Australian Field Ornithology 2012, **29**, 201–209

Reconstructing the diet of the Beach Stone-curlew *Esacus magnirostris* using scat analysis

Graham F. Mellish[1] *and David A. Rohweder*[2]*

[1]Southern Cross University, P.O. Box 157, Lismore NSW 2480, Australia, and
2A Mahogany Court, Orange NSW 2800, Australia
[2]Sandpiper Ecological Surveys, P.O. Box 401, Alstonville NSW 2477, Australia
*Corresponding author. Email: sandpipereco@optusnet.com.au

Summary. The diet of the Beach Stone-curlew *Esacus magnirostris* was examined by analysing 242 scat samples collected from four sites in northern New South Wales. All samples included remains of crabs, with some also containing fragments of insects and molluscs. Nine species of crab were identified. The Light Blue Soldier Crab *Mictyris longicarpus* was the most frequently recorded prey item (present in >80% of scats) at the Wooli and Nambucca Rivers, but the Dark Blue Soldier Crab *M. platycheles* was most frequently recorded (73% of scats) at the Corindi River. Seven of these crab species have not been described previously in the diet of the Stone-curlew. The diversity of crabs identified in scats indicates that Stone-curlews forage in a variety of habitat types.

Introduction

Information on diet is important for managing the habitat used by threatened birds, but there has been only limited research on the diet of resident shorebirds in Australia. In the case of the Beach Stone-curlew *Esacus magnirostris,* published information on diet is dominated by generalised descriptions of prey type. The most commonly used descriptions are 'crabs' and 'crustaceans', with some authors identifying species, such as the Light Blue Soldier Crab *Mictyris longicarpus* and Horn-eyed Ghost Crab *Ocypode ceratophthalma* (Clancy 1986; Geering 1988; Burnett *et al.* 1998). There are also records of Stone-curlews selecting other prey items, such as Pipis *Donax deltoides* (Lewis 1997) and Little Tern *Sternula albifrons* eggs (H. & B. Hole pers. comm.). Most data are based on opportunistic observations during daylight hours. However, although Stone-curlews occasionally forage during the day (Clancy 1986; Marchant & Higgins 1993), their mainly crepuscular and nocturnal foraging behaviour makes it difficult to accurately determine their diet based on daytime observations alone. This study aims to describe the diet of the Stone-curlew in northern New South Wales (NSW) by examining scats. Information gathered will contribute to the understanding of Beach Stone-curlew ecology and management requirements.

Methods

In February 2000, scat samples were collected from the Corindi, Nambucca and Manning (Farquhar Inlet) Rivers, and samples were collected in 2005 from the Wooli, Corindi and Nambucca Rivers, all situated in northern NSW (Figure 1). These sites were chosen because of the known presence there of resident breeding pairs of Beach Stone-curlews

