AUSTRALIAN FIELD ORNITHOLOGY 2010, **27**, 94–108

A Small Coastal High-tide Roost on North Stradbroke Island, South-eastern Queensland: Diversity, Seasonality and Disturbance of Birds

PETER M. KYNE

Moreton Bay Research Station, Centre for Marine Studies, The University of Queensland, Dunwich, Queensland 4183
(Present address: Tropical Rivers and Coastal Knowledge, Charles Darwin University, Darwin, Northern Territory 0909; Email: peter.kyne@cdu.edu.au)

Summary

Weekly counts of a small high-tide roost-site in the town of Dunwich, North Stradbroke Island, south-eastern Queensland, were undertaken over a 55-week period in 2007–2008. Twenty-two species of bird were recorded utilising the roost during counts, including five species of shorebird that breed in the Arctic, four species of shorebird that breed in Australia and six species of tern. Five species contributed ~90% of counted individuals: Australian Pied Oystercatcher *Haematopus longirostris* (56%), Eastern Curlew *Numenius madagascariensis* (10%), Silver Gull *Chroicocephalus novaehollandiae* (10%), Caspian Tern *Hydroprogne caspia* (7%) and Gull-billed Tern *Gelochelidon nilotica* (6%). Small shorebird species were largely absent from the site. During the study period, species richness and species diversity were highest in winter and spring and lowest in summer and autumn. Peak counts of Australian Pied Oystercatcher indicate that this is an internationally important site for that species. Less than one fifth (18.5%) of counts were disturbed by natural stimuli (raptors), whereas nearly half (48.1%) were disturbed by human stimuli. The highest proportion of human disturbances was from people walking unleashed dogs (44% of recorded encounters). Management recommendations to minimise disturbance to this site include educating the community and local government on the value of the site as an important wildlife area, and enforcing existing state and local regulations designed to minimise disturbance to shorebirds and to manage dogs.

Introduction

Moreton Bay in south-eastern Queensland is an internationally important site for migratory shorebirds that breed in the Arctic (Thompson 1990, 1993; EPA 2005); its large size, location on the East Asian–Australasian Flyway, and the availability of considerable areas of feeding habitat and safe roosting locations all contribute to its importance. There are 112 identified high-tide roosts in Moreton Bay (EPA 2005) and these are used year-round, by migratory species during the austral summer months, by Arctic-breeding species remaining in their non-breeding grounds over the austral winter, and by resident Australian shorebirds and other migratory and resident waterbird species (including terns) (Thompson 1990, 1993, 1998; EPA 2005; Chan & Dening 2007). The available roost-sites in Moreton Bay vary considerably in size and in the number of birds frequenting them. Although attention is often paid to larger sites, smaller roosts (small in terms of both area available for roosting, and in number of birds utilising the site) may be locally important if they are close to substantial feeding areas (intertidal areas for shorebirds, open water for seabirds) or if there is a lack of other suitable roost-sites nearby. Small roosts add to the cumulative area available for roosting birds and provide a network of sites at the landscape scale.

Where high-tide roosts occur within urban environments or overlap with recreationally popular areas, disturbance may be high, which can limit the suitability of a site (Smit & Visser 1993; Rogers 2003; Rogers *et al.* 2006; Chan & Dening 2007). Moreton Bay's shorebird habitats are under the management of the Moreton Bay Marine Park, declared in 1993 and rezoned in 2009 to provide greater levels of conservation protection. The boundaries of the marine park extend to the highest tideline, and regulations exist for the minimisation of disturbance by people, dogs and boats (EPA 2005). Enforcement is often lacking (pers. obs.), however, and smaller roosts may not receive any direct management for the conservation of roosting species. Therefore, in the case of small local roost-sites, raising public awareness can effectively contribute to reducing disturbance of the birds and thus improve the suitability of the site, as has been demonstrated by the success of management campaigns at important shorebird habitats elsewhere (e.g. Burger *et al.* 2004).

Dunwich, a small town (population ~900) on North Stradbroke Island, ~40 km east of Brisbane city in eastern Moreton Bay, supports a small high-tide roost-site frequented by a variety of migratory and resident shorebirds, as well as seabirds (i.e. terns) and other waterbirds. Aspects of this site (e.g. close proximity to extensive areas of intertidal mud- and sandflats, good field of view: Rogers 2003; Zharikov & Milton 2009) suggest that it is a suitable roosting environment, but initial observations highlighted that it is also a highly disturbed location. Thus, the aims of this study were to examine temporal (seasonal) variation in shorebird and seabird use of the Dunwich high-tide roost, to document levels and sources of disturbance on roosting birds at the site, and to recommend effective management strategies to maximise the suitability of the site as roosting habitat.

Study area and methods

The high-tide roost subject to the present study is situated on a small sandspit at Bradburys Beach, Dunwich, Queensland (27°30′S, 153°24′E) (Plate 19). The town of Dunwich is located on the western side of North Stradbroke Island in eastern Moreton Bay (see Thompson 1998, EPA 2005 and Zharikov & Milton 2009 for details on the characteristics of Moreton Bay in relation to shorebird habitat and use). At low tide the roost-site is surrounded by exposed sand- and mudflats with small areas of seagrass dominated by *Zostera capricorni*. To the north is the man-made channel into One Mile Harbour terminating at One Mile public jetty and boat ramp, which receives regular boat traffic. The roost is separated from the jetty by a stretch of beach and a low rock wall. A further sandy beach extends southward of the roost. Immediately behind the roost-site (to the east) is a small shallow tidal lagoon with a patch of mangroves (primarily Grey Mangroves *Avicennia marina*), mostly on the southern side. The lagoon is connected to the Bay only on the highest tides (only on a single occasion during this study period). Behind the lagoon is a caravan and camping park. The count-site was restricted to the sandy spit and the area immediately bayside (the lagoon is rarely used as a roost-site). The same area was counted consistently across the study period.

