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Provision of artificial shelter on beaches is associated with improved shorebird fledging success

GRAINNE S. MAGUIRE, ANDREW K. DUIVENVOORDEN,
MICHAEL A. WESTON and ROBYN ADAMS

Summary

Artificial chick shelters might improve productivity of beach-nesting birds threatened by anthropogenic disturbance. We investigated the efficacy of three different chick shelter designs against four criteria: accessibility to chicks over time, thermal insulation, conspicuousness to beach-goers, and practicality (cost and ease of transport). One design ('A-frame') was selected because it offered the greatest thermal insulation, was the least conspicuous, most cost effective, and performed equally well in terms of accessibility. We deployed these artificial shelters on Hooded Plover *Thinornis rubricollis* territories where broods were present ($n = 11$), and compared the behaviour and survival rate of chicks to that at control sites ($n = 10$). We were unable to discern any difference in the behaviour of broods when artificial shelters were available. However, the survival rate of chicks to fledging was 71.8% higher where an artificial shelter was provided ($n = 21$ broods). This was validated by analysing data from a larger sample of broods monitored as part of an active volunteer-based management programme; shelters conferred a 42.8% increase in survival to fledging ($n = 81$ broods). Thus, artificial shelters have the potential to increase survival rates of threatened shorebird chicks, though the mechanisms through which survival is increased require further investigation.

Introduction

Sandy beaches are heavily used for human recreation (Schlacher *et al.* 2007), placing stress on some populations of beach-nesting birds, which breed at the time when humans are most abundant (Baird and Dann 2003). Ground-nesting shorebirds and seabirds are particularly vulnerable to having their cryptic chicks inadvertently crushed by humans. Furthermore, disturbance to brood-rearing parents can lead to the temporary abandonment of young, and as a consequence, an increase in depredation rates and thermal stress of chicks (e.g. Burger 1981, Flemming *et al.* 1988, Bergstrom 1991, Visser and Ricklefs 1993a,b, Weston and Elgar 2005). Chicks may also suffer from energetic stress, with high levels of disturbance, particularly from humans and dogs, often decreasing foraging time and increasing energy-expensive evasion/escape responses (e.g. Flemming *et al.* 1988, Beintema and Visser 1989, Burger 1991, Loegering and Fraser 1995, Lord *et al.* 1997, Weston and Elgar 2005). Low chick survival is a major contributor to the impoverished conservation status of many shorebird populations worldwide (e.g. Piping Plover *Charadrius melodus* US Fish and Wildlife Service 1996; Hooded Plover, Weston and Elgar 2005; New Zealand Dotterel, *C. obscurus*, Dowding and Davis 2007; Western Snowy Plover, *C. alexandrinus*, US Fish and Wildlife Service 2007).

Ameliorating threats to beach-nesting birds, while simultaneously maintaining human recreational access to beaches, is a challenge faced by conservation managers. While methods for improving hatching success, such as fencing, have been largely effective (Jimenez *et al.* 2001, Stoyle

2001, 2002, Ikuta and Blumstein 2003, Wills *et al.* 2003, Murphy *et al.* 2003, Lafferty *et al.* 2006; authors' unpubl. data) but see Mabee and Estelle (2000), the precocial chicks of beach-nesting birds are more difficult to protect because although they are flightless, they are free-roaming and forage in areas most commonly used by recreationists, specifically, close to the water's edge and wrack line (Mueller 1982, Schulz and Bamford 1987, Murphy *et al.* 2003, Weston 2005). Furthermore, avian depredation accounts for a high proportion of precocial chick mortality, so that large enclosures to exclude predatory birds are often not viable, and instead may increase adult mortality (Hatch 1970, Buech 1976, Mueller 1982, Burness and Morris 1992, Schulz 1992, Murphy *et al.* 2003, Ivan and Murphy 2005). Current approaches to chick management commonly involve the use of signage and regulations to reduce human disturbance. However, these have proved less successful than for egg protection, because management efforts tend to occur over larger sections of beaches, and so are less intensive. Thus, disturbance remains prevalent for chicks.