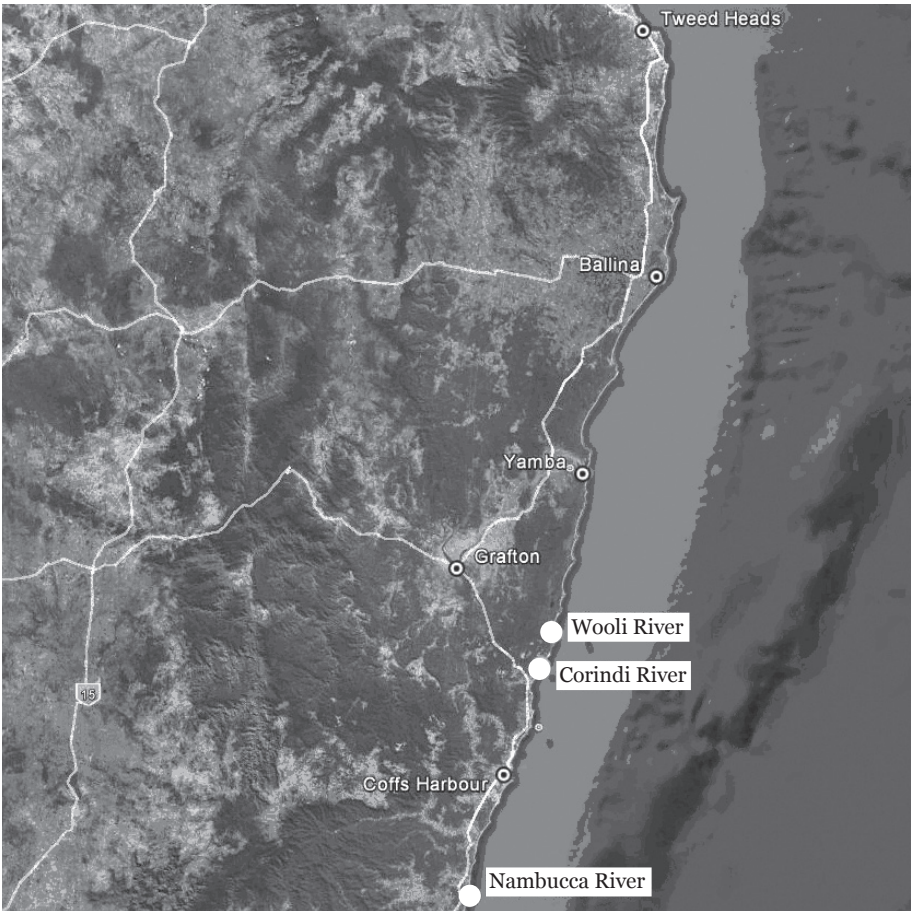

Figure 1. Location of Wooli, Corindi and Nambucca Rivers in northern NSW. Image source: Sensis.

(Rohweder 2003). Beach Stone-curlews were observed foraging at the Wooli and Nambucca sites in 2005. In February 2000, 1 hour was spent observing Stone-curlews at night at the Nambucca estuary using a Litton GEN III M983 image intensifier.

Sample collection

Twenty-four scat and prey fragments, discarded parts of prey, were gathered in February 2000, and a total of 218 samples was collected in August (Wooli and Corindi) and October (Nambucca) 2005. The latter samples were recorded as fresh (soft/moist, deposited within the preceding 2–3 days) or dry (dry/hard, deposited within several months). During 2005, approximately three person hours were spent collecting scats at each site; samples were collected opportunistically in 2000. Beach Stone-curlews were recorded at all sites at the time of sampling, and opportunistic observations on foraging were made where possible.

Beach Stone-curlew scats were distinguished from those of other species of shorebird on the basis of size, shape, consistency and location. All samples were collected from known

shelter- and nest-sites used by resident pairs of Stone-curlews. Most samples were collected from areas with overstorey vegetation (which reduces the likelihood of use by other shorebirds). The open area of sandbank sampled at the Nambucca River was clearly used by Stone-curlews judging from the abundance of uniform scats and the close proximity of tall vegetation and a known nest- and shelter-site (Rohweder 2003).

If there was doubt over the origin of a scat, it was discarded. The only scats not attributed to Beach Stone-curlew were nine scats, from a more open area at the southern end of the Wooli site dominated by the Marine Yabby *Callianassa* sp., and most likely from Eastern Curlews *Numenius madagascariensis*. They were not included in the analysis.

Each sample was individually sieved through 0.5-mm mesh (following Dit Durrel & Kelly 1990 and Dann 1993) to remove excess mud, silt and sand, and the remaining fragments were placed directly into sample jars with 70% ethanol (Dit Durrel & Kelly 1990; Dann 1993; Galbraith *et al.* 1993). All samples were labelled according to the type of sample (i.e. fresh or dry), as well as the site location and date collected. A representative sample of crustaceans was collected from each sample site to assist with the identification of prey species.

