Investigating the impacts of human activities on oystercatcher presence and foraging behaviour along a multi-use recreational sandy beach ecosystem

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DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

SIGNED: Emma Vanderzon Date: 10/11/2022

PREFACE

This thesis represents a novel body of scientific work that has been prepared by the candidate under direction of their supervisors. The final dissertation presented herein is work of intellectual merit that has been produced by various inputs as follows:

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The candidate acknowledges that authorship of any resulting publication from this work will be guided by advice from the supervisors and may include other authors who contributed intellectual merit in the project.

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FORMAT OF THESIS

This thesis has been written as a journal format following the Biological Conservation instructions to authors. The following appendices have been included (Appendix B) to show additional work that was not presented in the journal article.

In addition, the literature review for STEM7001 has been included as a non-assessable appendix.

ABSTRACT

Shorebirds utilising sandy beaches as primary habitat in developed coastal areas are often subjected to human disturbances in the form of recreational activities. Responses by shorebirds to human disturbances can often carry fitness consequences, so it is important to understand whether recreational activities could be causing behavioural changes. The aim of this project was to identify whether recreational human activities at sites along the south-eastern Fleurieu Peninsula could be impacting oystercatcher species. The objective was to determine if there is a correlation between pied and sooty oystercatcher abundance and foraging behaviour with recreational activities that are known to act as disturbances to shorebird (e.g. people, dogs, and off-road vehicles). The results indicated differences between the two oystercatcher species in the disturbances that were correlated to their abundance and foraging behaviour. The abundance of pied oystercatchers showed no correlation with human disturbances, while sooty oystercatchers was correlated to people, and decreased as numbers of people increased. Pied oystercatcher foraging was positively correlated with people, air temperature and wind speed, while there was no correlation between sooty oystercatchers and human activities. These findings highlight that shorebird species using the same habitats may not be influenced by the same human activities and that foraging behaviour does not necessarily decrease with greater levels of human disturbance. This suggests that shorebird abundance and foraging behaviour has the potential to be impacted by some human related disturbances, but some activities may be correlated and not act as a disturbance or could have a neutral/positive impact.

Key words: shorebirds, abundance foraging behaviour, oystercatchers, human disturbance, recreational activities, sandy beach habitat

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1. INTRODUCTION

Sandy beaches are versatile habitats that provide functional links between terrestrial and marine environments (Defeo et al., 2009). For shorebirds, sandy beaches provide critical habitat for nesting and foraging, particularly along coastlines that have dissipative type beach systems with abundance of food (e.g. molluscs, crustaceans and annelids) (Defeo and McLachlan, 2005, Defeo et al., 2009, Hubbard and Dugan, 2003, Jones et al., 2007). These coastal beaches with large intertidal areas are very important for many populations of shorebirds worldwide during stopovers on migration or during the non-breeding period (Lunardi and Macedo, 2014). Shorebirds play an important role in ecosystems as top predators, consuming prey across multiple trophic levels and heavily contributing to mass and energy fluxes across food webs (Burger, 1991, Dugan et al., 2003, Moreira, 1997, Ramli and Norazlimi, 2017, Schlacher et al., 2007). Shorebirds also act as indicators of environmental health and biodiversity which makes them model organisms for understanding ecological processes (Bakker et al., 2021, Defeo et al., 2009, Gregory and van Strien, 2010).

In developed coastal areas, shorebirds inhabiting sandy beaches are often subjected to human disturbance, usually in the form of recreational activities (Defeo et al., 2009, van der Kolk et al., 2022). A disturbance is defined as any activity leading directly or indirectly to a change in the behaviour and/or physiology of an animal (Ellenberg et al., 2006, Nisbet, 2000, Schlacher et al., 2013). Thus, human disturbances are those caused by human activity that can alter the regular behaviour of animals. Human disturbance has been found to adversely affect many behaviours in shorebirds that are crucial to survival and reproduction, such as feeding, breeding, roosting, and migration (Burger et al., 2010, Coleman et al., 2003, Rodgers and Schwikert, 2003, Verhulst et al., 2001). In particular, human disturbances during shorebird feeding (Burger, 1981, Thomas et al., 2003) can result in higher energy expenditure and reduction in time spent on foraging (Burger, 1981, Verhulst et al., 2001, Stillman and Goss-Custard, 2002, Coleman et al., 2003, Thomas et al., 2003, Defeo et al., 2009). Further, the disruption to foraging can impact the ability for shorebirds to build fat reserves and conserve energy to fulfil their annual cycle of migration and breeding (Spencer, 2010), and hence have long-term consequences for survival and fitness, impacting population trends (Hockin et al., 1992, Pfister et al., 1992, Schummer and Eddleman, 2003).

Different human activities may disturb and impact shorebirds in different ways. The presence of people on beaches is one of the most significant and common human activities that may disturb foraging and breeding success of shorebirds. Numerous studies have found that people present on beaches used as foraging sites decreases the overall time shorebirds spend foraging and increases vigilance (i.e. carefully watching for danger) (Burger, 1991, Burger et al., 2004, Fitzpatrick and Bouchez, 2010, Verhulst et al., 2001, Ramli and Norazlimi, 2017, Schlacher et al., 2013, Yasué, 2005). Shorebird response to human presence is often species specific, such as the distance that a human may approach before a bird flies/runs away (e.g. flushes) and the time spent in vigilance (Rodgers and Smith, 1997, Schlacher et al., 2013), which can be influenced by the frequency of exposure to the disturbance (habituation), and habitat use (Schlacher et al., 2013). Shorebird species may also differ in their habitat use, which could influence how they respond to human disturbances. For example, Schlacher et al. (2013) found that there was clear separation between crested terns (*Thalasseus bergii*) and other shorebird species in their behavioural response to disturbance, where they spent more time in vigilance and escaping from human stimuli compared to other species. Those results were attributed to terns using the beach to preen rather than directly forage, therefore spending more time in vigilance compared to oystercatchers, who were frequently exposed to human walking on the same beach through the tern's foraging area. People fishing on beach shorelines is also an example of a disturbance that can impact shorebirds directly by reducing large prey items and overall food availability or invertebrate availability (Ferns et al., 2000, Lunardi and Macedo, 2014, Masero et al., 2008), and indirectly by increasing the amount of people visiting the beach (Blumstein et al., 2003, Spencer, 2010). People fishing on beach shores have been found to increase flight and alertness in some shorebird species (Schummer and Eddleman, 2003).

In addition to people being present on beaches, dogwalkers are also a common occurrence that can disturb shorebirds (Blumstein et al., 2003, Burger and Gochfeld, 1991, Ramli and Norazlimi, 2017, Spencer, 2010, West et al., 2002, Williams et al., 2009). Studies have found that people walking with dogs are perceived as a greater threat to shorebirds than a person walking without a dog (Burger, 1981, Glover et al., 2011, Lafferty, 2001a). Dogs being leashed can also reduce the probability of a shorebird being disturbed by a dog and the number of birds responding per disturbance (Lafferty, 2001a, Lafferty, 2001b). In response to the presence of dogs on beaches, shorebird species tend to fly away (Burger et al., 2004) and decrease their time spent foraging (Thomas et al., 2003). Yet, in regard to vigilance the results are mixed, with some studies showing that dogs can increase the time that shorebirds spend in vigilance (Burger, 1986), while others identify that dogs did not significantly increase vigilance in shorebirds (Fitzpatrick and Bouchez, 2010).

The use of vehicles on beaches is an activity that can be very destructive, causing displacement of shorebirds and disrupting foraging behaviour and, in some cases, incidents of collisions between vehicles and shorebirds (Defeo et al., 2009, Meager et al., 2012, Schlacher et al., 2007, Schlacher et al., 2013, Schlacher et al., 2014, Weston et al., 2014). Weston et al. (2014) found that even when vehicle drivers took evasive action towards shorebirds, birds were still disturbed at the same rate compared to when the vehicle direction or speed was changed. Off-road vehicles (ORVs) are often the most common human related disturbance encountered by shorebirds who use vehicle permitted beaches as their primary foraging site (Schlacher et al., 2013).

Environmental conditions such as air temperature and wind speed can affect tolerance towards disturbances in shorebirds through variations in metabolic requirements. For example, foraging behaviour and time spent foraging may increase when energetic requirements are higher (e.g. at lower air temperatures or higher wind speeds) (Davidson, 1981, Fernandez-Juricic et al., 2002). Shorebirds foraging on sandy beaches may also have to adjust their foraging habits and/or prey species taken at lower air temperatures. Western sandpipers (*Calidris mauri*) have been found to alter their foraging behaviour at lower temperatures by increasing "probing" (e.g. burrowing their beak into the sand) as a response to temperature affecting burying depth of invertebrate prey (Nebel and Thompson, 2005). Unfavourable weather conditions can also increase the energy costs of thermoregulation in shorebirds, during periods of low temperature and high wind speeds (Davidson, 1981).

Oystercatchers are a conspicuous group of shorebirds predominantly seen along the Western and south-Eastern coastline and Tasmania (Wooding, 2019, Taylor et al., 2014, Lauro and Nol, 1995, Jones, 2016), consisting of two species: the Australian pied oystercatcher (*Haematopus longirostris*) and the sooty oystercatcher (*Haematopus fuliginosus*)(Jones, 2016). Both species typically have the similar foraging habits, prey selection and bill size (Lauro and Nol, 1995). But more specifically, sooty oystercatchers can forage on hard substrates and accumulated beach wrack along rocky coastal areas with higher percentages of hard-shelled prey, while pied oystercatchers generally forage on soft substrate along estuaries and sandy beaches (Lauro and Nol, 1995, Jones, 2016). Compared to the Eurasian oystercatcher (*Haematopus ostralegus*), both the pied and sooty oystercatcher have been underrepresented in previous studies, with many aspects of their ecology and factors impacting their survival being poorly understood (Taylor et al., 2014, Wooding, 2019)**.** The IUCN conservation status for both species is listed as "Least concern" (Hansen et al., 2014, Taylor et al., 2014), with no evidence of recent declines in Victoria and Tasmania, however the northern New South Wales population is in decline (Taylor et al., 2014). In New South Wales (NSW), the pied oystercatcher is cited as endangered and in South Australia (SA) the species has been categorised as near threatened under the SA National Parks & Wildlife (NPW) Act, 1972 (Jones, 2016). The main current and potential threats to oystercatcher species include human recreation disturbance, coastal development, habitat loss, recreational and commercial fishing of their food sources and environmental changes associated with global climate change (Jones, 2016, Taylor et al., 2014). Oystercatchers have been found to show behavioural modifications when disturbed, and suffer reduced foraging success (Coleman et al., 2003). Behavioural modifications can include increased time in vigilance, flushing at greater approach distances, delayed arrival and earlier departure from foraging and roosting sites, and shifting their preferred foraging site (Thomas et al., 2003, Schlacher et al., 2013, Ramli and Norazlimi, 2017, Fitzpatrick and Bouchez, 2010).