One suggested technique for reducing the effects of disturbance and predation of chicks on beaches is the placement of artificial 'chick shelters' within the breeding area (Weston 2005). A chick shelter is a purpose-built shelter with solid, closed walls, roof and at least one opening, which provides concealment and protection from crushing and/or shade that chicks can use when needed. This differs from open wire cages which serve only to prevent predator access. Artificial chick shelters potentially offer a practical way to increase fledging rates of beach-nesting birds by protecting them from crushing and offering a refuge from predators (Burness and Morris 1992, Stoyle 2002). Shelters also have the potential to reduce thermal and energetic stress experienced by chicks in highly disturbed areas. On beaches with low amounts of natural shelter such as seaweed/kelp, flotsam/jetsam, other debris or vegetation, placement of artificial shelters on the beach may provide refuge closer to profitable foraging areas (Flemming *et al.* 1988, Yalden and Yalden 1989, Lord *et al.* 1997, Goldin and Regosin 1998, Weston and Elgar 2005). Shelters may also provide a thermally suitable and stable microclimate, so that less brooding from adults may be required, particularly in extreme weather (Burger 1981, Mueller 1982, Burness and Morris 1992, Dowling and Weston 1999, Weston and Elgar 2005). Shelters marked with appropriate warnings may also help to avoid the well-intentioned or mischievous collection and removal of young (Anon 1999, D. Ryan *in litt.*)

The provision of artificial shelters for threatened shorebird chicks has been limited but has shown promise as a management tool for increasing fledging success in some species (Mueller 1982, Burness and Morris 1992, Lafferty 2001). However, effectiveness may be contingent on the design of the shelter. We therefore conducted field trials comparing three different chick shelter designs in relation to four criteria: 1) the influence of sand movement on the accessibility of shelter openings over time, 2) thermal protection properties (insulation), 3) the likelihood of detection by predators and people (limiting or even counteracting any benefit), and 4) their practicality in terms of cost and ease of transport. We selected the best shelter design to then investigate use of shelters by the threatened Hooded Plover *Thinornis rubricollis* on heavily-used Victorian beaches. We compared chicks in areas with only natural shelter available, versus those with artificial shelter present, in relation to three criteria: 1) how often artificial shelters were used, 2) potential energetic benefits inferred by time spent in different behaviours (i.e. foraging, brooding, hiding, resting), time spent in more energetically profitable habitat and the distance travelled in response to a threat encounter (i.e. escape distance), and 3) overall fledging success.

Methods

Study species

Hooded Plovers are socially monogamous, territorial birds with complete biparental care (Weston and Elgar 2005). They suffer high chick mortality probably in large part due to predators and disturbance, and this mortality contributes to population declines (Weston 2003).

Selecting the optimal shelter design

Comparisons of shelter designs (see below) occurred during October and November 2006. Shelters were placed on beaches along the Mornington Peninsula, Bellarine Peninsula and Bass Coast in southern Victoria, Australia. These locations experience high levels of human visitation and have high Hooded Plover abundance (Weston 2003). A 'site' was defined as a section of beach approximately 1 km in length. At each site, we randomly placed one shelter of each design at least 200 m apart. Shelters were only placed in suitable Hooded Plover habitat and were always placed at least 50 m from a beach access point, so spacing between shelters varied. Shelters were placed halfway between the high tide mark and the base of the dunes; a compromise between providing shelter close to foraging habitat (the lower beach) but avoiding inundation by high water. The shelters were oriented with an opening facing the water, because chicks generally move perpendicular to the water line when seeking cover (Weston and Elgar 2005).

Shelter designs

We compared three wooden shelter designs which varied in terms of shape, size, weight and number of entrance/exit openings. These are referred to as 'A-frame' (Fig. 1), 'square' (Fig. 2) or 'rectangle' (Fig. 3) based on their shape, and were selected because they were safe for beach-goers (heavy pipes could potentially be dangerous to recreationists), because wood is commonly beach cast, and because they were easy to manufacture and so offered the opportunity for widespread deployment by community groups.