Scat analysis

Samples were spread into petri dishes and analysed using a stereo-microscope. Samples consisted of prey fragments, mud, sand, and occasionally plant material stuck to scats on collection. All identifiable prey remains were removed for further analysis; selected remains consisted of fragments with characteristics that could be used in identification, e.g. chelipeds (claws and nippers), pleopods (walking legs), orbital teeth (spines in the orbit), and the gastric mill (chitinous stomach component). Identification keys, relevant literature, and reference samples were used to identify prey with assistance from an invertebrate taxonomist, Lexie Walker. Most fragments were identified to species or family level, but some could be identified only to class or phylum. Unidentified matter consisted mainly of crushed carapace, thoracic appendages and internal organs with no diagnostic features.

Prey species were recorded as present or absent and expressed as a percentage of the total samples in which that prey type was present (i.e. frequency of occurrence) at each site and for each time period. Chi-squared analysis was used to test for differences between the three sites for all samples from 2005. Amphipods (Order Amphipoda) and feathers recorded in the samples were excluded from analysis. Amphipods were present only in fresh samples and were completely undigested, suggesting that they were present on scats after digestion had occurred. Feathers were very small, and may have been ingested during preening. Species with a low frequency of occurrence, such as Pipi and Burrowing Sand Crab *Matuta* sp., were grouped together.

Results

Opportunistic observations of diet

At Nambucca, three Beach Stone-curlews were recorded feeding on Light Blue Soldier Crabs at low tide, and at night one adult was observed carrying a dismembered ghost crab *Ocypode* sp. At Wooli, one Stone-curlew was observed foraging on soldier crabs *Mictyris* spp. for 10 minutes at low tide.

Prey type and frequency of occurrence

From all samples, 438 prey items from 14 taxa were recorded, with 36 items unidentifiable. One taxon was unidentifiable, one was identified to class, one to

Table 1. Number and frequency of occurrence of prey species found in 218 Beach Stone-curlew scats collected in August and October 2005 from Wooli (n = 73), Corindi (n = 74), and Nambucca (n = 71) Rivers. Percentage of scats with each prey species is shown in parentheses. Other species include Pipi *Donax deltoides*, other molluscs, and Burrowing Sand Crab *Matuta* sp.

Prey species	*Site*		
	Wooli	*Corindi*	*Nambucca*
Crabs			
Ocypodidae			
Horn-eyed Ghost Crab *Ocypode ceratophthalma*	11 (15)	–	2 (3)
Common Ghost Crab *Ocypode cordimana*	–	2 (3)	–
Myctyridae			
Light Blue Soldier Crab *Mictyris longicarpus*	59 (81)	50 (68)	58 (82)
Dark Blue Soldier Crab *Mictyris* sp. cf. *platycheles*	6 (8)	54 (73)	7 (10)
Grapsidae			
Red-fingered Marsh Crab *Sesarma erythrodactyla*	2 (3)	2 (3)	–
Grey Shore Crab *Helice leachi*	4 (6)	2 (3)	10 (14)
Variegated Shore Crab *Leptograpsus variegatus*	6 (8)	6 (8)	6 (9)
Spotted Smooth Shore Crab *Paragrapsus laevis*	3 (4)	7 (10)	–
Sowrie Crab *Plagusia* sp. cf. *glabra*	3 (4)	–	17 (24)
Insects	7 (10)	5 (7)	9 (13)
Other species	2 (3)	5 (7)	7 (10)
Unidentifiable	9 (12)	1 (1)	11 (16)
Total prey items	**112**	**134**	**127**

phylum, and the remaining 11 were identified to species. The insect and mollusc fragments were identified to class only, with the exception of Pipis. Fragments of species that could not be confidently identified but were clearly different from all other species were recorded as unidentifiable.