In this study, we investigated whether human activities significantly impacted the abundance and foraging behaviour of oystercatcher species (*Haematopus*). More specifically, we recorded the abundance and numbers of foraging oystercatchers along with the different human activities that occurred on the beach at the same time (e.g. number of people, dogs, and ORVs) and weather conditions across multiple sites along the beaches of the Southern-eastern Fleurieu Peninsula. We expected that oystercatchers would be present and foraging in significantly smaller numbers when many human activities occurred (references) and that, on the contrary, we would observe significantly greater numbers of birds (present and foraging) when human activities were low or absent (Jones, 2016) more references.

2.0 METHODS

2.1 STUDY SITES

We conducted all observations between December 2021 and June 2022 across three locations and ten sites: Middleton Beach (sites 1-5), Goolwa Beach (sites 6-8), and the Murray Mouth Estuary near Hindmarsh Island (sites 9 and 10) (Table 1, Figure 1). These sites were selected as they have been surveyed for oystercatcher abundance and human activities by Jones (2016), between 2011 and 2015. Oystercatchers are known to use these beaches as foraging grounds, with their primary food source being the Goolwa cockle (*Donax deltoids*) (Jones, 2016). Recreational cockle fishers contribute to a large proportion of human activity across beached from Middleton to the Murray Mouth during the recreational cockle harvesting season (November to May each year) (Ferguson and Mayfield, 2006). There are many access points to all the sites, with many carparks at Middleton and Goolwa, walking tracks through sand dunes at Goolwa (e.g. sites 7, 8 and 9) as well as ORV access from the main Goolwa beach carpark at site 6. The Murray Mouth Estuary is a relatively sheltered beach area, with access to the beach via carpark at Sugars Beach and the Murray Mouth Lookout on Hindmarsh Island, and ORV access from the beach at site 9 by driving around from the main Goolwa beach carpark (Jones, 2016).

Table 1: Locations and habitat types of the 10 sites used to monitor oystercatcher abundance and human activities/disturbances (adapted from Jones. 2016)

Site#	Site name	GPS Position	Habitat type
1	Middleton Point	-35.514017, 138.708753	Grey Sandstone Outcrop, Ocean Beach
2	Chapman Rd,Middleton	-35.513667, 138.719389	Ocean Beach
3	Skye Street,Middleton	-35.514741, 138.726163	Eroded intertidal limestone platform,Ocean Beach
4	Middleton Cliffs	-35.515823, 138.736835	Limestone cliff, overlooking OceanBeach
5	Tahiti Tce, Middleton	-35.517409, 138.746177	Ocean Beach, sand dunes
6	Beach Rd, Goolwa	-35.523028, 138.773250	Ocean Beach, sand dunes
7	Barrage Beach	-35.532324, 138.803889	Ocean Beach, sand dunes
8	Beacon 19 Beach	-35.538016, 138.821833	Ocean Beach, sand dunes
9	Sugars Beach, Hindmarsh Island	-35.549667, 138.878944	Intertidal sand flats inside the western Murray Mouth
10	Murray Mouth Lookout, Hindmarsh Island	-35.552146, 138.887717	Intertidal sand flats, between Hindmarshand Bird Islands

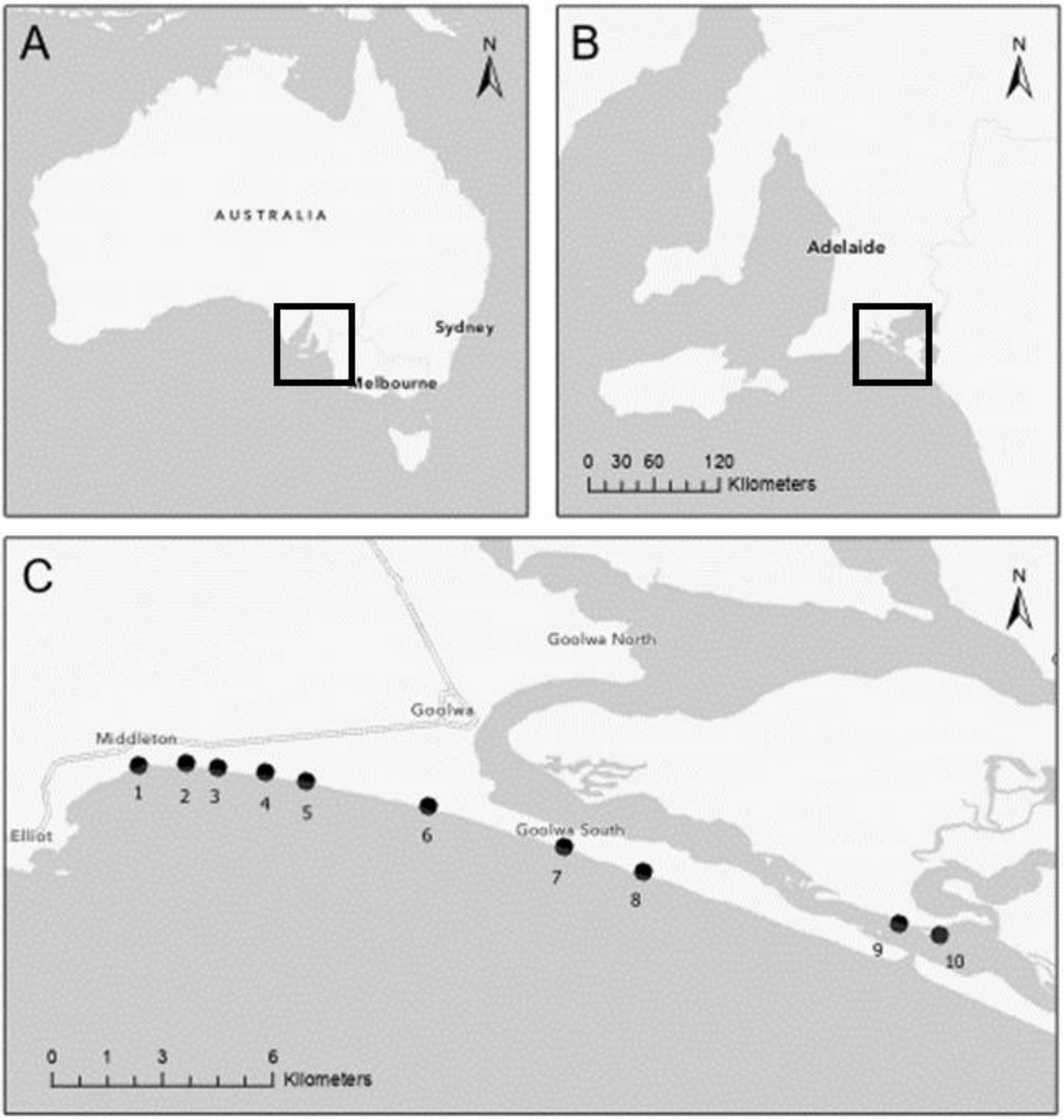

Figure 1: (A) Map of Australia indicating the location of the study study area (south-eastern Fleurieu Peninsula, South Australia, Australia). (B) Location of the study area in proximity to Adelaide. (C) Detailed locations of the 10 sites used to observe oystercatcher foraging behaviour (sites 3, 7 and 9/10) and abundance (sites 1-10) in relation to human activities and environmental conditions (adapted from Jones, 2016).

2.2 GENERAL FIELD METHODS

We selected fieldwork days randomly where possible, while making sure to include weekdays, weekends, and public holidays to capture human activity across all day types, as it is likely that human activity may be higher on weekends and public holidays compared to weekdays. The order that sites were visited was randomized for each fieldtrip to avoid sampling bias and to minimize the chances of seeing the same oystercatcher individuals if they were moving from one site to another between observation periods. Each individual bird observed was treated as a new individual at each site since there was no way to track individual bird movement. All observations were conducted at low tide, or first light when low tide was earlier than sunrise, as shorebirds predominantly forage on sandy beaches at low tide where most of the beach is exposed (Spencer, 2010). We visited sites by driving to the closest carpark with beach view/access. For sites with beach access (Sites 2, 3, 4, 6, 7, 8, 9, 10), we observed the oystercatchers on the beach in line with the access point (i.e., stairs from the carpark) close to the water's edge. In instances where oystercatchers were present directly in front of the beach access point, we observed them as close to the dunes as possible to avoid disturbing their behaviour. For sites with no beach access (Sites 1 and 5), we made our observations from the closest lookout point.

2.3 ABUNDANCE

We observed oystercatcher abundance once per month at all ten sites (Figure 1). The observations were split over two consecutive days (five sites one day, five sites the second day) to ensure that observations were made at similar tidal states. We observed oystercatchers by scanning ~200m in either direction, using Nikon (Nikon Australia Pty Ltd) 8x42 binoculars. For each species at each site, we recorded the total number of individual oystercatchers identified per species along with air temperature (°C) and wind speed (km/h) obtained from the Bureau of Meteorology at the time and location of observations. The number of people, dogs (on and off leash) and ORVs (moving through the site and parked) on the beach were also counted and recorded.