Ten shelters of each design were constructed. Guidelines were drawn up to mark the depth at which each shelter would be buried, allowing for a height of 15 cm inside the A-frame, and 10 cm inside the square and rectangle. On each shelter, the message 'Threatened bird shelter. Do not disturb' was written on the most visible panel. Shelters were stained with a clear, waterproof, non-toxic outdoor decking stain.

Shelter selection process

We assessed each shelter design according to the following criteria (all data presented are means ± standard error, and the significance of results determined by a probability of < 0.05). All analyses were carried out using Genstat (version 7):

1) Accessibility of shelters. The accumulation or erosion of sand from around and inside shelters may render them unusable by chicks, by blocking openings, filling the internal space or creating steep inclines for chicks to climb. To compare the rate and intensity of sand movement around and inside shelters, we made weekly measurements over seven weeks of the vertical

Figure 1. The A-frame shelter was constructed of two 300 × 400 mm panels of 12 mm-thick exterior plywood screwed together via a 25 × 25 mm wooden crossbeam.

Figure 2. The square shelter was constructed using a 400 × 400 mm exterior plywood panel (10 mm thick) as a roof, with four 400 × 300 mm panels forming the walls, attached via 25 × 25 mm crossbeams. The walls were attached to each side of the 400 x 400 mm roof via their 300 mm end, to allow a gap of 100 mm at each corner, giving the square shelter four openings. The deeply buried walls of this shelter, and narrow openings were designed to resist attempts by predators to dig their way inside.

distance from the level of the sand to the top of the shelter at multiple points around entrance ways and at midpoints of the walls. Because the changes in sand level inside and outside the shelter were highly correlated, we used external measurements only in our analyses. We ran a Generalised Linear Mixed Model (GLMM) to test for variation in sand levels at shelter openings for the different designs over time (using the interaction term shelter type*week). For each individual shelter tested, an identifier 'shelter ID' was used as a random factor in the model to control for the multiple measurements points per shelter.

2) Thermal protection (insulation). Chick shelters may buffer chicks from environmental temperatures, as well as protecting them from wind and rain. We used cordless, waterproof Geosignal TF50 probes (Measurement range: −40°C to +70°C; Resolution: 9 bit [0.2% FS, 0.4° C]; size: 38 × 20 mm) to take temperature readings at 20-minute intervals over 24 hours between December 2006 and April 2007, both inside and outside shelters; $n = 15$ shelters, resulting in an average of 1,115 paired measurements for each shelter design (A-frame, $n = 1{,}096$; square, $n = 1{,}124$; rectangle, $n = 1{,}125$).

Given that there are no optimal temperature ranges for precocial chick survival available from the literature, we decided to explore the insulation abilities of shelters under conditions of relatively low (below 17 °C) and relatively high (above 30° C) ambient temperatures. We selected all ambient (outside shelter) temperature data meeting these criteria and used GLMM to test for variation in insulation properties (i.e. the difference between the internal shelter temperature and outside ambient temperature), according to shelter design. GLMM is more robust than ANOVA

Figure 3. The rectangle shelter was constructed of a 300 × 400 mm top panel of 18 mm thick exterior plywood. Two 400 × 240 mm lengths of 45 mm thick hardwood were screwed to the shorter ends of the top panel. Two 250 × 250 mm panels of 18 mm thick exterior plywood were attached to opposing ends of each of the longer sides of the top panel, creating openings on each side, but at opposite ends of the shelter.

at analysing an unbalanced dataset (i.e. the different sample sizes for paired data in desired temperature ranges per 24-hour sample), and allowed for 'shelter ID' to be nominated as a random term in the model to accommodate the repeated sampling of a shelter over a 24-hour period. We also explored the frequency at which the internal temperature was warmer, cooler, or the same as the ambient temperature for each shelter design using chi-square analysis.