Counts were conducted weekly, at a predetermined time (set by tidal conditions) each Monday between 9 July 2007 and 21 July 2008 (54 counts over 55 weeks). Although counts were not standardised for tide height, they were standardised for tide time; counts were conducted 1–1.5 hours prior to high tide. Counts were undertaken during daylight hours only. Unsuitable tides on 30 June 2008, and days either side, precluded a count that week. There were also unsuitable tides on 14 July 2008; instead, a count was performed on the afternoon of Sunday 13 July 2008. High-tide heights ranged from 1.51 to 2.62 m during the count period.

Each count was undertaken for a set time of 15 minutes. Counts were undertaken with a spotting scope and binoculars, with counters remaining at a distance from the roost that ensured that there was no disturbance to roosting birds from their presence. During the 15-minute count, all non-passerines present at the site, including roosting shorebirds and terns, were recorded, as also were all non-passerines that arrived at or flew over or past the

Dunwich high-tide roost at Bradburys Beach on North Stradbroke Island: looking north, with the count site on the left of the picture (the sandy spit left of the last trees), and One Mile Jetty on the right

Plate 19 Photo: Micha V. Jackson

Australian Pied Oystercatcher, Werribee Sewage Farm, Vic.

Plate 20 Photo: Micha V. Jackson

roost during the count time. However, for the analyses only birds roosting at the site were included (i.e. birds flying over or past the roost were excluded). Counts were recorded on Queensland Wader Study Group count sheets. Further opportunistic observations of the roost outside official count times during the period July 2007–July 2008 provided additional information on other non-passerine species utilising the roost (i.e. those species not recorded during the roost surveys). Counts were made for individual species.

For all counts undertaken during the study period (n = 54), the mean abundance (± Standard Error) of each species was determined by averaging the abundance per count. Mean abundance (± S.E.) of each species was also calculated for those counts that were either undisturbed or in which all birds were counted before disturbance occurred (n = 43). For the following calculations, however, only undisturbed counts or counts in which all birds were counted before disturbance were used. Total observed species richness (total number of species recorded) and species diversity (Shannon-Weiner index, $H' = -\sum p_i \ln p_i$, where p_i is the proportion of the total sample belonging to the ith species) were calculated for each season. The mean observed species richness of counts was compared between seasons using a one-way ANOVA with a *post hoc* pairwise multiple comparison procedure (Tukey Test). Data met the assumptions of normality and homogeneity of variances. To examine temporal variation in the abundance of individual species, the mean monthly abundance (± S.E.) was calculated for three species of shorebird (Australian Pied Oystercatcher *Haematopus longirostris*, Bar-tailed Godwit *Limosa lapponica*, Eastern Curlew *Numenius madagascariensis*) and four species of tern (Gull-billed Tern *Gelochelidon nilotica*, Caspian Tern *Hydroprogne caspia*, Lesser Crested Tern *Thalasseus bengalensis*, Crested Tern *T. bergii*). Austral seasons were defined as winter (Jun.–Aug.), spring (Sept.–Nov.), summer (Dec.–Feb.) and autumn (Mar.–May).

To measure disturbance, the roost-site was monitored for a period of 15 minutes before the count, during the 15-minute period of the count, and for 15 minutes after the count. Disturbance was defined as an encounter from a stimulus causing a response (non-flight or flight) in roosting birds. Terminology is modified from Weston & Elgar (2007): a stimulus was defined as any natural or human agent that had the potential to cause a response among roosting birds; an encounter was any event in which the stimuli passed within close proximity of the roost. Natural stimuli were low overflying raptors, and for each encounter the raptor species responsible was recorded. Human stimuli recorded were: walker(s) + dog (unleashed), walker(s) + dog (leashed), walker(s) only, dog only, fisher(s), bait collector, snorkellers, cyclist or vessel passing. The response of roosting birds to encounters was recorded as either a non-flight response (agitated behaviour including shuffling, tightening of roosting groups and disturbance-induced calling, but not resulting in any birds leaving the roost) or a flight response (all or some of the roosting birds departing from the roost). The proportion of counts disturbed (i.e. number of counts disturbed/total number of counts) by natural and human stimuli were compared between seasons.

Results

Species composition and abundance

Twenty-two species, including five species of migrant shorebird that breed in the Arctic, four species of shorebird that breed in Australia, and six species of tern, were recorded utilising the Dunwich high-tide roost during counts between 9 July 2007 and 21 July 2008 (Table 1). A total of 6162 birds was counted (4403 shorebirds, 1055 terns, 704 other non-passerines), with five species contributing ~90% of counted individuals: Australian Pied Oystercatcher (56%), Eastern Curlew (10%), Silver Gull *Chroicocephalus novaehollandiae* (10%), Caspian Tern (7%) and Gull-billed Tern (6%) (Table 1). Eight species were recorded only once during the counts. The Australian Pied Oystercatcher had the highest frequency of occurrence (present in 93% of counts) and the highest single count (205 individuals), and the Eastern Curlew was the most regularly recorded migrant shorebird that breeds in the Arctic (52% of counts), with a highest single count of 91 individuals (Table 1). Of the terns, the Caspian Tern was the most frequently occurring (81% of counts),

Table 1

Number counted, proportion of total of all birds counted, frequency of occurrence (%) for all counts (n = 54), mean abundance ± Standard Error for all counts (n = 54) and for undisturbed counts only (n = 43) and maximum single counts and months observed for 22 bird species recorded during counts at the Dunwich high-tide roost between July 2007 and July 2008.