2.4 FORAGING BEHAVIOUR

We observed oystercatcher foraging behaviour three times per month (independent to the abundance surveys) at three sites: site 3, site 7 and site 10 (i.e. one site per beach region). Birds were observed by scanning ~200m (or as far as species and behaviour can be confidently identified) in either direction, using Nikon 8x42 binoculars. For each species at each site, we recorded the total number of oystercatchers and identified how many were foraging (Table 2). We recorded air temperature (°C) and wind speed (km/h) obtained from the Bureau of Meteorology at the time and location of

Table 2: Ethogram of oystercatcher foraging behaviours recorded for pied and sooty oystercatchers in this study

Behaviour:	**Method:**	**Behavioural definition:**	**Reference (example):**
Foraging	Nudging/disturbing the sand with beak	Using feet to continuously tap the surface of the sand	(Burger, 1991, Schlacher et al., 2013, Tarr et al., 2010, Weston and Elgar, 2007)
	Probing	Pecking beak down into the sand, either while stationary or moving	(Yasué et al., 2003, Zharikov and Skilleter, 2003, Zharikov and Skilleter, 2004)
	Handling prey item	Picking up or stabbing open prey item using the beak	(Yasué et al., 2003, Zharikov and Skilleter, 2003, Zharikov and Skilleter, 2004)
	Consuming prey item	Visibly eating prey item	(Yasué, 2005, Yasué et al., 2003, Zharikov and Skilleter, 2003)
Resting	Sitting	Stationary, sitting, no signs of vigilance	(Tarr et al., 2010, Schlacher et al., 2013, Weston and Elgar, 2007, Yasué et al., 2003)
	Standing, stationary	Standing, stationary, no signs of vigilance	
Vigilance	Scanning and looking, either while stationary or moving	Lifting head and scanning for possible disturbance or in response to a disturbance (person, dog, vehicle)	(Burger and Gochfeld, 1991, Schlacher et al., 2013, Stolen, 2003, Yasué, 2005)

observations. The number of people, dogs (on and off leash) and ORVs (moving through the site and parked) on the beach. After the behavioural observations were recorded, we photographed the foraging behaviours with a Canon EOS 90D and Sigma 150-600m lense to be keep a record of the type of prey items being consumed, and examples of oystercatcher feeding behaviours (see Figure 2).

Figure 2: Examples of oystercatcher beaviour at foraging sites along the south-eastern Fleurieu peninsula; (A) probing behaviour by pied oystercatchers, (B-D) cockle handing by pied and sooty oystercatchers, (E) pied oystercatchers in vigilance, (F) pied and sooty oystercatchers resting in tire tracks

2.5 STATISTICAL ANALYSIS

Prior to analysis, data was assessed for collinearity between (1) continuous predictors using the variance inflation factors (VIF) analysis and (2) categorical predictors using Pearson's correlations (Fox et al., 2015, Zuur et al., 2009). VIF values were found to be <2 confirming no collinearity between continuous predictors; however, collinearity was found between the factors 'people' and 'dogs' and between 'people' and 'ORVs'. For each dataset (e.g. 'abundance' and 'foraging'), Models 1 and 3 included the fixed factors 'people', 'air temperature' and 'wind speed', while Models 2 and 4 included 'dogs', 'ORVs', 'air temperature' and 'wind speed'. 'Site' (sites 1 through 10) and 'Julian date' were assigned as random factors in all models. We analysed pied oystercatchers and sooty oystercatchers separately to see whether there was a difference between what could impact their abundance and foraging behaviour at the species level. Since vehicles are not seen driving at Middleton beach sites, an additional model was run to determine if vehicles are a significant disturbance at sites 6-9 where vehicles are allowed. The model included 'ORVs', 'air temperature' and 'wind speed' as fixed factors and did not produce any significant results (refer to Appendix B). We performed all statistical analyses in RStudio v. 2022.7.1.554 (RStudio Team, 2020).

2.5.1 Oystercatcher abundance

The total number of oystercatchers was examined using two generalised linear mixed models (GLMM) (Models 1-4) with a negative binomial distribution and a logit link function, fitted using the R package 'lmer4', with 'wind speed (km/h)', 'air temperature (°C)', 'people', 'dogs', and 'ORVs' as fixed factors.

2.5.2 Foraging behaviour

The percentage of foraging oystercatchers was examined using two GLMMs (Models 5-8) with a Poisson distribution and a logit link function, with 'wind speed (km/h)', 'air temperature (°C)', 'people', 'dogs', and 'ORVs' as fixed factors. The zero-inflated models were fitted using the R package 'glmmTMB' (Brooks et al., 2017), using a single zero-inflation parameter applied to all observations (*ziformula = ~1*).

3.0 RESULTS

3.1 Oystercatcher abundance

On average, there were more pied oystercatchers present per survey (7.96 ± 18.50) compared to sooty oystercatchers (3.1 ± 7.45) (Table 3). Pied oystercatchers were present for 28 % of surveys, and 22 % of the surveys where birds were present had disturbances present (Table 3). Of the human disturbances pied oystercatchers encountered, people accounted for the highest proportion of disturbances (41-50 %, Table 4). Sooty abundance decreased when people were present in greater numbers (Figure 3.A, Figure 4.A) and increased when dogs were absent (Figure 3.B, Figure 4.B). People also accounted for the greatest proportion of disturbances (41-50 %, Table 4), with only 15 % of surveys having sooty oystercatchers and disturbances present (Table 3). The statistical tests showed that pied oystercatcher abundances were not found to be correlated with any of the human activities or environmental conditions (GLMM Model 1 and Model 3; Table 5), and that sooty oystercatcher abundances were significantly correlated to people (GLMM Model 2: 'people', P = 0.04 and dogs (GLMM Model 4: 'dogs', P = 0.03, Table 5), but not to ORVs.

Table 3: General summary results for pied and sooty oystercatchers observed per abundance observation survey at sandy beach sites along the south-easter south-eastern Fleurieu peninsula

General contributions for abundances	Species			
	Pied		Sooty	
Average individuals per survey (± s.d)	7.96 ± 18.50		3.1 ± 7.45	
Total no. of surveys	70		70	
	Total #	**Contribution %**	**Total #**	**Contribution %**
Surveys where birds were present	20	28.57	20	28.57
Surveys where birds were not present	50	71.43	50	71.43
Surveys with disturbances	63	90.00	63	90.00
Surveys without disturbances	7	10.00	7	10.00
Surveys with disturbance events where birds were present	16	22.86	11	15.71
Surveys with disturbance events where birds were not present	46	65.71	45	64.29

Table 4: Frequency of occurrence of human activity disturbances during abundance counts at 10 sandy beach sites, for the pied and sooty oystercatcher

Species	People	Dogs	ORVs
Pied oystercatcher	●●●●	●●	●●●
Sooty oystercatcher	●●●●	●●	●●

● <20%; ●● 20-30%; ●●● 31-40%; ●●●● 41-50%

Figure 3: Abundance of pied and sooty oystercatchers (mean ± SE) in relation to (A) the presence of people (<10, 10+), (B) the presence of dogs (present, absent)

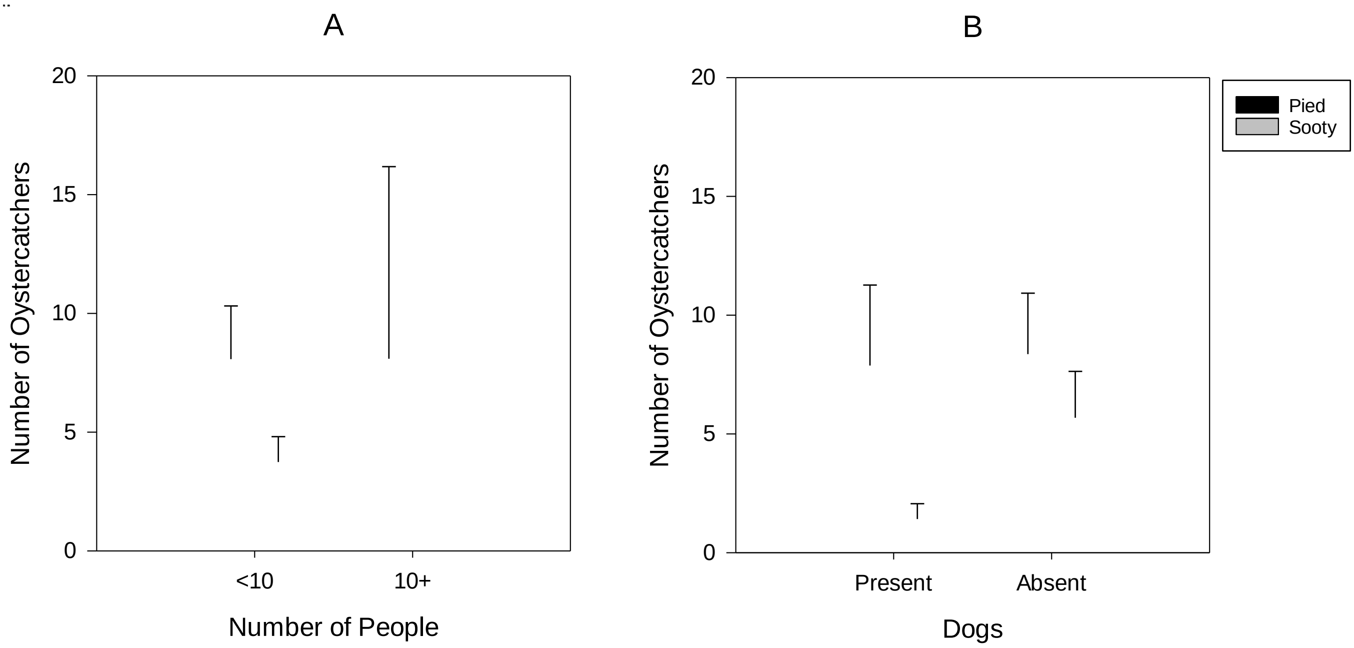

Figure 4: Proportion of sooty oystercatchers per survey in relation to (A) the proportion of people as a disturbance and (B) the proportion of dogs as a disturbance