3) Conspicuousness of shelters to people and predators. We noted whether shelters had been removed or displaced by people or predators when carrying out the above tests. To obtain a quantitative measure of the likelihood of disturbance to shelters, we also conducted 21 one-hour bouts of observation of individual shelters (seven per design). The observer was positioned at a vantage point that allowed a 360 degree view of the shelter and surroundings, but was inconspicuous to subjects (people and animals). To obtain reactions from naive subjects, we placed shelters on beaches where they had not been previously used (i.e. for above tests of criteria 1–2). Using logistic regression, we explored variation in the likelihood of a person detecting a shelter according to their distance from the shelter, and design of the shelter. Distance from the shelter was categorised as the closest distance a subject passed the shelter without detecting it, or alternatively, the distance at which the shelter was detected (< 5 m, < 10 m, < 20 m, < 50 m). To determine post-hoc differences in the interaction between shelter design and the distance of the subject from the shelter, we had to exclude data in the < 5 and < 50 m categories due to small sample size, and conduct independent logistic regressions for the remaining datasets. We also performed a logistic regression to determine if people were more likely to approach shelters of different designs.

4) Practicality, specifically cost, maintenance, and ease of implementation. We compared the strengths and weaknesses of each design in terms of construction cost and time, weight and ease of transportation, as well as the average time taken to deploy shelters.

Benefits conferred by the optimal shelter design

High nest and brood failure rates meant that an adequate sample size would be difficult to achieve, thus the breeding success of 82 pairs of Hooded Plovers was monitored during the study period to rapidly detect extant broods. Of 147 nests, 41.5% hatched successfully and 16.3% successfully fledged at least one chick (authors' unpubl. data). Due to such low chick survival, we aimed to observe chicks in the field as soon as possible after they were first sighted and alternated between provision of artificial or no shelter for each reported brood. Our observations extended from Port Fairy (38°21.580 E, 142°18.064 S) in the west to Venus Bay (38° 42.675 E, 145° 48.978 S) in the east. All sites were wide ocean beach, backed by vegetated dunes with the main cover on the beach itself being seaweed, with very little to no driftwood. We assumed that there was no bias in human pressure at sites with or without artificial shelter ($n = 81$). Indeed there was no difference in frequency of occurrence of people (sites with shelters, 4.46 ± 0.69 mean people per visit; without shelters, 4.41 ± 0.34; Mann-Whitney $U = 642$, $P = 0.793$; authors' unpubl. data).

We observed a total of 21 broods, 11 with access to natural shelter only (i.e. seaweed/kelp, flotsam/jetsam and dune-grass) and 10 with additional access to an artificial shelter. Chicks were aged based on either known hatching date or a combination of expected hatching date and appearance. Ages ranged from 1 to 25 days old (with shelter range: 2–25 days, 10.00 ± 2.14 days; without shelter range: 1–10 days, 4.38 ± 0.76 days; Mann Whitney $U = 35.5$, $P = 0.067$).

We observed chicks using a spotting scope (× 30) from 40–80 m away from a concealed position, between 08h45 and 19h30. Each observation lasted for two hours (referred to as an observation session), intended to be long enough to observe chicks experiencing at least one encounter (defined as a stimulus coming within 100 m of a brood, and thus being close enough to possibly elicit a reaction from chicks).

For broods provided with artificial shelter, we placed one shelter (of the optimal design) halfway between the high-tide mark and the base of the dune with an opening facing the water.

Broods without artificial shelter were similarly approached. After placement, we waited 15 minutes before beginning the observation so that any observer-related disturbance associated with shelter placement would be minimised. We measured the benefits associated with shelters using the following three criteria:

1) Use of shelters. We recorded the number of occasions chicks went inside shelters during each two-hour observation session, together with any events that may have triggered use. We also kept records of opportunistic sightings (made by land managers and volunteers monitoring hooded plover breeding success) of shelter use over two breeding seasons, 2006/2007 and 2007/2008.

2) Energetic benefits. To explore whether chicks with artificial shelter experienced energetic benefits, we recorded the activity budget of chicks within the brood during each observation session. We categorised their behaviour as: foraging (actively searching and pecking at substrate); resting (when chicks passively stood or sat still for more than 30 seconds); brooded by parents; and hiding (generally after an encounter and characterised by a flattening of the body against the substrate or natural shelter such as seaweed/flotsam). We also recorded the broods' movements across different 'zones' of the beach, defined as: water's edge (which included rock platforms), the beach between the water's edge and base of the foredune (divided equally into lower, middle and upper sections), and dune (after Weston and Elgar 2005). Because our data revealed use of different zones of the beach to be highly correlated with one another, only lower beach, upper beach and dune were selected for analysis.