Common name	*Species name*	*Number counted*	*Proportion*	*Frequency All counts*	*Mean All counts*	*Mean Undisturbed counts*	*Max. single count*	*Months observed*
Australian Wood Duck	*Chenonetta jubata*	7	<0.01	3.70	0.13 ± 0.09	0.07 ± 0.07	4	Mar., Jun.
Little Pied Cormorant	*Microcarbo melanoleucos*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Aug.
Australian Pelican	*Pelecanus conspicillatus*	75	0.01	35.19	1.39 ± 0.37	1.70 ± 0.46	11	Jul.–Sept., Dec., Mar.–Jun.
Striated Heron	*Butorides striata*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Jul.
Little Egret	*Egretta garzetta*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Feb.
Eastern Reef Egret	*Egretta sacra*	2	<0.01	3.70	0.04 ± 0.03	0.05 ± 0.03	1	Feb., May
Beach Stone-curlew	*Esacus magnirostris*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Sept.
Australian Pied Oystercatcher	*Haematopus longirostris*	3475	0.56	92.59	64.35 ± 7.81	78.05 ± 8.57	205	All
Sooty Oystercatcher	*Haematopus fuliginosus*	7	<0.01	7.41	0.13 ± 0.08	0.16 ± 0.10	4	Jul., Oct., Jan.
Pacific Golden Plover	*Pluvialis fulva*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Oct.
Masked Lapwing	*Vanellus miles*	101	0.02	46.30	1.87 ± 0.55	2.12 ± 0.68	21	All
Bar-tailed Godwit	*Limosa lapponica*	172	0.03	18.52	3.19 ± 1.21	3.93 ± 1.51	40	Jul., Aug., Oct., Dec., Feb., Mar.
Eastern Curlew	*Numenius madagascariensis*	644	0.10	51.85	11.93 ± 2.87	14.77 ± 3.48	91	Jul.–Oct., Dec., Feb., Mar., May, Jun.
Grey-tailed Tattler	*Tringa brevipes*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Sept.
Common Greenshank	*Tringa nebularia*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Apr.

Table 1 continued

Common name	*Species name*	*Number counted*	*Proportion*	*Frequency All counts*	*Mean All counts*	*Mean Undisturbed counts*	*Max. single count*	*Months observed*
Little Tern	*Sternula albifrons*	1	<0.01	1.85	0.02 ± 0.02	0.02 ± 0.02	1	Dec.
Gull-billed Tern	*Gelochelidon nilotica*	386	0.06	46.30	7.15 ± 1.83	8.84 ± 2.23	81	Jul.–Oct., Apr.–Jun.
Caspian Tern	*Hydroprogne caspia*	427	0.07	81.48	7.91 ± 1.04	9.58 ± 1.17	28	All
Common Tern	*Sterna hirundo*	3	<0.01	3.70	0.06 ± 0.04	0.07 ± 0.05	2	Oct., Dec.
Lesser Crested Tern	*Thalasseus bengalensis*	104	0.02	20.37	1.93 ± 0.89	2.26 ± 1.10	43	Jul.–Oct., Apr., Jun.
Crested Tern	*Thalasseus bergii*	134	0.02	33.33	2.48 ± 0.96	3.09 ± 1.19	37	Jul., Aug., Oct., Mar.–Jun.
Silver Gull	*Chroicocephalus novaehollandiae*	617	0.10	72.22	11.43 ± 1.83	13.23 ± 2.15	49	All

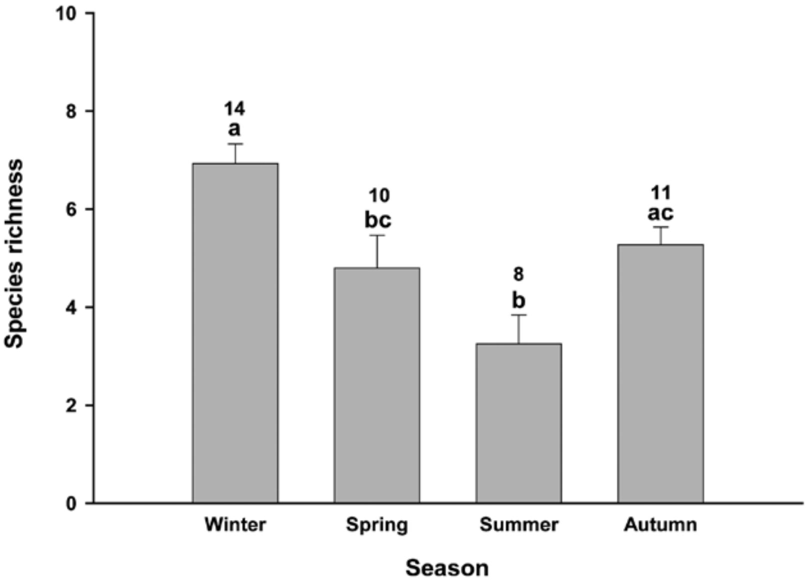

Figure 1. **Seasonal variation in mean observed species richness (number of species ± S.E.) at the Dunwich high-tide roost. Numbers indicate sample size (only undisturbed counts and counts in which all birds were counted before disturbance were used). Letters above each season indicate significant differences (Tukey Tests, *p* <0.05). Seasons with a letter in common are not significantly different.**

followed by the Gull-billed Tern (46%). Counts peaked at 81 for Gull-billed Tern and 43 for Lesser Crested Tern (Table 1).

