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Day–night foraging behaviour of banded dotterels (*Charadrius bicinctus*) in the Richmond River estuary, northern New South Wales, Australia

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Abstract The foraging behaviour of banded dotterels during day and night was compared at two sites in the Richmond River estuary, northern New South Wales, Australia. Dotterels foraged during all nights of the survey, although the majority of their food intake came from day feeding. Feeding success rate (no. prey/minute) did not differ significantly between lunar phases or night visibility categories but average feeding success rate was lower at night than during the day. Dotterels foraged on a range of prey including sentinel crabs (*Macropthalamus* spp.), soldier crabs (*Mictyris longicarpus*), shrimps (*Penaeus* spp.) and polychaete worms. At night soldier crabs represented a greater proportion of prey consumed than during the day. No polychaete worms were recorded being taken at night. Dotterels displayed a range of foraging behaviours, although the typical dotterel technique of wait-walk-peck-wait was most commonly recorded. Significant differences in the proportion of time that birds spent waiting, flying and vigilant, and the number of pecks/minute and paces/walk were recorded between day and night. Foraging behaviour did not differ between the study sites.

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Keywords banded dotterel; *Charadrius bicinctus*; nocturnal foraging, New South Wales

INTRODUCTION

The banded dotterel (*Charadrius bicinctus*) is a small shorebird that breeds in New Zealand. During autumn, part of the population migrates to Australia where they remain until late winter (Pierce 1999). Whilst in Australia, banded dotterels spend most of their time in coastal habitats, where they forage and roost on intertidal sandflats in estuaries and on ocean beaches.

Banded dotterels forage during both day and night (Pierce 1980; Marchant & Higgins 1993), although birds may use a different feeding method at night (Dann 1991). Changes in foraging intensity may occur throughout the day, with the highest intensity recorded in the early morning and late evening (Pierce 1980). Peaks in foraging activity at these times may be to compensate for reduced feeding success at night.

In estuarine habitats in Australia, banded dotterels appear to spend the majority of time foraging on moist sandy substrates where they use a typical plover feeding technique, of searching for prey, then running and pecking at prey items on the sand surface (Dann 1991). Possible tactile feeding methods (jabbing & probing) have been observed during poor weather conditions, and possibly at night (Dann 1991; Marchant & Higgins 1993). The type of prey targeted may vary between sites, although crabs appear to represent an important dietary component during the non-breeding season.

Dann (1991) reported on the foraging behaviour and diet of banded dotterels at a south-temperate site in Westernport Bay, Victoria. The aim of this study was to collect similar information in a sub-tropical estuarine system in northern New South Wales

STUDY AREA & METHODS

Study area

Habitat use by banded dotterels was studied in the Richmond River estuary, northern New South Wales, Australia (Fig. 1). Direct observations of birds were made at two intertidal sandflats, Mobbs Bay and RSL (Fig. 1). Both survey sites were characterised by a sandy substrate that received some artificial light at night from the township of Ballina. Rohweder & Baverstock (1996) provide further information on the characteristics of the study area

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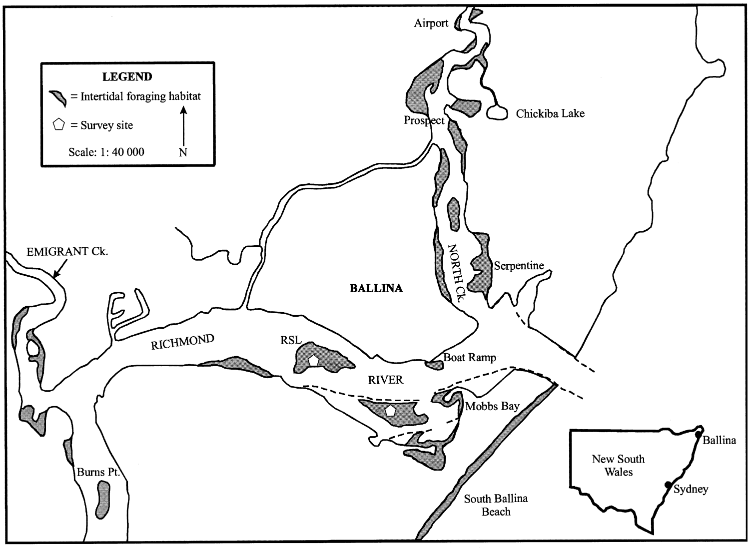

Figure 1 The location of survey sites in the Richmond River estuary, northern New South Wales, Australia.