The frequency of occurrence of prey types did not differ significantly between sites (P >0.05). Remains of Light Blue Soldier Crabs and Dark Blue Soldier Crabs *Mictyris platycheles* were recorded in scats at all sites. The Light Blue Soldier Crab was the most frequently recorded prey item at Wooli and Nambucca, but the Dark Blue Soldier Crab was most frequent at Corindi (Table 1). Significant

Table 2. Number and frequency of occurrence of prey species found in 173 dry (D) and 45 fresh (F) Beach Stone-curlew scats collected in August and October 2005 from Wooli (48 D, 25 F), Corindi (63 D, 11 F), and Nambucca (62 D, 9 F) Rivers. Percentage of scats with each prey species is shown in parentheses. Other species include Pipi, other molluscs and Burrowing Sand Crab.

Prey species	*Site*					
	Wooli		*Corindi*		*Nambucca*	
	D	*F*	*D*	*F*	*D*	*F*
Crabs						
Ocypodidae						
Horn-eyed Ghost Crab	6 (13)	5 (20)	–	–	–	2 (22)
Common Ghost Crab	–	–	2 (3)	–	–	–
Myctyridae						
Light Blue Soldier Crab	37 (77)	22 (88)	43 (68)	7 (64)	54 (87)	4 (44)
Dark Blue Soldier Crab	5 (10)	1 (4)	45 (71)	9 (82)	6 (10)	1 (11)
Grapsidae						
Red-fingered Marsh Crab	2 (4)	–	2 (3)	–	–	–
Grey Shore Crab	2 (4)	2 (8)	2 (3)	–	4 (7)	6 (66)
Variegated Shore Crab	6 (13)	–	6 (10)	–	6 (10)	–
Spotted Smooth Shore Crab	3 (6)	–	7 (11)	–	–	–
Sowrie Crab	3 (6)	–	–	–	17 (27)	–
Insects	4 (8)	3 (12)	4 (6)	1 (9)	5 (8)	4 (44)
Other species	–	2 (8)	5 (8)	–	7 (11)	–
Unidentifiable	7 (15)	2 (8)	1 (2)	–	11 (18)	–
Total prey items	**75**	**37**	**117**	**17**	**110**	**17**

differences in frequency were recorded for Dark Blue Soldier Crab ($\chi^2_2 = 93.93$, $n = 218$, $P < 0.05$), grapsid crabs ($\chi^2_2 = 11.50$, $n = 218$, $P < 0.05$), and unidentifiable prey ($\chi^2_2 = 9.24$, $n = 218$, $P < 0.05$). Grapsid crabs had a significantly greater average occurrence in scats at Nambucca (46%) than at Wooli (25%) and Corindi (23%). The Dark Blue Soldier Crab had a significantly higher occurrence at Corindi (73%) than at Nambucca (10%) and Wooli (8%).

The greatest number of prey species identified in scats was at Wooli (8 species) followed by Corindi (7) and Nambucca (6), with four species common to all sites (Table 1). The Common Ghost Crab *Ocypode cordimana* was recorded at Corindi only, whereas the Horn-eyed Ghost Crab was recorded at Wooli and Nambucca (Table 1). The Red-fingered Marsh Crab *Sesarma erythrodactyla* and the Spotted Smooth Shore Crab *Paragrapsus laevis* were recorded in a small proportion of samples at Wooli and Corindi.

Table 3. Number and frequency of occurrence of prey species found in 24 dry Beach Stone-curlew scats collected in February 2000 from Farquhar Inlet (9), and Corindi (7) and Nambucca (8) Rivers. Percentage of scats with each prey species is shown in parentheses. Other species include Pipi, other molluscs and Burrowing Sand Crab.