During the period July 2007 to July 2008, opportunistic records of sightings at the roost (e.g. observations made outside official count times) produced an additional five non-passerine species utilising the roost that were not recorded during the roost surveys: Chestnut Teal *Anas castanea* (maximum number recorded 2; month observed Apr.), Little Black Cormorant *Phalacrocorax sulcirostris* (~300; Aug.), Royal Spoonbill *Platalea regia* (4; Feb.), Double-banded Plover *Charadrius bicinctus* (5; Apr.) and Whimbrel *Numenius phaeopus* (13; Apr., Jul. and Aug.).

Temporal variation in species richness, diversity and abundance

Total observed species richness and species diversity were highest in winter (14 species, $H' = 1.673$) and spring (15 species, $H' = 1.523$), and lowest in summer (11 species, $H' = 1.059$) and autumn (12 species, $H' = 1.160$). Mean observed species richness differed significantly between seasons (one-way ANOVA, $F_{3,39} = 9.314$, $p < 0.001$), with significant differences between winter and spring, winter and summer, and summer and autumn (Figure 1). Of the nine shorebird and tern species recorded with a frequency of occurrence >5%, three (Australian Pied Oystercatcher, Masked Lapwing *Vanellus miles* and Caspian Tern) were present year-round, Bar-tailed Godwit and Eastern Curlew were present in all seasons but not all months, Sooty Oystercatcher *Haematopus fuliginosus* was sporadic at the roost, and Gull-billed, Lesser Crested and Crested Terns were absent in late spring and summer (Figure 2).

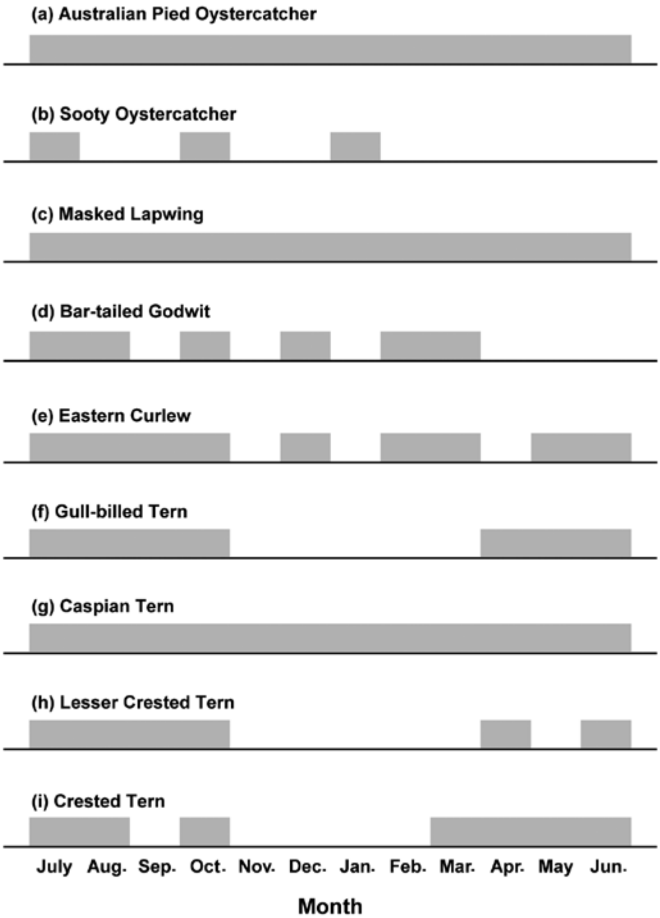

Figure 2. Seasonality of shorebirds (a–e) and terns (f–i) with >5% frequency of occurrence at the Dunwich high-tide roost.

There was considerable variability in the monthly abundance of the more common shorebird and tern species (Figure 3). Australian Pied Oystercatchers showed a peak in abundance from April to July (Figure 3a), Bar-tailed Godwits in July (Figure 3b) (see also below), Eastern Curlews from July to September with a smaller peak in February (Figure 3c), Gull-billed Terns in July (Figure 3d), Lesser Crested Terns in August (Figure 3f), and Crested Terns in July and with a smaller peak in March (Figure 3g). Although Caspian Terns were present year-round, numbers peaked from July to October and again from March to July, with numbers much lower from November to February (Figure 3e), the same period when Gull-billed, Lesser Crested and Crested Terns were absent (Figures 2–3). There was some interannual variation evident in some of these species: although numbers of Bar-tailed Godwits peaked in July 2007, they were not recorded in July 2008; in addition, Eastern Curlew, Gull-billed Tern and Crested Tern numbers were considerably higher in July 2007 than July 2008 (Figure 3).