METHODS

Foraging behaviour was recorded by selecting individual birds at random from within a feeding flock. Each individual was observed continuously for two minutes and its behaviour documented at 10 sec. intervals (frequency of occurrence method). Behaviour was divided into nine categories (Table 1). All prey items captured during the two-minute period were recorded regardless of whether their capture coincided with a 10 sec. observation. Observations stopped if a bird moved out of sight or left the mudflat. Additional data were collected on some individuals by undertaking a separate observation immediately following the initial two-minute period (direct count method). This involved counting the number of pecks in a two-minute period, followed by the number of paces and individual movements made in a separate one-minute period.

All observations were recorded on a constantly running tape recorder. Feeding observations were conducted in the four-hour period surrounding low tide, with observations scheduled around the lunar phase. This was done to ensure that behaviour was sampled during spring and neap tides and to account for the influence of the moon on night foraging.

Day observations were made using a 20-60 x 80 mm spotting scope, while night observations were made using a combination of a 20-60 x 80 mm spotting scope, a Litton GEN III M983 image intensifier and a 50-watt spotlight fitted with an infrared filter. Birds were observed from an exposed position on the sandflats. The majority of observations were made between May and July 1997, with some early observations undertaken between May and June 1995. Observations were conducted during 20 day and 20 night low tides at each site.

Nocturnal visibility was assessed on a subjective scale (good, moderate, poor) using quadrat marker pegs as a guide (Rohweder & Lewis 2002). Visibility was regarded as good when the marker pegs at the rear of the quadrat were visible with the naked eye and poor when the marker pegs at the front of the quadrat were only just discernible with the naked eye. An attempt was made to identify all prey items, although this was not always possible, particularly at night.

Influence of infrared light

To observe foraging behaviour at night it was necessary to use an infrared spotlight. However, preliminary observations indicated that birds could detect the infrared light. There was concern that birds could benefit from having the substrate around them illuminated, possibly leading to increased feeding rates and altered foraging behaviour.

To assess the influence of infrared light a brief field study was conducted over two nights during the full moon in mid-April 1997. Birds were observed using the same methods described above. Analysis of variance was used to compare observations made using a 25 watt spotlight with no infra-red filter and a spotting scope, observations made with a night scope and spotting scope, but no spotlight, and observations made with a 25 watt spotlight with an infrared filter a spotting scope and a night scope.

Data analysis

A total of 511 two-minute observations were conducted. The number of replicates was reduced to 80 (20/site/time period) to account for a lack of independence between replicates. Data reduction

Table 1 Definitions of behaviours reported in this study.

Behaviour	Definition
Waiting/searching	Behaviour mostly occurs after a walk and peck when the bird is actively searching for prey.
Walking	Bird moving across the substrate at a slow steady pace. This generally occurs following a wait or peck.
Running	Bird moves rapidly across the substratum.
Flying	Bird in flight.
Pecking	Bird strikes bill on the substratum one or more times.
Feeding	Bird manipulating and consuming a prey item.
Comfort (preening & loafing)	Bird preening or loafing (i.e. standing on one leg, bill tucked under wing etc).
Alert (vigilant)	Bird appears alarmed, utters alarm call, looking at an approaching predator, bird may be motionless or moving.
Aggression	Bird chasing or being chased by another bird.

was achieved by averaging all observations within each low tide period to provide a single replicate for that period.

Foraging behaviour (frequency of occurrence method) was summarised by dividing the number of observations for each activity by the total number of 10 sec. observations within a two-minute observation period to give a percentage value. Data for each two-minute observation were then averaged for each low tide period. The end result was a single figure (proportion) for each activity recorded during each low tide. Percentages were transformed using the arcsine transformation. The averaged values for each low tide were then used in a repeated measures ANOVA comparing foraging behaviour between day and night and feeding success rate between day/night, lunar phase and night visibility. Site was included in the ANOVA as a between-subjects factor. The number of prey consumed per observation was expressed as number/minute (i.e. feeding success rate) to enable comparison between observations of different lengths.