We summed the time each chick within a brood performed a given behaviour, and time spent on zones of the beach, and transformed these into proportions for each brood by dividing by the observation time (120 min, minus any time chicks were lost from sight, 13.69 ± 2.80 min per chick) multiplied by the number of chicks in the brood. Variation in the proportion of time devoted to foraging, resting, hiding and brooding was analysed using GLMM with a linear link function for normally distributed data or a logarithm link function for Poisson distributed data, with chick age, the number of encounters and the presence of a shelter as factors in each model. A 'brood identifier' was included as a random factor in all analyses. Similar models were used for assessing variation in the proportion of time broods spent on different beach zones. In each analysis, we used age as a covariate.

To explore whether the presence of a shelter altered the escape response of chicks to disturbance, we calculated the difference in the position of chicks on the beach (graded as: water's edge = 1, lower beach = 2, mid-beach = 3, upper beach = 4, dune = 5), before and after an encounter. We then analysed the variation in the number of beach zones broods moved in reaction to a disturbance using GLMM using presence of an artificial shelter as a factor, and the proximity of the encounter and age as covariates. A 'brood identifier' was included as a random factor.

3. Fledging success. All pairs with chicks were visited using a standard approach of detecting the pair through binoculars from a distance of at least 100 m to observe the brood before they went into hiding. Where the pair was sighted and the brood was not seen, the observer then left the area and hid 100 m or more away and waited until the pair returned to their undisturbed behaviour. The observer watched for up to 40 minutes. At least three visits where the chicks were not sighted were required for the brood to be recorded as dead, and this was coupled with observations of non-breeding behaviour (the pair having no tendency to return to a location or to behave defensively). Furthermore, in the majority of cases, a new nest was initiated within the time it would have taken the brood to reach fledging age, signalling that the pair had definitely lost their chicks.

We left shelters in situ after their initial placement for the remainder of the brood-rearing period. Chicks fledge at around 35 days after hatching (Weston 2000). We excluded broods that were given shelter late in the chick phase (i.e. older than 14 days, $n = 3$), so that there were 11 with shelter and 10 without, used in the analysis. Chick age did not differ between treatments (6.45 ± 1.25 with shelter vs. 4.38 ± 0.76 without shelter; Mann-Whitney $U = 35.5$, df = 1, $P = 0.165$). We used logistic regression to compare the likelihood of a brood fledging with 'shelter presence' as a factor in the model and 'age' as a covariate. We validated our results by examining a larger number of territories within the study area where shelters were deployed in the 2006/2007 ($n = 39$) and 2007/2008 breeding seasons ($n = 42$). Exact age data were unavailable for this analysis but only broods first observed under two weeks old were included. These data were analysed in a separate GLMM analysis where territory was included as a random term to control for broods from the same pair over different seasons.

Results

Tests of shelter design

Criterion 1. Accessibility of shelters

On average, sand level altered by only −0.22 cm at shelter openings (A-frame, −3.92 to 3.77 cm, $n = 9$; square, −2.65 to 5.65 cm, $n = 9$; rectangle, −6.3 to 2.35 cm, $n = 8$). There was no significant difference in the overall sand accumulation at openings according to shelter design (GLMM, interaction term shelter type*week: Wald Statistic = 1.09, df = 2, $P = 0.58$).

Openings were completely filled 8.6% of the time (A-frame one of 18 opening checks; square four of 36; rectangle one of 16). However, openings also became deeper due to sand erosion, with the most extreme examples being increases of 11 cm (square, $n = 36$ opening checks), 5.9 cm (A-frame, $n = 18$), and 5.3 cm (rectangle, $n = 16$).

Criterion 2. Thermal protection (insulation)

During the testing period, the ambient temperature was 22.46 ± 0.14 °C (9.82-48.64 °C, $n =$ 3,348 temperature recordings). For ambient temperatures above 30 °C, shelters were on average 9.0 °C cooler; there was no significant difference in the degree of cooling between shelter designs (see Table 1). Similarly, there was no significant difference in the insulation offered by shelter designs at ambient temperatures below 17 °C, when on average shelters were 0.8 °C warmer than the ambient temperature (see Table 1).