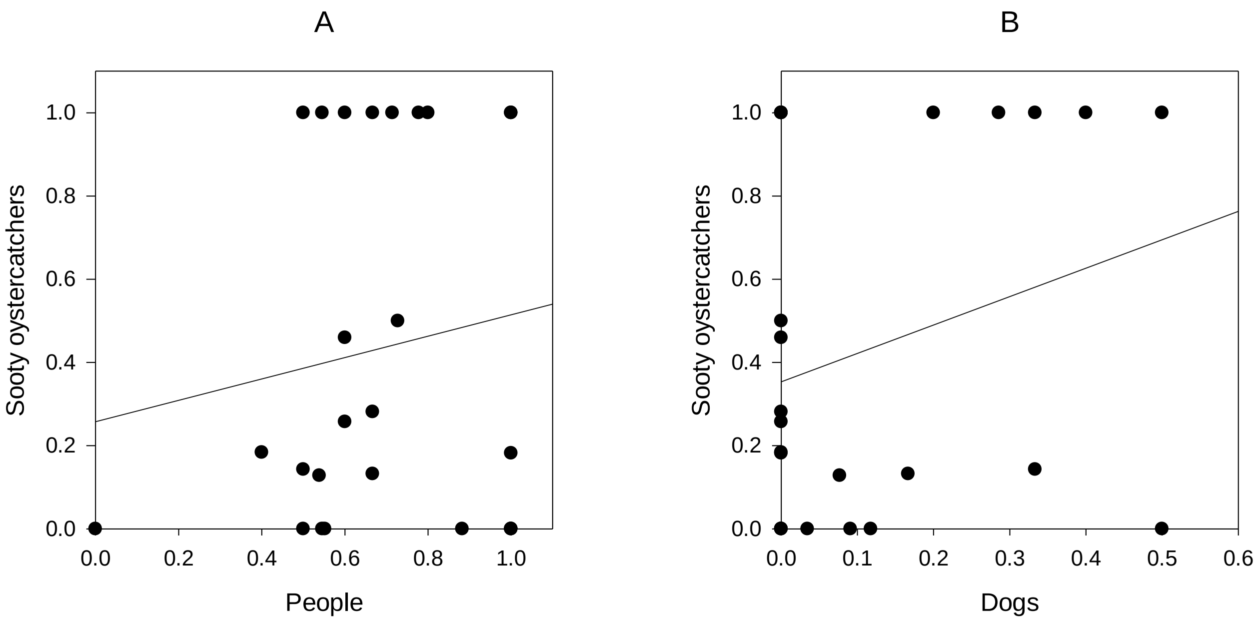

Table 5: Output table from the generalised linear mixed models assessing the abundance of pied and sooty oystercatchers in response to human activity and environmental conditions

Fixed Factors	**Estimate**	**Standard Error**	**z-value**	**P-value**
Model 1: Total pied (n=70)				
Intercept	-8.48	3.40	-2.49	0.01*
People	-0.02	0.08	-0.23	0.82
Air temperature	0.08	0.09	0.91	0.36
Wind speed	-0.05	0.11	-0.49	0.62
Model 2: Total sooty (n=70)				
Intercept	1.35	2.16	0.63	0.53
People	-0.25	0.13	-1.97	**0.04**
Air temperature	-0.03	0.10	-0.26	0.80
Wind speed	-0.01	0.11	-0.06	0.10
Model 3: Total Pied (n=70)				
(Intercept)	-7.37	4.18	-1.76	0.08
Dogs	-0.06	0.47	-0.13	0.89
ORVs	0.16	0.17	0.91	0.36
Air Temperature	0.04	0.08	0.52	0.60
Wind Speed	-0.06	0.11	-0.55	0.58
Model 4: Total Sooty (n=70)				
(Intercept)	2.09	2.30	0.91	0.36
Dogs	-0.77	0.35	-2.24	**0.03***
ORVs	0.09	0.24	0.37	0.71
Air Temperature	-0.05	0.11	-0.46	0.64
Wind Speed	-0.01	0.12	-0.12	0.91

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘ ’

3.2 Foraging behaviour

On average, there were more pied oystercatchers (8.82 ±17.38) and pied oystercatchers foraging per (3.24 ± 8.37), versus sooty oystercatchers (1.52 ± 3.93) (Table 6). People accounted for 41-50 % of foraging behaviour disturbances for both species. Dogs accounted for 31-40 % and < 20 % of foraging behaviour disturbances for sooty and pied oystercatchers, respectively. Presence of ORVs accounted for 31-40 % and < 20 % to foraging disturbances for pied and sooty oystercatchers (Table 7). Pied oystercatcher foraging increased as the proportion of people as a disturbance increased

Table 6: General summary results for pied and sooty oystercatchers observed per foraging observation survey at sandy beach sites along the south-easter south-eastern Fleurieu peninsula

General contributions for foraging	Species			
	Pied		Sooty	
Average individuals per survey (± s.d)		8.82 ± 17.38		2.96 ± 5.79
Average individuals foraging per survey (± s.d)		3.24 ± 8.37		1.52 ± 3.93
Average individuals resting per survey (± s.d)		2.90 ± 8.97		0.58 ± 1.70
Average individuals in vigilance per survey (± s.d)		2.77 ± 9.83		0.88 ± 3.30
Total no. of surveys		84		84
	Total #	**Contribution %**	**Total #**	**Contribution %**
Surveys with disturbances	62	73.81%	62	73.81%
Surveys without disturbances	22	26.19%	22	26.19%
Surveys where birds were present	36	42.86%	31	36.90%
Surveys where birds were not present	48	57.14%	53	63.10%
Surveys where birds were foraging	28	33.33%	21	25.00%
Surveys where birds were not foraging (resting or vigilance)	8	9.52%	10	11.90%
Surveys with disturbance events where birds were foraging	24	28.57%	19	22.62%
Surveys with disturbance events where birds were not foraging (resting or vigilance)	2	2.38%	6	7.14%
Surveys with disturbance events with no birds present	13	15.48%	14	16.67%
Surveys with disturbances with birds present	27	32.14%	25	29.76%

Table 7: Frequency of occurrence of human activity disturbances during foraging observations at 10 sandy beach sites, for the pied and sooty oystercatcher

Species	People	Dogs	ORVs
Pied oystercatcher	●●●●	●	●●●
Sooty oystercatcher	●●●●	●●●	●

● <20%; ●● 20-30%; ●●● 31-40%; ●●●● 41-50%

(Figure 5), and as air temperature and wind speed increased (Figure 6). The percentage of pied oystercatchers foraging increased when people were present (Figure 7.A) and was highest when air temperature was between 10-19 degrees (Figure 8.A) and wind speed between 20-29 km/h (Figure 8.B). Sooty foraging generally increased as wind speed increased (Figure 8.A, Figure 9). The percentage of pied oystercatchers foraging was found to be significantly correlated to the number of people, air temperature and wind speed (GLMM Model 1: 'people', p = 0.01; 'air temperature', p = 0.02; 'wind speed', p = 0.00; Table 8). The percentage of sooty oystercatchers foraging was only significantly correlated wind speed (GLMM Model 2: 'wind speed', p = 0.03; Table 4). Neither pied or sooty oystercatcher foraging was found to be correlated with the number of dogs or ORVs.

Figure 5: The proportion of pied oystercatchers foraging ser survey against the proportion of people

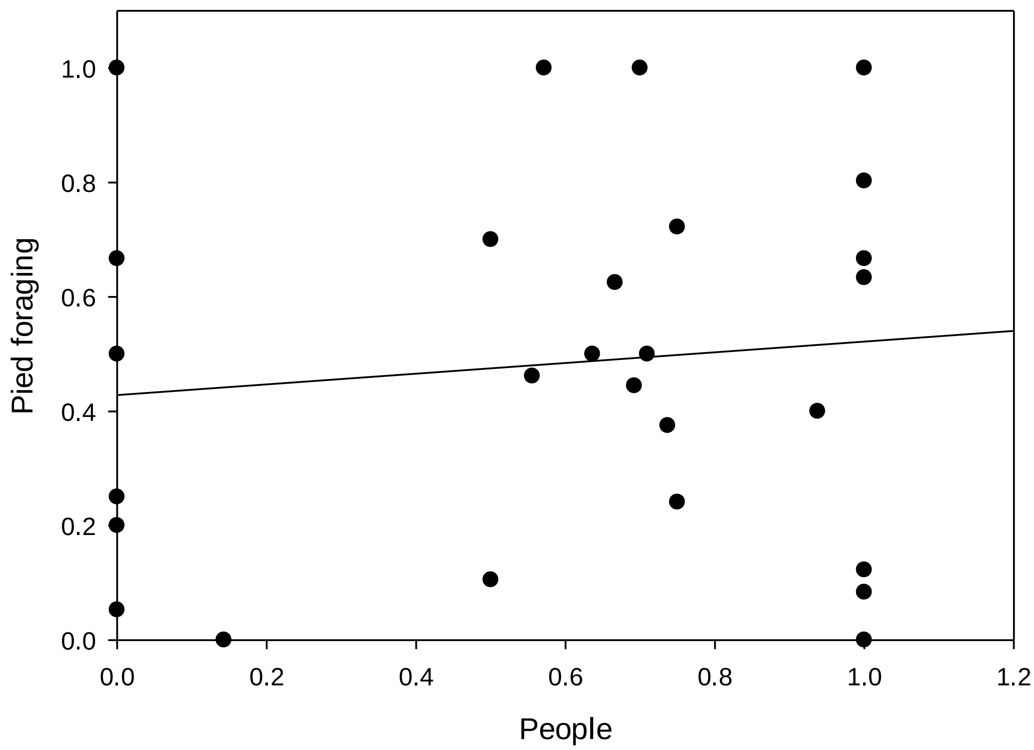

Figure 6: The proportion of pied oystercatchers foraging ser survey plotted against (A) air temperature (°C) and (B) wind speed (km/h)

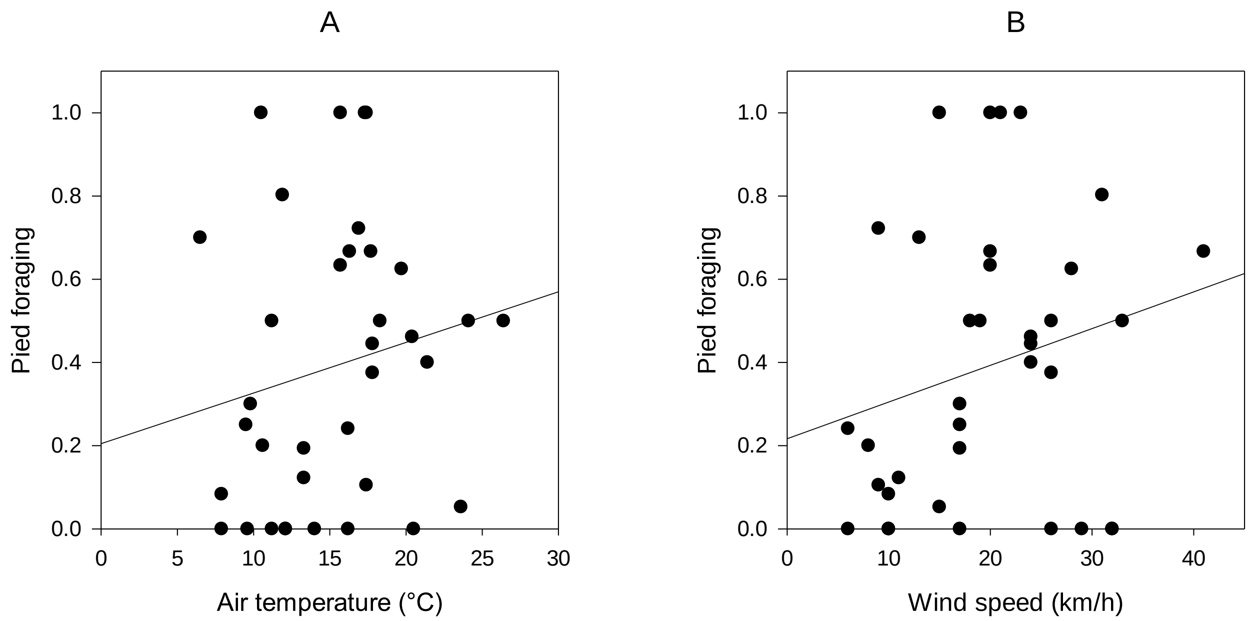

Figure 7: Percentage of pied and sooty oystercatchers foraging (mean ± SE) in relation to (A) the presence of people (absent, present) and (B) the presence of dogs (absent, present)