The additional observation data (direct count method) were used to calculate the number of pecks/minute, number of paces/minute and number of paces/walk during day and night. These data were analysed using repeated measures ANOVA.

RESULTS

Comparison of foraging behaviour with and without infra-red light

Comparison of the foraging behaviour of banded dotterels between the three treatments provided varied results (Table 2). The number of pecks/minute was significantly greater when birds were observed with an unfiltered spotlight and spotting scope compared to when they were observed using just the night scope. There was no significant difference in pecking rate between the infrared filter with night scope and just the night scope (Table 2). Banded dotterels spent a significantly greater amount of time walking when observed with the infrared spotlight, night scope and spotting scope than when observed with the night scope and no spotlight.

Feeding success and prey type

Feeding success rate did not differ significantly between day and night at either site (Table 3), although average feeding success was lower at night (0.52 ± *se* 0.143 prey/minute;) than during day (0.76 ± 0.19 prey/minute). Feeding success did not vary significantly in relation to night visibility (P = 0.097; df 1, 8; F = 3.53), or lunar phase (P = 0.557; df = 1, 12; F = 0.364).

Banded dotterels foraged primarily on crabs, although some polychaete worms and shrimps were taken (Fig. 2). Soldier crabs (*Mictyris longicarpus*) were the dominant prey item at RSL, followed by sentinel crabs (*Macropthalamus* spp.). The proportion of soldier crabs taken at RSL increased at night, while the proportion of sentinel crabs decreased at night (Fig. 2).

Sentinel crabs were the dominant prey item during the day at Mobbs Bay, followed by soldier crabs and shrimps (*Penaeus* spp.). Soldier crabs were the only prey identified at night at Mobbs Bay. Unidentified prey was large and most likely

Table 2 Comparison of nocturnal foraging behaviour of banded dotterels under different methods of observation. The numbers are mean percentage of observations spent in that activity (± *se*); *ns* = not significant.

Behaviour	Method			ANOVA results
	No light, $n = 6$	Light with filter, $n = 7$	Light no filter, $n = 6$	
Waiting	51.7 (8.6)	63.6 (8.0)	44.5 (8.6)	*ns*
Pecking	7.3 (3.6)	12.9 (3.4)	10.0 (3.1)	*ns*
Walking	4.5 (5.7)	24.7 (5.3)	16.3 (5.7)	$P = 0.023$, $df = 2, 16$, $F = 4.82$; Tukeys HSD $P<0.05$; no light < light with filter
Pecks/minute	1.52 (0.7)	3.8 (0.7)	4.8 (0.8)	$P = 0.027$, $df = 2,16$, $F = 4.57$; Tukeys HSD $P<0.05$; no light < light no filter

Table 3 Mean percentage (± *se*) distribution of foraging behaviours of banded dotterels at two sites in the Richmond River estuary, and results of repeated measures ANOVA (D/N*Site) between day and night and between sites; *df* = 1, 38; *ns* = not significant; na = no analysis performed.

Behaviour	Mobbs Day		RSL		RM ANOVA D/N* Site
	Day, $n = 20$	Night, $n = 20$	Day, $n = 20$	Night, $n = 20$	
Wait/search	42.49 (2.29)	51.83 (3.22)	46.16 (2.74)	50.25 (2.95)	D/N:P = 0.038 Site: *ns*
Running	9.59 (2.2)	14.08 (2.74)	10.21 (2.96)	10.92 (2.82)	D/N: ns Site: ns
Pecking	13.1 (3.05)	10.45 (1.86)	11.61 (2.34)	9.98 (1.60)	D/N: ns Site: ns
Flying	0.616 (0.21)	0.11 (0.07)	1.49 (0.67)	0.56 (0.09)	D/N: P = 0.002 Site: ns
Walking	18.96 (2.23)	12.83 (1.86)	16.17 (2.51)	18.06 (3.35)	D/N: ns Site: ns
Feeding	6.29 (1.18)	5.63 (1.82)	6.22 (1.40)	5.46 (1.82)	D/N: ns Site: ns
Success	0.78 (0.14)	0.94 (0.40)	0.73 (0.20)	0.46 (0.24)	D/N: ns Site: ns
Comfort	8.53 (3.87)	4.81 (1.56)	5.57 (3.10)	4.93 (2.45)	D/N: ns Site: ns
Alert	2.13 (0.93)	0.38 (0.38)	1.65 (0.78)	0.07 (0.07)	D/N: P = 0.004 Site: ns
Aggression	0.12 (0.05)	0	0	0	na