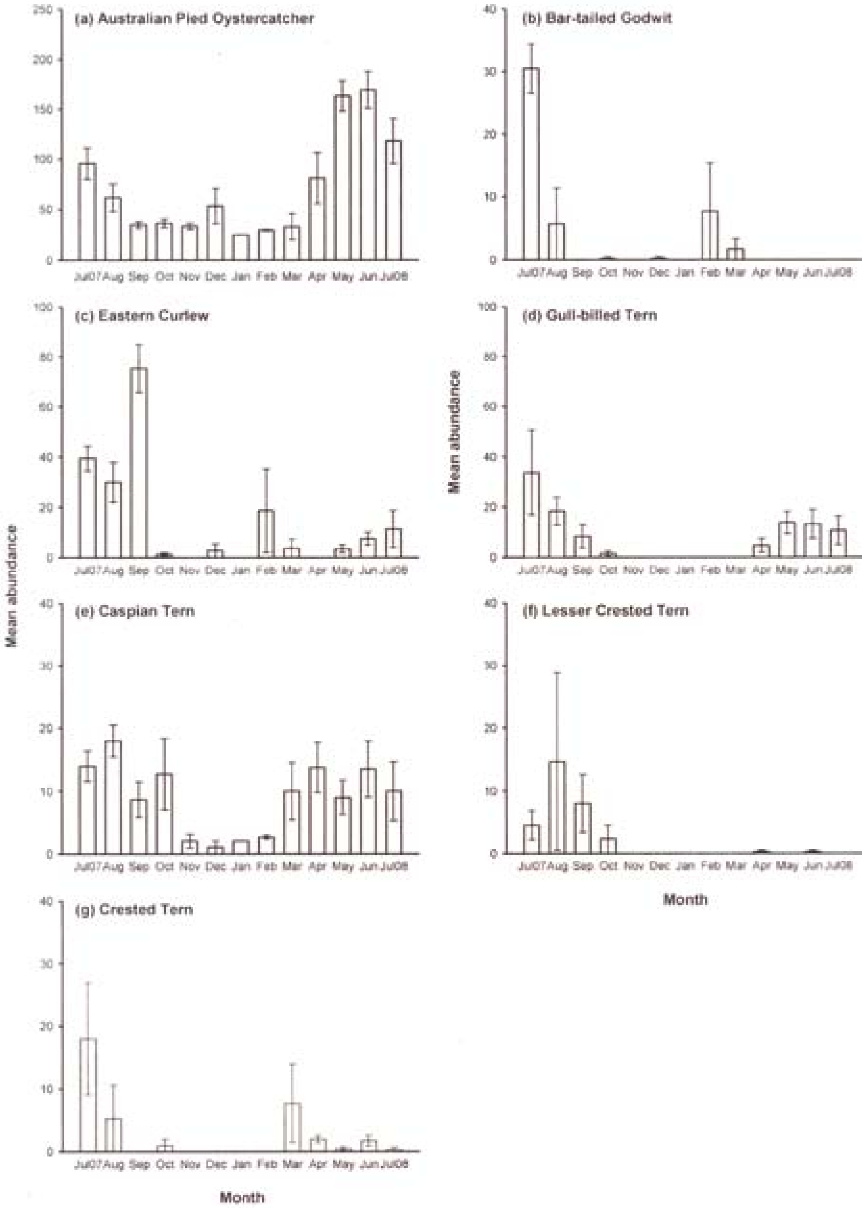

Figure 3. **Mean monthly abundance (number of individuals/count ± S.E.) of shorebirds (a–c) and terns (d–g) at the Dunwich high-tide roost between July 2007 and July 2008. Only undisturbed counts and counts in which all birds were counted before disturbance were used (n = 43). Note different scales on the y-axis.**

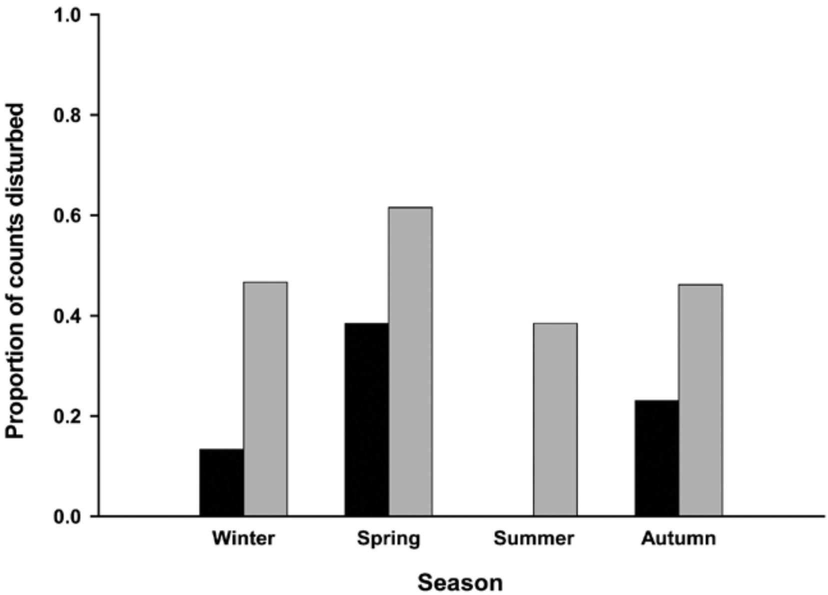

Figure 4. Seasonal variation in the proportion of roost-site counts disturbed by natural (black bars) and human (grey bars) stimuli at the Dunwich high-tide roost.