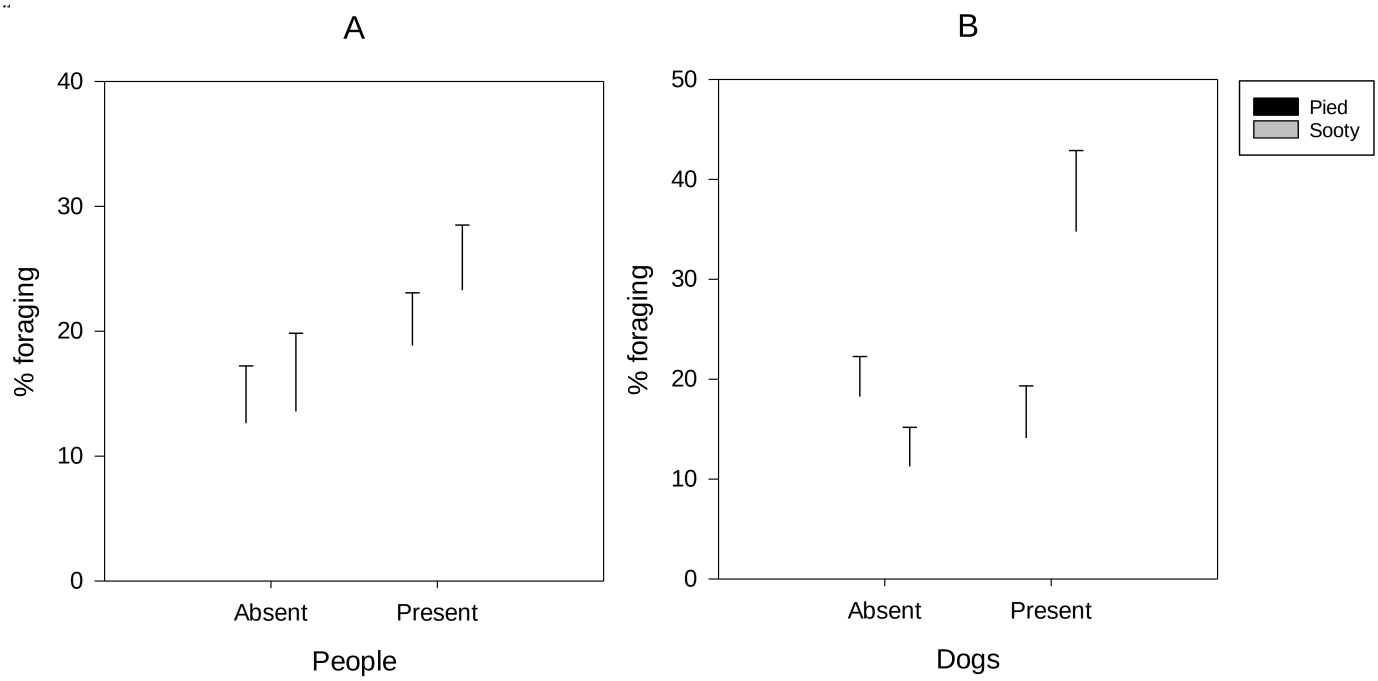

Figure 8: Percentage of pied and sooty oystercatchers foraging (mean ± SE) in relation to (A) wind speed (km/hr) and (B) air temperature (°C)

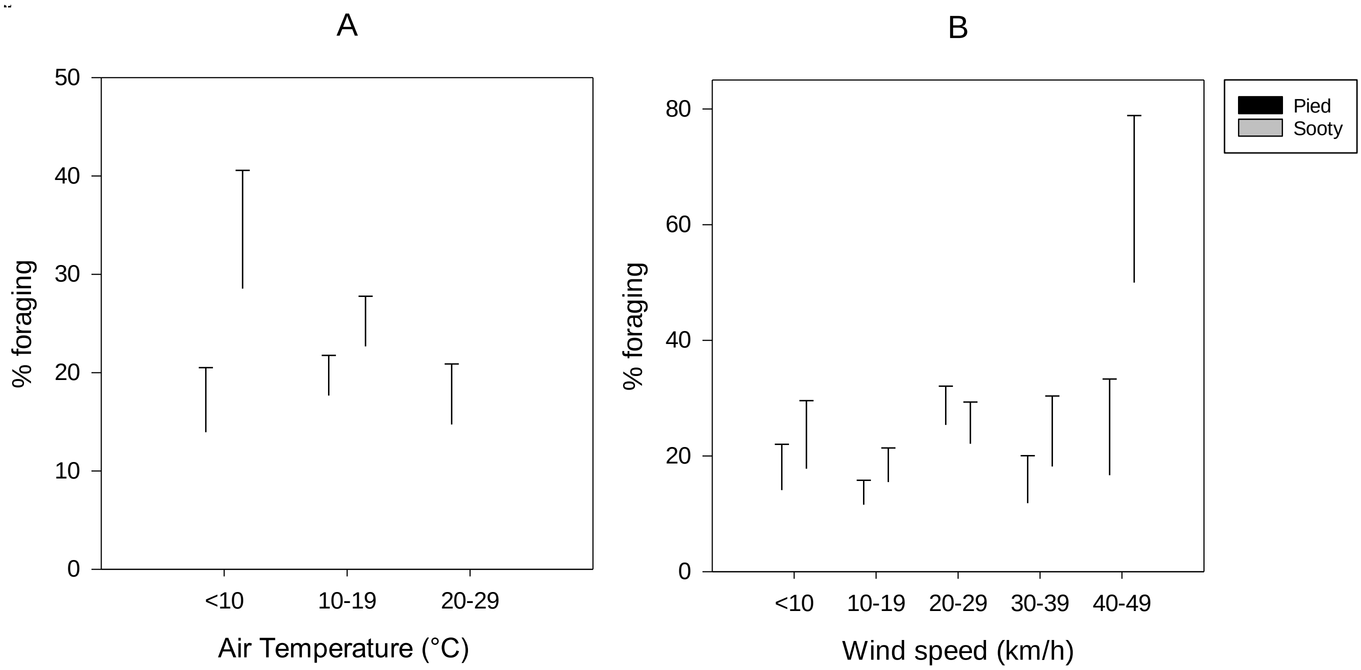

Figure 9: The proportion of sooty oystercatchers foraging ser survey plotted against wind speed (km/h)

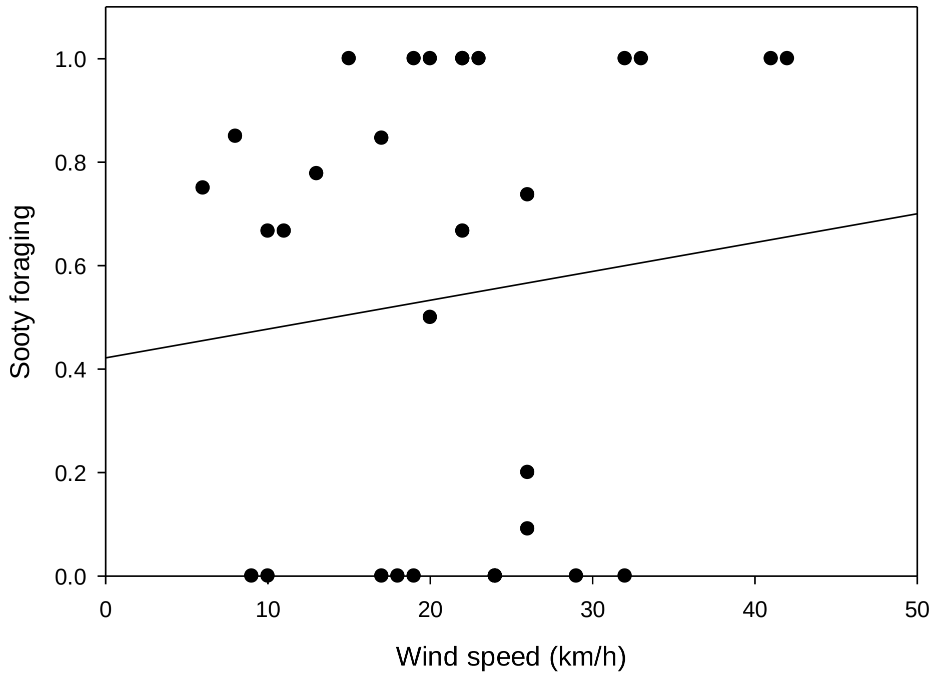

Table 8: Output table from the generalised linear mixed models assessing the percentage of foraging pied and sooty oystercatchers in response to human activity and environmental conditions

Fixed Factors	Estimate	Standard Error	z-value	P-value
Model 5: % Pied Foraging (n=84)				
(Intercept)	3.53	0.54	6.56	**0.00*****
People	0.06	0.02	2.68	**0.01****
Air Temperature	-0.08	0.04	-2.25	**0.02***
Wind Speed	0.06	0.01	6.15	**0.00**
Model 6: % Sooty Foraging (n=84)				
(Intercept)	3.72	0.65	5.74	**0.00*****
People	-0.03	0.02	-1.55	0.12
Air Temperature	0.01	0.04	0.32	0.75
Wind Speed	0.02	0.01	2.18	**0.03***
Model 7: % Pied Foraging (n=84)				
(Intercept)	2.90	0.47	6.23	**0.00*****
Dogs	0.11	0.14	0.77	0.44
ORVs	-0.04	0.03	-1.38	0.17
Air Temperature	-0.02	0.02	-0.67	0.50
Wind Speed	0.05	0.01	5.74	**0.00*****
Model 8: % Sooty Foraging (n=84)				
(Intercept)	3.34	0.60	5.57	**0.00*****
Dogs	0.07	0.05	1.39	0.16
ORVs	-0.08	0.06	-1.36	0.17
Air Temperature	0.04	0.04	0.86	0.39
Wind Speed	0.02	0.01	1.39	0.17

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘ ’

4.0 DISCUSSION

Human activities as a disturbance has been found to adversely affect shorebirds at sandy beaches, by altering abundance and altering foraging behaviour (Burger et al., 2010, Burger, 1981, Coleman et al., 2003, Defeo et al., 2009, Rodgers and Schwikert, 2003, Stillman and Goss-Custard, 2002, Thomas et al., 2003, Verhulst et al., 2001). In this study, we found that abundance and foraging behaviour of pied and sooty oystercatcher was not correlated with the same human activities and that foraging behaviour did not necessarily decrease with greater levels of human disturbance. These results suggest that oystercatcher abundance and foraging behaviour has the potential to be impacted by some human related disturbances, but some activities may be correlated and not act as a disturbance or have a neutral/positive impact.