included sentinel crabs, soldier crabs or shrimps. It was difficult to distinguish between small individuals of these species at night at both sites.

The majority of crabs consumed had a carapace width less than 1.5 cm. Most sentinel crabs consumed had a carapace width less than 1.0 cm, whilst most soldier crabs had a carapace width of approximately 0.5 cm. Similar sized crabs were taken during both day and night. Banded dotterels regularly captured larger crabs (e.g. sentinel crabs > 1.5 cm and soldier crabs > 1.0 cm) but they left these after a 3-5 sec. handling period. Individuals were also observed eating the remains of larger crabs that had been captured and partially consumed by eastern curlews (*Numenius madagascariensis*) and bar-tailed godwits (*Limosa lapponica*).

Foraging behaviour

Banded dotterels displayed a typical plover foraging technique of searching for prey (waiting) then walking to peck at a prey item or walking to a new waiting position. Dotterels were often recorded pecking immediately after waiting, possibly trying to capture prey in their immediate vicinity. Although not recorded as a separate feeding activity, banded dotterels were observed to forage using a repeated pecking technique, which could almost be described as jabbing. This technique was observed most frequently at night and generally occurred when a bird had located a prey item.

Banded dotterels spent significantly more time waiting at night than during the day, significantly more time flying during the day and significantly more time alert during the day (Table 3). The proportion of observations that birds walked, pecked, ran, foraged and preened did not change significantly between day and night (Table 3).

The number of pecks/minute was significantly greater at night (mean 11.43 ± *se* 1.33, *n* = 36) than during the day (mean 7.77 ± 0.57, *n* = 36; *P* = 0.001; *df* = 1, 31), whilst the number of paces/walk was significantly greater during the day (mean 6.67 ± 0.4, *n* = 35) than at night (mean 5.44 ± 0.45, *n* = 16; *P* = 0.044; *df* = 1, 15). No significant difference was recorded for the number of paces/minute during the day (mean 93.16 ± 7.14, *n* = 36) and at night (mean 103.57 ± 8.49, *n* = 16; *P* = 0.879; *df* = 1, 15).

DISCUSSION

Foraging behaviour

The foraging behaviour of banded dotterels was similar to other species of plover (i.e. wait-walk-peck-walk-wait; Pienkowski 1982, 1983), although banded dotterels often pecked immediately after waiting for a brief period and their rate of foraging was faster than for other plovers in the Richmond River estuary (D. Rohweder unpubl. data). A similar foraging technique was used during day and night although, a peck immediately following a wait was recorded more frequently at night, suggesting that birds were trying to capture prey in close proximity. This behaviour may be due to reduced prey detection distances at night (Pienkowski 1983), or a greater abundance of prey. Dotterels were also recorded using a repeated pecking technique during both the day and night. Similar behaviour was recorded by Dann (1991), which he attributed to a tactile feeding method. Repeated pecking seemed to occur when a bird had located, but then lost, a prey item, with repeated pecks used to re-locate it.

The foraging behaviours of banded dotterels are similar to those recorded for other species of plover. Staine and Burger (1994) found that piping plovers (*Charadrius melodus*) spent more time searching (waiting) for prey at night, and similar was recorded for grey plovers (*Pluvialis squatarola*) by Pienkowski (1983) and Turpie & Hockey (1993). Banded dotterels may spend more time waiting/searching at night to account for a reduced ability to detect prey. An increase in waiting time at night may explain the reduced feeding success rate as birds would cover less feeding area and therefore encounter fewer prey items (Turpie & Hockey 1993). Dann's (1991) observation that banded dotterels took shorter paces at night further supports the suggestion that birds cover shorter distances whilst foraging at night.