Disturbance

Disturbance by natural stimuli (low overflying raptors) was recorded during 18.5% of counts; 10 counts were disturbed by natural stimuli, with a total of 12 encounters (two counts had two encounters each). The proportion of counts disturbed by natural stimuli was highest during spring and autumn, and lowest in summer (no encounters recorded) and winter (Figure 4). Brahminy Kites *Haliastur indus* accounted for six encounters, and Eastern Ospreys *Pandion cristatus*, White-bellied Sea-Eagles *Haliaeetus leucogaster* and Whistling Kites *Haliastur sphenurus* accounted for two encounters each. The response of roosting birds to raptor species varied, suggesting different levels of perceived risk; White-bellied Sea-Eagles induced a flight response among the majority of roosting birds on both encounters, Brahminy Kites caused a flight response on three (of six) encounters (this response was largely restricted to terns and gulls), Whistling Kites caused a flight response in the majority of birds on one (of two) encounters, and Eastern Ospreys did not cause a flight response in either encounter observed.

Disturbance by human stimuli was recorded in nearly half (48.1%) of the counts; 26 counts were disturbed by human stimuli, with a total of 34 encounters (five counts had two encounters each, and one count had four encounters). The proportion of counts disturbed by human stimuli was fairly consistent across all seasons, although there was a peak in spring (Figure 4). Of the nine human stimuli recorded, people walking unleashed dogs accounted for the highest proportion of encounters (44% of recorded encounters); the majority of encounters from all stimuli resulted in a flight response amongst roosting birds (Table 2).

Table 2

Number and proportion of disturbances by human stimuli at the Dunwich high-tide roost between July 2007 and July 2008, and number of disturbances by each stimulus causing a flight response in roosting birds.

Stimulus	*Number of encounters*	*Proportion of encounters*	*Number causing flight response*
Walker(s) + dog (unleashed)	15	0.44	12
Fisher(s)	5	0.15	5
Walker(s) + dog (leashed)	3	0.09	0
Dog only	3	0.09	3
Walker(s) only	3	0.09	3
Vessel passing	2	0.06	1
Cyclist	1	0.03	1
Bait collector	1	0.03	1
Snorkellers	1	0.03	1

Discussion

The Dunwich roost-site at Bradburys Beach on North Stradbroke Island is part of a network of 112 high-tide roosts in Moreton Bay (EPA 2005), and, despite the small area available to roosting birds, this study demonstrates that it is an important link in that network. It thus deserves adequate management to minimise disturbance to roosting birds. Winter counts of large shorebirds that breed in the Arctic (Bar-tailed Godwit and Eastern Curlew) and the resident shorebird, Australian Pied Oystercatcher, combined with peak winter counts for several tern species (Gull-billed, Caspian, Lesser Crested and Crested Terns) highlight its apparent local importance during that season. This roost-site possesses a number of attributes that are important for roosting birds, including close proximity to extensive areas of intertidal foraging areas and a good field of view (Rogers 2003; Zharikov & Milton 2009). Seasonal patterns of occurrence may be related to larger-scale movement and abundance patterns of the species recorded; additionally, local factors may also influence the observed patterns. Although not examined during this study, the role of seasonal variation in high-tide levels in explaining the species composition of the roost warrants further exploration.

Factors such as the size of the roost-site, food availability in intertidal areas close to the roost, distance to suitable foraging areas, and disturbance levels, or a combination of these, may explain some of the diversity and abundance of birds observed at the roost. There was a general size threshold for roosting shorebird species, and disturbance levels alone probably do not explain the lack of small species at Dunwich, as large species (including Eastern Curlew, which occurred regularly at the roost) are more sensitive to disturbance (Thompson 1993; Higgins & Davies 1996). Although some attribute(s) of the site may make it unsuitable for small shorebirds, an alternative explanation is that ample roosting and, in particular, foraging habitat for smaller species exist elsewhere (e.g. Moreton Island to the north of North Stradbroke Island), and are favoured by small species. On the other hand, considerable areas of foraging habitat favoured by the Australian Pied Oystercatcher, the dominant species at the Dunwich roost, are available on north-western North Stradbroke Island.

The Australian Pied Oystercatcher is considered to be uncommon despite its widespread Australian distribution (Hewish 1990; Marchant & Higgins 1993). The patterns of occurrence and abundance at the Dunwich roost-site are consistent with winter movements to estuaries and embayments, and with the formation of wintering flocks for the non-breeding season (Marchant & Higgins 1993; Weston & Heislers 1995). The Dunwich roost provides access to extensive intertidal feeding areas preferred by Oystercatchers (pers. obs.). The previous published high count for this species in Moreton Bay of 185 birds was also recorded during a winter survey (J. Thompson in Hewish 1990). Three counts of the Dunwich roost exceeded this number and would promote Moreton Bay from a ranking of 19th by Watkins (1993) to the 14th most important site for the species in Australia. Counts during the present study indicate that the Dunwich roost is an internationally important site (using the 1% criterion: Watkins 1993) for the Australian Pied Oystercatcher, with up to ~2% of the estimated global population (11 000 birds: Watkins 1993) present at any one time. The roost thus qualifies as a 'critical shorebird site' under the Queensland Department of Environment and Resource Management's Shorebird Management Strategy for Moreton Bay (EPA 2005). Habitat disturbance has been cited as a cause for concern for the Oystercatcher in New South Wales and Queensland, particularly given the increased use of beaches and estuaries for recreational activities (Marchant & Higgins 1993; Wilson 1994; Fisher *et al.* 1998). Population declines caused by human disturbance and related breeding failure have been suspected for the species, including historically for Moreton Bay (Mayo 1931; Marchant & Higgins 1993; Wilson 1994; Fisher *et al.* 1998). Given these concerns, internationally and locally important sites, including the Dunwich roost, require management to limit human-induced impacts.