Disturbances by people is a common human activity that can alter the abundance and behaviour of foraging and roosting shorebirds on sandy beaches (Burger, 1991, Burger and Gochfeld, 1991, Lunardi and Macedo, 2014, Ramli and Norazlimi, 2017, Schlacher et al., 2013, Verhulst et al., 2001, Yasué, 2005). However, there may be some cases where people - specifically recreational fishers - being present at shorebird foraging sites can have a non-negative impact (Ferns et al., 2000, Lunardi and Macedo, 2014). In this study we found that pied oystercatcher abundance did not show any correlation to human disturbance activities, and that pied oystercatcher foraging was positively correlated with people. The lack of correlation between abundance and human disturbances could indicate that oystercatchers do not recognise human activity as disturbance stimuli, especially if the perceived value of a resource (i.e., the feeding/roosting location) is high despite there being a potential risk of disturbance (Glover et al., 2011, Yasué, 2005). Another possible explanation is that pied oystercatchers are habituated to human activities. Habituation generally occurs in situations where individuals are exposed to repeated disturbances that are non-lethal, where individuals will then lower the fitness costs incurred by their response (e.g. by not flushing or spending less time in vigilance) (Glover et al., 2011, Schlacher et al., 2013, Whittaker and Knight, 1998). Due to the large sandy beach habitat available and used by the pied oystercatchers and the frequent human activities occurring along the beaches, these activities may not be viewed as a threat and therefore not correlated with abundance along these beaches. The positive correlation found between people and pied oystercatcher foraging could potentially be explained by the recreational cockle fishers that were often observed at Middleton and Goolwa beach, which contributed to the numbers of people present on beaches. If cockle fishers were accounting for high proportions of people on the beach during oystercatcher foraging, this could be a sign that birds do not recognise fishers as a potential threat and may be more concerned with optimising their energy use to utilise plentiful food sources, rather than spending time in vigilance and decreasing the time spent foraging (Lafferty, 2001a, Ramli and Norazlimi, 2017). Oystercatchers could be using cockle fishers as an indicator for foraging sites with abundance prey items or following or scavenging undersized cockles that have been left behind by the cockle fishers. This would require further investigation into possible competition between people and oystercatchers for cockles, and the potential oystercatcher- fisher relationships. This kind of relationship has been found for shorebirds at a study site in north-eastern Brazil, where intertidal areas where sediment was being overturned by shellfishers had higher rates of shorebird foraging (Lunardi and Macedo, 2014). Lunardi and Macedo (2014) suggested that these shorebirds' foraging strategy could be taking advantage of human shellfishing.

In shorebirds, there has been evidence of changes in abundance and modified behavioural responses in areas that receive frequent visits by people and dogs (Coleman et al., 2003, Fitzpatrick and Bouchez, 2010, Lafferty, 2001a, Ramli and Norazlimi, 2017, Schlacher et al., 2013). This could be the result of learning by shorebirds, and therefore, signs of habituation (Glover et al., 2011). In this study, we found that sooty oystercatcher abundance decreased when people and dogs were present, however there was no correlation between sooty oystercatcher foraging behaviour and human disturbances. The presence of dogs as a human related disturbance at crucial shorebird habitats can cause the greatest negative impact to shorebirds, whether they are on a leash or unleashed. Many studies have found that shorebirds and other bird species will respond to dogs as a greater threat (i.e by flushing sooner and reducing foraging time) than people walking without a dog (Lord et al., 2001, Miller et al., 2001, Ramli and Norazlimi, 2017). Sooty oystercatchers were also seen less frequently compared to pied oystercatchers, often in smaller groups. Group size has often been associated with disturbance response, where larger flock sizes will have increased feeding rates (Yasué, 2005). This is usually a result of individual birds spending less time in vigilance to scan for threats since there are more individuals present in the flock to identify a threat, compared to how frequently they would scan in smaller groups (Barnard, 1980). Lower numbers of smaller groups of sooty oystercatchers could therefore been more prone to human disturbances if they were spending more time in vigilance due to the smaller groups size, and reducing their overall abundance by dispersing from sites with human disturbances. Gill et al. (2001) has suggested that human disturbances may not have population consequences if the availability of suitable alternative habitats outweighs the fitness cost of a disturbance. The lack of correlation between sooty foraging behaviour and human disturbances could indicate that the birds are utilising multiple foraging sites and move freely between roosting and foraging locations to avoid high levels of human disturbances. Similar to the pied oystercatchers, there may be habituation that has occurred between sooty oystercatchers and human activities when foraging on beaches with disturbances, however we cannot conclusively draw these claims from our study. This would require more research into specific foraging/vigilance responses to human activities, such as flush distance, time spent foraging/in vigilance, and the duration of disturbance.

The differences in factors correlated with abundance of pied and sooty oystercatchers could be attributed to variation in site use by each species, and the differences in human activities occurring at those sites. Pied oystercatchers accounted for most bird observations during each survey and were often seen in large groups (particularly at Goolwa beach and the Murray Mouth), spread out across a large area (i.e. closer to the shoreline when foraging and higher up the beach when resting). Despite almost all surveys having human disturbances present, pied oystercatcher abundance was not found to be significantly correlated with human disturbance activities. Sooty oystercatchers instead were seen in lower numbers compared to pied oystercatchers, often at Middleton beach sites. The Middleton beach sites had high densities of people and dogs present on the beach, especially during the summer months, and surfers would walk through the rocks to get to the water causing the oystercatchers to flush temporarily. Sooty oystercatchers were also often observed roosting and foraging at site 10, where the main disturbances were people and dogs. These observations were reflected by the results showing a significant correlation of people and dogs to sooty oystercatcher abundance.

Air temperature and wind speed were also found to correlate with oystercatcher foraging behaviour. Foraging behaviour of shorebirds can be affected by air temperature and wind speed, particularly when excessively high wind speeds or low air temperatures affect prey distribution as well as foraging behaviour (Burger, 1991, Goss-Custard, 1969, Smith, 1975). Our results found that the proportion of pied oystercatchers foraging increased as air temperature and wind speed increased, and that sooty oystercatcher foraging increased as wind speed increased. Foraging increasing with increasing air temperatures was not unexpected (Davidson, 1981), however it was assumed that foraging would decrease with increasing wind speeds. Jones (2015) found that south-west winds during summer and autumn appeared to indirectly influence the presence of sooty oystercatchers, where the winds would bring sea grass (e.g. beach-cast wrack) onto the beach, which the sooty oystercatchers would flock to and forage upon the rich food resources within, such as crustaceans and molluscs (Baring et al., 2014). Similar observations were made in this study, where sooty oystercatchers would occasionally be seen foraging on accumulated seagrass as well in the sand at Middleton beach sites. It could also be that pied and sooty oystercatchers are still able to forage efficiently when there is higher wind speed, or that foraging habitat like was observed at site 10 are more protected from direct wind gusts, and that foraging birds will move to these sites on windier days. The correlations found between some oystercatcher species highlight that there are multiple factors that should be taken into account when trying to access changes in the abundance and foraging behaviour of shorebird species, even at beaches where human activities are present and may be assumed to be the predominant agent of disturbance.

5.0 CONCLUSION

This study has indicated that various human disturbance activities can correlate with abundance and foraging behaviour of pied and sooty oystercatchers at sites along the south-eastern Fleurieu Peninsula. The correlation between human activities and environmental factors to behaviour and numbers varied between species and the type of disturbance. While this study cannot specifically identify what is influencing the oystercatchers, it has provided insight into the study sites and the potential for human disturbances to cause disturbances to these shorebird species that are sharing the beaches with humans. Of the human disturbances recorded, people and dogs were found to be correlated with oystercatcher abundance and foraging, but the extent to which is still unknown. Further efforts should be taken into understanding the specific responses made by foraging oystercatchers to human disturbances, and also seek to understand if there is an interaction between cockle fishers and oystercatchers at their specific foraging sites. This could be done by spending more time monitoring the time it takes for oystercatchers show a disturbance response, the duration of human disturbances, and the foraging success of oystercatchers when people are present and not present. Understanding this possible interaction between oystercatchers and recreational fishing and other human activities along beaches would also be useful in future regulations and management of dogs and cockle fishers on beaches, and to avoid major disturbances to these important shorebird species that rely on sandy beach habitats as foraging areas and breeding sites. This information is also more critical to determine, particularly if pied oystercatchers in South Australia continue to decline and need to be considered for protection status.

