (e.g., small body size, long migration distances, short stopover durations, difficulty in capturing migrating shorebirds) exist, this may be possible in future as technology for tracking shorebirds throughout their annual cycle improves and becomes more affordable. Alternatively, the use of stress hormone levels as an indicator of disturbance-induced fitness costs is an emerging field that could be used to assess whether stress levels differ between shorebirds in undisturbed and disturbed areas, as has been examined previously in other bird species (Dantzer et al. 2014). However, before this approach could be used, many components of the methodology need to be addressed and require further testing such as species and sex-specific differences in stress hormone levels and the link between increased stress hormone levels and decreased reproductive success and survival (Dantzer et al. 2014).

Given the declining status of many shorebird populations and potential for human activity to affect shorebird fitness, PRNPR and similar stopover areas may want to consider management options for reducing shorebird disturbance. One management option to improve habitat quality for migrating shorebirds at PRNPR, and similar coastal stopover areas, would be to close wide beach sectors during seasonal peaks in spring migration from late April until the end of May and fall migration from mid-July until the end of September, as is done in a number of protected areas globally (e.g., WHSRN 2009; New Jersey Division of Fish and Wildlife 2013). However, as PRNPR

is a popular recreational area, seasonal beach closures would undoubtedly be unpopular with local recreationists and tourists alike. The overall impact on and dissatisfaction among site users could be decreased by limiting beach restrictions to the most impactful user groups (i.e., dog walking, running, biking) and/or the beach zones most used by shorebirds (intertidal and swash zones). Buffer zones of 50 m or more based on our findings are an alternate option for improving habitat quality for migratory shorebirds. Of the options considered, buffer zones would have the least impact on site users but most beach users do not voluntarily give shorebirds the space needed to avoid disturbing them (Burger and Niles 2013; Schlacher et al. 2013a). As such, the efficacy of buffer zones would likely be low unless actively enforced. Buffer zone enforcement may be more complicated and require more resources compared to outright beach closures and activity restrictions.

Although many studies have identified ways that people are affecting shorebirds and suggested various management actions, few studies have evaluated the success of management measures when introduced. The evaluation of management measures aimed at improving the quality of stopover and staging sites for shorebirds should be a focus of future research so that resources can be concentrated on the most effective management measures.

Appendix

See Tables 6 and 7.

Table 6 Total counts of shorebirds observed during 524 survey hours across 20 beach sectors in the Long Beach Unit of Pacific Rim National Park Reserve during spring and fall migration from late April until the end of May, in 2012 (50 survey hours) and 2013 (59.5 survey hours), and July through October in 2011 (142 survey hours), 2012 (91.5 survey hours), 2013 (101.5 survey hours), and 2014 (79.5 survey hours)

Species		2011	2012		2013		2014
Common name	Latin name	Fall	Spring	Fall	Spring	Fall	Fall
Baird's Sandpiper	*Calidris bairdii*	6	0	7	1	0	0
Black-Bellied Plover	*Pluvialis squatarola*	9	19	3	136	2	13
Black Oystercatcher	*Haematopus bachmani*	0	63	16	47	20	32
Black Turnstone	*Arenaria melanocephala*	8	0	7	0	0	1
Dunlin	*Calidris alpina*	0	176	0	303	0	0
Greater Yellowlegs	*Tringa melanoleuca*	1	0	2	0	2	0
Killdeer	*Charadrius vociferus*	24	3	37	32	7	0
Least Sandpiper	*Calidris minutilla*	11	47	67	2	52	40
Lesser Yellowlegs	*Tringa flavipes*	1	0	0	0	0	0
Marbled Godwit	*Limosa fedoa*	0	0	0	0	0	3
Red Knot	*Calidris canutus*	0	2	0	0	7	0
Red-Necked Phalarope	*Phalaropus lobatus*	0	14	0	0	0	0
Sanderling	*Calidris alba*	2519	1409	1608	520	950	2377
Short-billed Dowitcher	*Limnodromus griseus*	0	25	0	14	1	0
Semipalmated Plover	*Charadrius semipalmatus*	421	547	497	684	709	755
Semipalmated Sandpiper	*Calidris pusilla*	0	5	0	0	0	0
Surfbird	*Aphriza virgata*	0	0	35	0	90	0
Unidentified shorebirds		94	224	2	20	513	163
Wandering Tattler	*Heteroscelus incanus*	0	0	0	0	0	3
Western Sandpiper	*Calidris mauri*	2025	2328	1710	924	914	4039
Whimbrel	*Numenius phaeopus*	0	166	34	73	17	28

Surveys were conducted throughout migration, on a near daily basis, at 1–7 beach sectors per day

Table 7 Abundance of macroinvertebrates sampled at shorebird monitoring sites along the Long Beach Unit of Pacific Rim National Park Reserve, Vancouver Island, British Columbia, from April to August 2013

Class	Order	Family	Species	Abundance
Entognatha	Collembola (subclass)	Unknown		50
Gastropoda	Unknown	Olivellidae	*Olivella biplicata*	4
Insecta	Coleoptera	Staphylinidae	Unknown	111
Insecta	Unknown			2
Malacostraca	Amphipoda	Talitridae	*Megalorchestia californiana*	671
Malacostraca	Isopoda	Cirolanidae	Unknown	355
Malacostraca	Isopoda	Oniscidea (sub order)	Unknown	26
Malacostraca	Isopoda	Unknown		173
Malacostraca	Amphipoda	Gammaridea (sub order)	Unknown	189
Polychaeta	Capitellida	Arenicolidae	*Arenicola marina*	2
Polychaeta	Scolecida (subclass)	Opheliidae	*Euzonus* spp.	1582
Polychaeta	Phyllodocida	Glyceridae	Unknown	95
Polychaeta	Unknown			66

Invertebrates were classified to lowest level possible

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