Moreton Bay is also an internationally important site for the Eastern Curlew (Thompson 1993; Watkins 1993; EPA 2005), especially the eastern bay (Thompson 1993). Global and national or regional declines in this species have been well documented and discussed (see Close & Newman 1984; Higgins & Davies 1996; Reid & Park 2003). Numbers at Dunwich peaked at 91 individuals in September (a possible southward migration event), and there were smaller but relatively consistent counts during winter 2007 (Figure 3), suggesting a preference for this roost by at least a proportion of the population remaining in Moreton Bay for the austral winter. As with the Australian Pied Oystercatcher, use of roosts may be related to access to extensive foraging areas. Congdon & Catterall (1994) showed that Eastern Curlew abundance and density in foraging areas were related to the width of the tidal flats, and Finn *et al.* (2007) showed that substrate resistance was the best predictor of Curlew density. The soft-substrate intertidal flats around Dunwich are ~400–500 m wide (Congdon & Catterall 1994), and may offer substantial foraging area. The Eastern Curlew is easily disturbed (Close & Newman 1984; Thompson 1993; Higgins & Davies 1996), and was often the first species to depart from the Dunwich roost when a disturbance occurred (pers. obs.). Consistent disturbance at this roost may limit the species' use of preferred foraging areas, and may provide an example of 'roost-constrained access to feeding grounds' (Rogers *et al.* 2006).

Disturbance by humans came from a number of sources, but predominantly from people walking unleashed dogs (44% of recorded encounters) (Table 2). Natural disturbance from raptors also occurs at the site, and the combination of this and consistent human disturbance may result in high energy costs to the birds. Rogers *et al.* (2006) noted that if the energy expenditure associated with roosting (energy costs in transit to and from the roost, and at the roost) exceeds daily energy requirements for maintenance, moulting and pre-migration fuelling, then there will be some loss of feeding areas, as it becomes uneconomical for individual birds to utilise them. Forcing birds into higher-density foraging areas can reduce food intake, most likely through competition (Smit & Visser 1993). Such 'density-dependent limits on food availability' (Rogers *et al.* 2006) may compromise individual survivorship. Observations indicated that when disturbed, Australian Pied Oystercatchers relocated to other local sites near the roost (often sandy beaches), with some degree of flock dispersal often a consequence. These alternative roosting areas did not appear to be preferred by the birds, which generally behaved in a nervous and unsettled manner there (pers. obs.). In contrast with these short localised movements, if disturbed, Eastern Curlews and Bar-tailed Godwits almost always headed out into Moreton Bay, generally tracking either northwards (possibly towards Amity Banks, which under suitable conditions are a larger roost-site) or westwards (possibly to Peel Island or the western Bay). However, not all observed disturbances resulted in a flight response, and it appears that Australian Pied Oystercatchers are at least partially habituated to walkers and walkers with leashed dogs, if they remain on the beach above the roost-site. Research into tolerance distances of roosting species would help with the creation of exclusion zones if these were seen as a management option.

The level of human-induced disturbance recorded at the roost-site during the study highlights that existing management is, at present, failing to deter considerable disturbance to roosting birds. Effective management requires a joint strategy involving the state agency (Queensland Department of Environment and Resource Management) responsible for the management of Moreton Bay Marine Park, which includes the roost itself to the high tideline, and the local authority (Redland City Council) responsible for the surrounding land and for dog management. Although state regulations exist to limit disturbance to shorebirds in Moreton Bay, and local law specifies that dogs are required to be leashed on public lands, there is little to no enforcement of such regulations at present around the roost-site (pers. obs.). Community education on the value of the roost and its use by a diversity of migratory and resident species, including rare and threatened species (Beach Stone-curlew *Esacus magnirostris*, Sooty Oystercatcher, Eastern Curlew and Little Tern are listed in Queensland's *Nature Conservation Act*), is required. In some instances pet-owners were observed unleashing their dogs to allow them to run through the roosting birds (pers. obs.). Knowledge of the energy costs to individual birds associated with disturbance, including the potential loss of feeding areas (Smit & Visser 1993; Rogers *et al.* 2006), the declining status of some species, and that disturbance has been implicated in the long-term decline of shorebirds at some locations (i.e. Pfister *et al.* 1992), may reduce this sort of activity. Although unleashed dogs caused flight responses in roosting birds in most instances, leashed dogs did not (although the number of instances observed was low). Dog-owners leashing their pets generally walked higher up on the beach, away from the roosting birds (pers. obs.), suggesting that they were aware of the roost-site. Williams *et al.* (2009) showed that if dog-owners believe that their pets are a threat to wildlife they are more likely to feel an obligation towards leashing their dogs. An obligation is also more likely to be felt when there is a community expectation that dogs should be leashed (Williams *et al.* 2009).