Prey species	*Site*		
	Farquhar	*Corindi*	*Nambucca*
Crabs			
Ocypodidae			
Horn-eyed Ghost Crab	2 (22)	4 (57)	4 (50)
Common Ghost Crab	7 (78)	4 (57)	2 (25)
Myctryidae			
Light Blue Soldier Crab	3 (33)	3 (43)	3 (38)
Dark Blue Soldier Crab	–	–	–
Grapsidae			
Red-fingered Marsh Crab	–	–	1 (13)
Grey Shore Crab	–	–	3 (38)
Variegated Shore Crab	–	–	–
Spotted Smooth Shore Crab	–	–	–
Sowrie Crab	–	–	–
Insects	5 (56)	1 (14)	4 (50)
Other species	3 (33)	–	1 (13)
Unidentifiable	6 (67)	2 (27)	7 (89)
Total prey items	**26**	**14**	**25**

The Dark Blue Soldier Crab and Light Blue Soldier Crab were recorded in both fresh and dry samples at all sites (Table 2). A greater number of prey types was recorded in dry than in fresh samples at all sites (Table 2). The only prey type unique to fresh samples was 'other species' at Wooli. The Grey Shore Crab *Helice leachi* was the only grapsid recorded in fresh samples.

Substantially fewer prey items were recorded in the samples from 2000, although fewer samples were collected then. Ghost crabs had a higher frequency in the samples from 2000, but the frequency of soldier crabs was substantially lower than in the scats collected in 2005 (Table 3). The total number of prey types recorded in 2000 and 2005 was similar at Nambucca but not at Corindi.

Discussion

Prey types

Crabs comprised >80% of the species of prey recorded, which is consistent with previous observations (Clancy 1986; Geering 1988; Marchant & Higgins 1993; Burnett *et al.* 1998). The results suggest that Beach Stone-curlews forage in most littoral and intertidal habitats within the vicinity of their shelter-sites.

Prey includes species from intertidal sand- and mudflats, mangroves, saltmarsh, estuarine shorelines and rocky shores (Dakin & Bennett 1987).

Grey Shore Crabs and Spotted Smooth Shore Crabs are typical of upper tidal areas, Red-fingered Marsh Crabs occur within mangroves and saltmarsh, Light Blue and Dark Blue Soldier Crabs utilise intertidal sandflats, ghost crabs range from the high-tide line to several hundred metres inland, and Burrowing Sand Crabs occur on sandy beaches near the low-tide mark (Dakin & Bennett 1987; Jones & Morgan 1994; Davey 1998). Both the Sowrie Crab *Plagusia* sp. and Variegated Shore Crab *Leptograpsus variegatus* inhabit rocky shores, where they occur in the intertidal zone. The Sowrie Crab inhabits rock pools at lower tidal levels, often in groups, which could make it a favoured prey item, although it would be difficult to capture. Crabs of rocky shores may move to more exposed positions at night (Edgar 2001) and, if so, this would make Sowrie Crabs more accessible to Stone-curlews. Both Sowrie Crab and Variegated Shore Crab remains were recorded in the same Stone-curlew scat on two occasions (GFM & DAR pers. obs.), suggesting that these species may be consumed at the same time.

Ghost crabs are large crustaceans that occur in high densities at some sites. The two species, Common and Horn-eyed Ghost Crabs, inhabit different areas of sandy beach habitats but both are fast moving, agile and active at night. The former occurs in drier sandy areas up to 300 m from the high-water mark, whereas the latter occurs closer to the shoreline (GFM & DAR pers. obs.). Horn-eyed Ghost Crabs can be particularly abundant on some beaches, which, coupled with their large size, makes them an attractive prey item. Beach Stone-curlews have been observed moving from estuaries to ocean beaches at dusk, and tracks supporting this behaviour have been observed during early-morning observations.

Preferred prey

The diet of the Beach Stone-curlew in northern NSW is dominated by soldier crabs and supplemented with other species of crab from various habitats. This species may need to forage on a range of prey types to account for tidal and diurnal differences in prey availability. The mass movement of soldier crabs over sandflats makes them a particularly attractive prey item as many can be captured with minimal effort. However, soldier crabs are not active throughout the entire tide period, and observations suggest that Stone-curlews foraging on them quickly reach a digestive bottleneck and need to digest prey before resuming feeding activity, in a manner similar to the Eurasian Oystercatcher *Haematopus ostralegus* feeding on mussels (Zwarts *et al.* 1996). By the time that prey is digested, soldier crabs may no longer be active on the surface.