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APPENDIX A

Table 1: Percentage frequency of occurrence of human activity disturbances during abundance counts at 10 sandy beach sites, for the pied and sooty oystercatcher

Species	People	Dogs	ORVs
Pied oystercatcher	47.06%	20.59%	32.35%
Sooty oystercatcher	50.00%	22.22%	27.78%

Table 2: Percentage frequency of occurrence of human activity disturbances during foraging observations at 10 sandy beach sites, for the pied and sooty oystercatcher

Species	People	Dogs	ORVs
Pied oystercatcher	46.34%	19.51%	34.15%
Sooty oystercatcher	48.48%	36.36%	15.15%

Model output for ORVs and environmental conditions at site 6-9

Fixed Factors	Estimate	Standard Error	z-value	P-value
Model 1: Total pied (n=35)				
Intercept	1.85	1.86	1.00	0.32
ORVs	0.13	0.15	0.83	0.41
Air temperature	0.05	0.09	0.61	0.54
Wind speed	-0.08	0.11	-0.71	0.48
Model 2: Total sooty (n=35)				
Intercept	-0.06	2.62	-0.02	0.98
ORVs	0.02	0.21	0.12	0.91
Air temperature	0.05	0.15	0.31	0.75
Wind speed	-0.03	0.13	-0.26	0.82
Model 3: Pied foraging (n=63)				
(Intercept)	2.75	0.44	6.28	0.00
ORVs	-0.02	0.02	-0.90	0.37
Air Temperature	-0.01	0.02	-0.61	0.54
Wind Speed	0.05	0.01	6.14	0.00

Model 4: Sooty foraging (n=63)				
(Intercept)	1.60	1.13	1.41	0.16
ORVs	-0.10	0.08	-1.24	0.21
Air Temperature	0.15	0.95	1.62	0.11
Wind Speed	0.01	0.03	0.39	0.70

Cockle samples were recorded during each foraging survey for additional information that was not presented in this paper. Methods as follows.

Cockle sampling methods:

Cockle (P. deltoids) sampling was done using a time-based hand-digging technique adapted from Gray et al. (2014). Cockles sampled were taken at sites 3, 7 and 10 after behavioural observations are completed. Sand from a randomly selected area along the shoreline (approximately $0.1m^2$) was continuously scooped using a small handheld shovel into a net for 20 seconds. The net was then rinsed to remove sand and the cockles collected in the net were counted and categorised based on size (<10 mm, 11<35 mm or >35 mm). These steps were repeated two more times, so that there were three cockle sample replicates per site. This method is only relevant to the second aim of this project.

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APPENDIX B

Impacts of human disturbances on the foraging behaviour of shorebirds and waterbirds

Abstract:

The foraging grounds of shorebirds and waterbirds are often frequented by human activity. This often results in birds being subjected to disturbances by humans that has the potential to impact foraging behaviour. This review discusses finding from various studies on how human disturbances can alter the foraging behaviour of both shorebirds and waterbirds at beach, estuarine, and wetland habitats. Presence of humans at foraging sites was the most common human disturbance discussed but would elicit differing degrees of altered foraging behaviour depending on a variety of factors (i.e., species, habitat use, frequency of disturbance, fitness payoff). Off-road vehicles and boats also heavily impacted flushing and vigilance of foraging shorebirds on sandy beaches, and waterbirds at wetland habitats within close proximity to roads. Understanding the interactions between humans and birds at their foraging sites is extremely important for conservation and management efforts at locations heavily used by humans and birds. Shorebirds and waterbirds are highly susceptible to changes in their environments and human disturbances could impact the fitness of individuals and have wider implications to species and populations.

Introduction:

Environments such as sandy beaches, estuaries and wetlands are increasingly subjected to human disturbances due to the economic services and recreational activities they provide to humans (Defeo et al. 2009). Increased human activity and subsequent disturbances have caused substantial temporal and spatial overlap between humans and coastal or waterbird species with human activity taking place within close proximity to critical foraging and breeding habitats (Hill et al. 1997; Lafferty 2001; Priest, Straw, & Weston 2002; Glover et al. 2011; Schlacher et al. 2013; Ramli & Norazlimi 2017; Goss-Custard et al. 2019). Shorebirds are generally coastal bird species that forage on beaches and intertidal mudflats during low tide but may nest in other adjacent habitats such as dunes or parklands (Ramli & Norazlimi 2017). Waterbird, however, refers to bird species that rely entirely on wetlands for all aspect of their life history including foraging, nesting, loafing and moulting (Rajpar & Zakaria 2010; Ramli & Norazlimi 2017).

A disturbance is defined as a stimulus that elicits a change in behaviour and/or physiological in animals (Schlacher et al. 2013). Human disturbances are therefore disturbances caused by human activity that alters the regular behaviour of animals. This literature review aims to investigate how human disturbances can alter the foraging behaviour of shorebirds and waterbirds. Specifically, how foraging birds respond to disturbances such as human presence and recreational activities (i.e., driving motorised vehicles), and the implications and impacts these disturbances may have on the survival and reproduction of birds. Disturbance to foraging birds can result in decreased foraging rates, shifts in feeding times, decreased food intake and displacement or population shifts to foraging sites that are less impacted (Defeo et al. 2009). This can have negative consequences for the reproduction and fitness of birds that may already be stressed due to anthropogenic impacts such as habitat loss, pollution, and competition for resources (Borgmann 2011). It is important to understand how human activities are impacting the behaviour of shorebirds and waterbirds as they are sensitive to changes in their environments and are therefore highly susceptible to disturbances (Burger, 1981; Pfister et al. 1992; Hill et al. 1997; Verhulst et al. 2001; Stolen 2003; Defeo et al. 2009; Glover et al. 2011). They are also critical components of estuarine mudflats, sandy beaches, and wetlands habitats, playing key roles in food webs and contributing to ecosystem functioning (Burger 1991; Schlacher et al. 2007; Defeo et al. 2009; Ramli & Norazlimi 2017). This review focuses on foraging behaviour as foraging grounds of shorebirds and waterbirds often overlap with human activities such as walking or driving on beaches. Understanding these interactions between foraging birds and human disturbances can assist with conservation and management guidelines of recreational habitat use, particularly at sites where birds species are of concern or in decline.

Human presence:

The presence of humans at foraging grounds is the most significant and common human disturbance to foraging birds. Numerous studies have found that people being present at foraging sites increases vigilance of shorebirds and waterbirds and decreases the overall time spent foraging (Burger 1991; Burger & Gochfeld 1998; Fitzpatrick & Bouchez 1998; Verhulst et al. 2001; Burger et al. 2004; Borgmann 2011; Schlacher et al. 2013; Yasué 2005; Ramli & Norazlimi 2017). These studied showed it was common for foraging birds to alter their behaviour in response to human presence to vigilance, walking away, or flushing. For example, Ramli and Norazlimi (2017) found that human presence contributed to 47.5% of disturbance events in the seven shorebird species they studied, where individuals would either halt feeding (totalling 81% of responses), or flush to another area. Also, human presence at mudflats has resulted in European oystercatchers (Haematopus ostralegus) reducing time spent foraging and attending nests (Verhulst et al. 2001). However, Verhulst et al. (2001) noted that presence of people is not common at their study site, therefore the reduced foraging time observed may have been stronger than if human presence was frequent. At a similar mudflat habitat, Trulio and Sokale (2008) found there was no relationship between the number of people present using recreational trails around the site and the proportion of birds foraging. However, 25% fewer shorebirds were detected near trails during days with increased amounts of people relative to non-trail sites (Trulio & Sokale 2008). In the absence of people, foraging piping plovers (Charadrius melodus) usually devote time to feeding, vigilance, and defending foraging territories (Burger 1991). With the presence of people on their foraging grounds, plovers allocated additional time to scan for people which increased as the number of people increased (Burger 1991). While increased vigilance would usually be beneficial to birds, aiding in predator avoidance, in this case it is reducing time that could be spent foraging since humans are not aiming to intentionally harm individuals.

The response of an individual bird to human presence can vary between species. Flush distance in response to human presence during foraging is often species specific (Borgmann 2011). For example, 72% of dabbling ducks responded by flushing due to approaching pedestrians when they were within 50 m (Pease, Rose & Butler 2005). Additionally, waterbirds at foraging grounds, both with walking trails and no trails, kept 170-200 m from observers and general pedestrians (Trulio & White 2017).

Compared to waterbirds, shorebirds allowed for human to approach them at closer distances (smaller flush distance) (Rodgers & Smith 1997). Of the six shorebird species studied by Schlacher et al. (2013), crested terns (Thalasseus bergii) showed the most significant response to human presence, with 42% of time spent alert and 12% of their time escaping human stimuli. There was also a clear separation between terns and other shorebirds in their behavioural response, which was contributed to their different strategies in habitat use; terns using the sandy beach to preen between foraging bouts in the surf-zone, while gull species foraged on the sandy intertidal zone. Since terns used the beach to preen rather than directly forage, they may not be exposed to frequent human presence in the same way an oystercatcher would be on their sandy beach foraging grounds where people can walk straight through. Therefore, the terns may have responded strongly to human presence at the sandy beach site (Schlacher et al. 2013). In another example of species specific responses, Ramli and Norazlimi (2017) noted that larger solitary species such as the Great egret (Ardea alba) responded by flying away when humans were within 10 m of them, but smaller flocking birds, such as the Common redshank (Tringa tetanus) or Lesser sand plover (Chardrius mongolus), were more likely to run away when an approaching human is within 1 m (Ramli and Norazlimi 2017). Thomas, Kvitek and Bretz (2003) found that 96% of foraging Sanderlings on sandy beach sites responded to human presence at 30 m or less, while Evans and Roberts (1993) reported an average flush distance of 12 m. Some authors have suggested that variation in response distances could be a result of cryptic plumage where birds rely on cryptic colouration and delayed response time to avoid predators (Fitzpatrick & Bouchez 1998; Lafferty 2001), but response distances could also rely on the costs of frequently avoiding people, which may outweigh the more direct costs of disturbance to the individual (Van Der Kohl et al. 2021).