A management strategy for the roost should involve three components, all of which are linked: (1) education of the community to create a community value for the roost-site as an important wildlife area, including placing informative signs at the roost to increase public awareness and dissuade disturbance, as has been successfully employed at other sites around Moreton Bay (EPA 2005; Zharikov & Milton 2009); (2) education of the local government concerning the roost-site and surrounds as an important wildlife area, encouraging recognition and protection of shorebirds (EPA 2005) and other birdlife; and (3) enforcement of existing state and local regulations to minimise disturbance to shorebirds and to manage dogs. Following increased public awareness and community value, limiting access to the site at high tide would provide a safer, more secure roosting environment, with options for high-tide or seasonal closures. These changes will require a more committed management approach from both the Queensland Department of Environment and Resource Management and the Redland City Council, as well as community engagement and involvement. The data presented here provide a baseline against which to measure changes in roost utilisation, including as a result of the improved management recommended here.

Acknowledgements

I thank the staff of the Moreton Bay Research Station, in particular Kevin Townsend, Kathy Townsend and Emma Lewis, for support during the period of the counts. Thanks to Emma Lewis, Harry Hines, Holly West and Micha Jackson for assistance with counts. Linda Cross and David Milton of the Queensland Wader Study Group assisted in the development of the project, and Linda Cross provided support throughout the count period. I thank Micha Jackson, David Milton and Danielle Warfe for comments on the manuscript.

References

Burger, J., Jeitner, C., Clark, K. & Niles, L.J. (2004), 'The effect of human activities on migrant shorebirds: Successful adaptive management', *Environmental Conservation* **31**, 283–288.

Chan, K. & Dening, J. (2007), 'Use of sandbanks by terns in Queensland, Australia: A priority for conservation in a popular recreational waterway', *Biodiversity and Conservation* **16**, 447–464.

Close, D. & Newman, O.M.G. (1984), 'The decline of the Eastern Curlew in south-eastern Australia', *Emu* **84**, 38–40.

Congdon, B.C. & Catterall, C.P. (1994), 'Factors influencing the Eastern Curlew's distribution and choice of foraging sites among tidal flats of Moreton Bay, south-eastern Queensland', *Wildlife Research* **21**, 507–518.

EPA (2005), *Shorebird Management Strategy: Moreton Bay*, Environmental Protection Agency (Queensland), Brisbane.

Finn, P.G., Catterall, C.P. & Driscoll, P.V. (2007), 'Determinants of preferred intertidal feeding habitat for Eastern Curlew: A study at two spatial scales', *Austral Ecology* **32**, 131–144.

Fisher, F., Hockings, M. & Hobson, R. (1998), 'Recreational impacts on waders on Fraser Island', *Sunbird* **28**, 1–11.

Hewish, M. (1990), 'The winter 1989 population monitoring count: Pied and Sooty Oystercatchers at monitored sites', *Stilt* **17**, 5–16.

Higgins, P.J. & Davies, S.J.J.F. (Eds) (1996), *Handbook of Australian, New Zealand and Antarctic Birds*, vol. 3, Oxford University Press, Melbourne.

Marchant, S. & Higgins, P.J. (Eds) (1993), *Handbook of Australian, New Zealand and Antarctic Birds*, vol. 2, Oxford University Press, Melbourne.

Mayo, L.M. (1931), 'A Queensland sanctuary', *Emu* **31**, 71–76.

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

Reid, T. & Park, P. (2003), 'Continuing decline of Eastern Curlew, *Numenius madagascariensis*, in Tasmania', *Emu* **103**, 279–283.

Rogers, D.I. (2003), 'High-tide roost choice by coastal waders', *Wader Study Group Bulletin* **100**, 73–79.

Rogers, D.I., Piersma, T. & Hassell, C.J. (2006), 'Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay', *Biological Conservation* **133**, 225–235.

Smit, C.J. & Visser, G.J.M. (1993), 'Effects of disturbance on shorebirds: A summary of existing knowledge from the Dutch Wadden Sea and Delta area', *Wader Study Group Bulletin* **68**, 6–19.

Thompson, J. (1990), 'A reassessment of the importance of Moreton Bay to migratory waders', *Sunbird* **20**, 83–88.

Thompson, J.J. (1993), 'Patterns of shorebird abundance in eastern Moreton Bay, Queensland', *Wildlife Research* **20**, 193–201.

Thompson, J.J. (1998), 'Interseasonal changes in shorebird habitat specialisation in Moreton Bay, Australia', *Emu* **98**, 117–126.

Watkins, D. (1993), *National Plan for Shorebird Conservation in Australia*, RAOU Report **90**.

Weston, M.A. & Elgar, M.A. (2007), 'Responses of incubating Hooded Plovers (*Thinornis rubricollis*) to disturbance', *Journal of Coastal Research* **23**, 569–576.

Weston, M. & Heislers, D. (1995), 'An estimate of the proportion of Pied Oystercatcher pairs overwintering on open ocean beaches in eastern Victoria, Australia', *Stilt* **26**, 43–45.

Williams, K.J.H., Weston, M.A., Henry, S. & Maguire, G.S. (2009), 'Birds and beaches, dogs and leashes: Dog owners' sense of obligation to leash dogs on beaches in Victoria, Australia', *Human Dimensions of Wildlife* **14**, 89–101.

Wilson, G.W. (1994), 'The status of the Pied Oystercatcher *Haematopus longirostris* on the coastal flats of Keppel Sands and Joskeleigh on the Capricorn Coast of central Queensland', *Sunbird* **24**, 73–79.

Zharikov, Y. & Milton, D.A. (2009), 'Valuing coastal habitats: Predicting high-tide roosts of non-breeding migratory shorebirds from landscape composition', *Emu* **109**, 107–120.

Received 29 October 2009 ■