Beach Stone-curlews may switch prey between seasons, with more ghost crabs consumed during the breeding season. The samples from 2000 were collected near shelter-sites late in the breeding season, and these samples contained a higher proportion of ghost crabs than samples collected in winter/spring 2005. Adult Stone-curlews may forage closer to nest- and/or shelter-sites during the breeding season (where they are more likely to encounter ghost crabs) or they may select ghost crabs to feed to chicks. Chicks were present at Corindi and Nambucca at the

time that the samples were collected in 2000 (Rohweder 2003), and scat samples were collected near nest-sites. By foraging close to nest-sites, time and energy spent moving to and from foraging habitat is minimised. As ghost crabs occur in burrows just above the high-water mark close to Stone-curlew nest-sites, they would be regularly encountered by Stone-curlews foraging at night. An adult ghost crab is equivalent in mass to several soldier crabs, although it is probably more difficult to capture. Its greater energy content may be offset by the time taken to capture and consume each crab, but the Stone-curlew may benefit from a greater protection of its eggs or chicks, with adults remaining closer to the nest-site. Ghost crabs can be taken whole to chicks whereas the smaller soldier crabs would need to be swallowed and regurgitated. Although regurgitating food may be a simpler form of delivery, ghost crabs represent a large biomass and may provide juveniles with experience handling larger crabs. Numerous ghost crab claws and empty carapaces were recorded near nest- and shelter-sites during 2000, suggesting that adult Stone-curlews dismember crabs and juveniles may consume the flesh but discard the carapace.

It is unknown how far Beach Stone-curlews travel to satisfy their daily energy requirements, but Bush Stone-curlews *Burhinus grallarius* travelled 1–2 km per night to suitable feeding grounds (Johnson & Baker-Gabb 1994). At Wooli, Beach Stone-curlews would need to travel up to 4 km to reach a rocky shore that is the favoured habitat of the Variegated Shore Crab. However, the low occurrence of this crab in Stone-curlew scats suggests that it is not a major component of the diet, and these crabs may be targeted outside the breeding season when Beach Stone-curlews often occur on ocean beaches.

Management

The Beach Stone-curlew is listed as Critically Endangered in NSW and Vulnerable in Queensland. There is evidence of increasing population size in some parts of Queensland and northern NSW (Milton 1998; Rohweder 2003), although the population in NSW is still small. Although Stone-curlews consume a variety of crustaceans from a range of coastal habitats, soldier crabs and ghost crabs are the most important prey items. To provide adequate foraging resources for this species in NSW, it is necessary to protect a matrix of different habitats in the vicinity of breeding and shelter sites.

There is limited information on the status of crustacean populations in NSW estuaries and ocean beaches, although various activities (including driving on beaches, collecting bait, water pollution and recreation: McPhee *et al.* 2002; Schlacher *et al.* 2007, 2008) may have direct and indirect effects on crustaceans. Schlacher *et al.* (2007) found that off-road vehicles can have a detrimental impact on Ghost Crab populations. Such an effect has particular implications for Beach Stone-curlews that nest on ocean beaches or rely on ocean beaches to satisfy part of their dietary needs. In northern NSW several recent and established pairs of Stone-curlews forage on ocean beaches that are used by 4-wheel-drive vehicles, and increasing vehicle use there may pose a direct threat to food resources and breeding success of Stone-curlews.

Acknowledgements

This project was undertaken by GM as part of an undergraduate degree at Southern Cross University. Ross Goldingay provided advice and guidance throughout the study and helpful comments on an early draft. Lexie Walker assisted with the identification of crustaceans and provided many essential crab keys and references, and Samuel Rohweder helped collect scats. David Charley, Greg Clancy and Paul Finn commented on the manuscript.

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Received 1 October 2010 ■