The extent to which foraging birds respond to human presence can also be influenced by factors such as seasonality, time of day, substrate, weather conditions, reproductive stage, flock and brood size, along with the amount of people nearby causing the disturbance (Burger et al. 1991; Yasué 2005; Peters and Otis 2005; Goss-Custard et al. 2020). For example, the foraging rates of Least sandpipers (Calidris minutilla) decreased with increasing flock size and the number of people present while foraging, despite feeding rate usually increasing as flock size increases (Yasué 2005). Increased feeding rates in large flocks is usually a result of individual birds spending less time in vigilance to scan for threats since there are so many individuals present to identify a threat, compared to how frequently they would scan in smaller groups (Barnard 1980). The rates of people at coastal areas and wetlands are typically higher during weekends and public holidays compared to weekdays (Glover et al. 2011; Goss-Custard et al. 2020). Stillman and Goss-Custard (2002) found that Eurasian oystercatchers (Haematopus ostralegus) were less likely to respond to people at their foraging sites later in winter when lost feeding time would be more costly and foraging conditions less favourable, even though human activity on beaches is expected to be reduced during winter. At estuaries, overlap of foraging shorebirds and humans can be limited by substrate type, where people may be present in greater numbers but avoid the muddy upper and middle reaches of coastlines where birds are foraging (Goss-Custard et al. 2020). However, spatial separation of shorebirds along estuary shorelines could be explained by birds actively avoiding highly disturbed areas. This is difficult to analyse without extensive records of bird populations numbers, species, records, population distribution across a habitat and knowledge of human activities/disturbances that have taken place in the area. Without these, it is almost impossible to know whether species have been impacted in the past or what 'normal' bird behaviour was like prior to extensive human disturbances.

Vehicle use (off-road vehicles and boats):

Vehicle use near or on foraging sites can be extremely destructive, causing disruptions to foraging behaviour and, in some cases, incidents of collisions (Defeo et al. 2009; Meager et al. 2012; Schlacher et al. 2013; Schlacher et al. 2014; Weston et al. 2014). Further, increasing demands on beaches for recreation can result in heavy and inappropriate vehicle use, which can cause displacement of birds from their preferred foraging sites (Schlacher et al. 2007; Schlacher et al. 2013; Weston et al. 2014). Weston et al. (2014) note that even when vehicle drivers took evasive action towards shorebirds, birds were disturbed at the same rates and intensities compared to when vehicles did not change their direction or speed. Schlacher et al. (2013) found that disturbance via vehicle was the most common human related disturbance encountered by shorebirds, which was to be expected since their study site is a common tourist destination for driving along beaches. Within 3 minutes of beginning observation, shorebirds would take flight in response to a vehicle driving on a beach (Schlacher et al. 2013). Also, flushing is the most noted behavioural response by waterbirds either foraging, roosting, or nesting, to off-road vehicles (McGowan & Simons 2006; Schlacher et al. 2013).

As with human presence, the location of foraging along the intertidal gradient often determines susceptibility to vehicles (Schlacher et al. 2013; Weston et al. 2014). For example, terns were more likely to take flight in response to off-road vehicles than oystercatchers and showed more intense responses (Weston et al. 2014), which can be attributed to differences in habitat use since terns 'migrate' up and down the beach-face between foraging and roosting (Schlacher et al. 2013). Oystercatchers and gull species primarily forage along the swash line, placing them in the direct path of vehicle traffic and increasing their likelihood of being disturbed or crushed by vehicles. Foraging wading birds such as the Snowy egret (Egretta thula), Great egret (Ardea alba) and Tricolored heron (Egretta trcolor) were also disturbed when vehicles slowed or stopped adjacent to them compared to when vehicles continued driving at a constant speed, with some species flushing or responding stronger to the vehicle disturbance than others (Stolen 2003). However, in the study by Stolen (2003) nearly half of the observations for foraging wading birds showed no response to the arrival of an observer or passing of a vehicle, suggesting that birds at this wetland site are habituated to vehicles and people. Similar flushing behaviour by waterbirds was observed by Rodgers and Smith (1997) in response to approaching vehicles, and it was recommended that 100 m buffer zones could be established in wetland areas for birds to forage and move away from vehicle disturbance.

While boats may not be as destructive as off-road vehicles that can drive directly through foraging sites, noise from motorized boats and boat approaches can still have impacts towards foraging waterbirds (Ronconi & Clair 2002; Ramli & Norazlimi 2017). Flushing in response to boat traffic is frequently observed in many species and can be influenced by boat characteristics such as approach distance, speed, and type (Pierce et al. 1993; Rodgers & Smith 1997; Burger 1998; Ronconi & Clair 2002; Ramli & Norazlimi 2017). Rodgers and Schwikert (2002) measured flush distance in response to non-motorised watercraft and motorised vehicles to foraging waterbirds and found that larger species flushed at greater distances to vehicles compared to smaller species. However, 11 of 16 waterbird species did not show a difference in flush distance between boat types (Rodgers & Schwikert 2002). Larger species flushing at greater distances could be attributed to larger birds needing more space to take off compared to smaller species. Ronconi and Clair (2002) found that Black guillemots (Cepphus grylle) were more likely to flush in response to boat disturbance as their distance from shore increased (~260 m distance from approaching boats) but this behaviour increased disproportionately when boats approached closer (~100 m). Other studies instead found that shorebirds typically flush only when boats are within 100 m (Pierce et al. 1993; Rodgers & Smith 1997). Peters and Otis (2005) found that Oystercatchers increased vigilant behaviour while foraging in response to increased boat activity, however there was no reduction of foraging time. Thus, while boat approaches can alter flushing and vigilance in foraging waterbirds, behavioural change is also dependent on species and the approach distance of boats to foraging grounds.

Implications and consequences of human disturbances on foraging behaviour:

Human disturbances to foraging shorebird and waterbirds can have detrimental consequences for fitness by modifying key behavioural traits that are crucial for survival and reproduction (Defeo et al. 2009; Verhulst et al. 2001). As discussed above, human disturbances to foraging birds can alter the time spent devoted to foraging (Burger 1991; Burger & Gochfeld 1998; Fitzpatrick & Bouchez 1998; Verhulst et al. 2001; Burger et al. 2004; Borgmann 2011; Schlacher et al. 2013; Yasué 2005; Ramli & Norazlimi 2017), as well as shift feeding times or location, and decrease food intake (Defeo et al. 2009; Verhulst et al. 2001). Long-term responses to altered foraging behaviour can include decreased parental care and decreased nesting or roosting densities, resulting in increased exposure and vulnerability of chicks and individuals to predators, and population shifts to sites that are less impacted by recreational activities (Defeo et al. 2009; Borgmann 2011). Decreased nest attendance reduces the proportion of time spent incubating eggs which can lead to altered densities of breeding birds and decreased reproductive output if levels of disturbance are maintained for a long period of time (Verhulst et al. 2001). For breeding Piping Plover's, their habitats are restricted to 100 m of coastal surf along their foraging territory rather than moving freely along a beach like many other shorebirds. People invading this territory can cause shifts in normal habitat use and decreases in foraging time, which is detrimental to the foraging success of both adults and chicks (Burger 1991). For plovers, brood size can be heavily impacted as it was found that larger brood sizes devoted less time to foraging, which could impact the survival of chicks (Burger 1991). For their size, shorebirds have high energy demands. This requires high rates of food intake in order to survive and successfully migrate to breeding grounds, as well as perform other essential activities such as grooming, parental care, and evading predators (Urfi et al. 1996). Displacement of shorebirds to foraging grounds that are less disturbed than where they would usually forage may not have suitable food sources in high abundances to meet their high energetic needs. High energy demands may also be linked to the nature of coastal terrains being very exposed to deleterious weather conditions, which can result in rapid mobilization of energy reserves (Kersten & Piersma 1987; Urfi et al. 1996).

The degree to which foraging birds are impacted by human disturbances could be attributed to the perceived threat of predation risk, and the cost of the response (Stillman & Goss-Custard 2002; West et al. 2002; Yasue 2006). Energetically stressed shorebirds respond less to human disturbance when the fitness cost of responding to the disturbance is greater than not responding (Stillman & Goss-Custard 2002; Beale & Monaghan 2004; Yasue 2006). It is thought that birds at disturbed sites will perceive humans as a “non-lethal” predation risk (Peters and Otis 2005), and birds that flush in response to disturbance may or may not return to their original foraging site depending on how great of a threat the human disturbance poses. Birds can become habituated by humans to disturbances. This relies on predictable patterns of human activity which birds can learn to recognize and not perceive as a threat (Fitzpatrick & Bouchez 1998). Recreational activities may have a greater disturbance effect if birds are not as habituated to vehicles at those sites (Stolen 2003). Ramli and Norazlimi (2017) found that habituation occurred when foraging birds showed no response to disturbances, despite humans being within close proximity, where other species or individuals had shown previous behaviour changes or avoidance. Numerous small disturbances can also be more damaging than fewer, larger disturbances (West et al. 2002). For example, constant small disturbances over a large area (i.e. such as people digging for bait or carefully walking through a habitat) leaves fewer patches for birds to move to if they are constantly being disturbed during foraging, as opposed to one large infrequent disturbance (i.e. such as a noisy fishing boat or water-ski) that may only impact birds in a smaller area (West et al. 2002).

Summary and conclusion:

Human disturbance at foraging sites does impact the foraging behaviour of shorebirds and waterbirds. However, the degree to which individuals respond to disturbances depends on many factors, such as species, the bird’s habitat uses, the frequency of disturbance and the pay off between fitness cost and altered behaviour. Flushing and increased vigilance were the most frequent behavioural changes seen in the studies discussed as a response to various human disturbances, although it is important to consider that birds who show increased vigilance and frequent flushing behaviour may not be the individuals that are most severely impacted by human disturbance. For example, species such as oystercatchers that may be habituated to the presence of people on their foraging grounds may still show signs of altered behaviour as a response to humans. However, they may be impacted less overall in the long term compared to a shorebird species that is no longer using a site because they have been so heavily impacted by human activities and have completely abandoned usual foraging sites. While the response of shorebirds and waterbirds to human disturbances has become well documented since the early 2000s, there still appears to be many species and habitats that have not been studied to an equal degree, particularly in Australia. There are also very few studies that have considered bait collecting or fishing as a direct competition for resources and a factor that may be altering foraging behaviour through means of food availability. Instead, studies have quantified fishing as a human presence disturbance (Urfi et al. 1996). The use of behavioural based models to assess the fitness impacts of human disturbance to foraging behaviour have also become increasing utilised (West et al. 2002, Yasue 2006). However, they are not always applicable in habitats used by migratory shorebird due to the substantial time needed and resources required to acquire necessary data (Hill et al. 1997; Yasue 2006). This is where habitats or species that are becoming of concern for being impacted by human activity need to be well monitored so that conservation management can be implemented. Ultimately, conservation management should strive to minimize the impacts of human disturbance to fitness rather than just focusing on the severity of behavioural responses from foraging birds, since disturbances during foraging may not necessarily impact birds outside of altering behaviour.

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