The smaller number of paces/walk at night would further reduce the area covered, as birds move shorter distances between waits. The reduction in the number of paces/walk at night could be in response to either a reduced ability of prey to detect birds or a reduction in the area over which birds can detect prey. Either way, shorter movements are likely to increase the ability of birds to detect prey and reduce the likelihood that prey would be overlooked. The impact of traversing smaller areas on food intake rate may not be negative if prey availability is greater (Dugan *et al.* 1981) and the behaviour displayed by banded dotterels could also be in response to increased prey activity and/or abundance at night.

The two methods of recording pecking (i.e. direct peck counts and frequency of occurrence) provided different results. The frequency of occurrence method identified a slight reduction in the average peck frequency at night (Table 3), whilst the direct counts recorded a significant increase in the number of pecks/minute at night. This difference is due to a combination of factors including, the speed of pecks which makes the behaviour more difficult to record within a 10 sec. observation period, the overall speed with which dotterels move across feeding areas, and the occurrence of repeated pecks which were recorded as a single peck by the frequency of occurrence method.

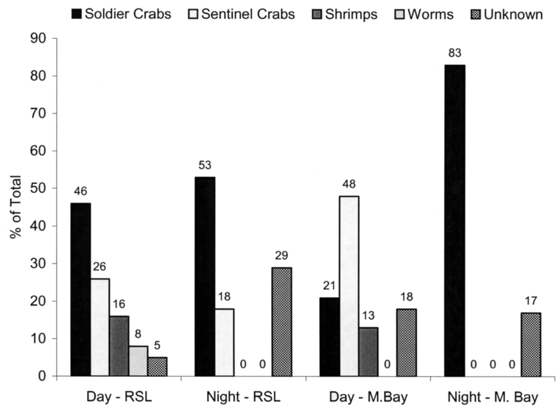

Figure 2 Proportion that different prey items were recorded being taken by banded dotterels at two sites in the Richmond River estuary. Percentage values are shown above bars.

The increase in pecks/minute at night is contrary to the results of other studies on plovers (Staine & Burger 1994; Pienkowski 1982, 1983) and could be due to the occurrence of high densities of small unrecorded prey items, or plovers may increase their opportunity of capturing prey through frequent pecks in a small area. The presence of unrecorded prey items is feasible given that high densities (e.g., 650 individuals/m^2) of small (2-5 mm) soldier crabs have been recorded in the study area in autumn (Rohweder 2000).

The nocturnal foraging behaviour of banded dotterels is likely to be affected by the presence of artificial light from nearby urban areas. It is likely that sight-feeding shorebirds would benefit from artificial light (Rohweder & Baverstock 1996; Rohweder & Lewis 2002). The presence of artificial light may have a mediating affect by reducing the degree to which feeding conditions change between day and night. The absence of a significant difference in feeding success rate between day and night is contrary to the results of other studies (e.g., Turpie & Hockey 1993) and may be due to artificial light, which creates a permanent full-moon affect resulting in elevated levels of food intake.

Prey type

In daylight, banded dotterels foraged on polychaete worms, sentinel crabs, soldier crabs, and shrimps. At night, however, they foraged predominantly on crabs. The reduced night intake of worms may result from the birds' inability to detect worms or the inability of observers to record them being eaten at night. It is worth noting that the majority of the unidentified prey at night was crabs. The conspicuous behaviour of crabs, particularly soldier crabs, makes them a readily detectable and available food source at night and this may explain why their consumption increased during that period. Soldier crabs have not been recorded previously in the diet of banded dotterels in Australia, although sentinel crabs have (Dann 1991; Marchant & Higgins 1993).

Comparison of the density of soldier crabs between day and night identified significant increases in density during night low tides (Rohweder 2000). Banded dotterels may respond by focussing on this prey item. The variety of prey consumed suggests that banded dotterels have some flexibility in the type of prey targeted, although birds may focus on large and conspicuous prey at night.

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