The frequency at which shelters were cooler, warmer or equal to the ambient temperature varied significantly according to shelter design (Table 1). The square and A-frame designs were more frequently cooler or hotter than ambient temperature (i.e. insulative), while the internal

Table 1. Internal temperature ranges of shelters relative to 'extreme' ambient temperatures (a negative temperature is one that is cooler than the ambient temperature) and frequency data for the number of occasions when shelters were cooler, warmer or equal to the ambient temperature. Asterisks indicate significant results (i.e. $P < 0.05$).

Ambient Temp.	*A-frame* (*n* = 1,096)	*Square* (*n* = 1,124)	*Rectangle* (*n* = 1,125)	GLMM output *Wald statistic*	 *df*	 *P*
	Internal temperature range					
> 30 °C	−21.7 to −1.5*	−17.6 to −0.5	−16.6 to −0.5	1.02	2	0.601
< 17 °C	−2.0 to 4.1	−2.7 to 4.6	−2.0 to 4.9	3.61	2	0.164
	Frequency					
Cooler	622	656	710	$\chi^2 = 83.28$	4	< 0.001*
Equal	46	43	116			
Warmer	428	425	299			

*For example, at temperatures above 30°C, this shelter design was between 1.5 and 21.7°C cooler than the ambient temperature.

temperature of the rectangle was more often equal to the ambient temperature, particularly when ambient temperatures were low (Table 1).

Criterion 3. Conspicuousness of shelters to people and predators

Over seven weeks, people moved shelters 7% of the time ($n = 210$ shelter checks), and a further five shelters had objects (beach litter, animal bones, flotsam/jetsam) placed inside or on top of them (A-frame, $n = 0$; square, $n = 1$; rectangle, $n = 4$). Overall these instances of shelter disturbance were unrelated to shelter design ($\chi^2_2 = 3.92$, $P = 0.141$).

There were significant differences in the likelihood that people would detect shelters of different designs. People were more likely to notice the rectangle than either the A-frame or square designs (Table 2). The distance of the shelter from the subject also significantly influenced its detection (Logistic Regression, $\chi^2_2 = 28.86$, $P < 0.001$), whereby all subjects within 5 m noticed the shelter, while none noticed the shelter from 50 m (Table 2). Due to low sample size, individual post-hoc tests could only be conducted for 10 m and 20 m distance categories. These revealed no difference in detection of the three designs (Table 2).

There was no significant difference in the likelihood of a person approaching a shelter according to either its design or the distance of that person from the shelter (Logistic Regression, $\chi^2_1 = 2.10$, $P = 0.147$). Only two of the 17 subjects (11.8%) noticing a shelter touched it (too few for analysis).

Of 157 occasions of birds passing shelters (Silver Gulls *Larus novaehollandiae*, Pacific Gulls *L. pacificus*, Hooded Plovers, ducks Anatidae spp., ravens *Corvus* spp., Australian Magpies *Gymnorhina tibicen*, Crested Terns *Sterna bergii* and White-faced Herons *Egretta novaehollandiae*), none apparently noticed or interacted with the shelters. Only one of 26 passing dogs approached a shelter, but this was in response to its owner approaching.

Criterion 4. Practicality

The A-frame design was the cheapest to construct, lightest, most easily transported, and the fastest to build and place in the field (see Table 3).

Shelter selection The square and A-frame shelters attracted the least human interference and offered superior insulation to the rectangle, but overall the A-frame offered a greater thermal benefit and was the more practical of the two designs. Thus, the A-frame shelter was used in subsequent experiments.

Table 2. The percentage of human/shelter interactions, according to shelter design. N values refer to the number of groups of people passing by a shelter during an observation period. Asterisks indicate significant results ($P < 0.05$).

	Shelter design	A-frame ($n = 34$)	Square ($n = 71$)	Rectangle ($n = 45$)	Total ($n = 150$)	Logistic regression results		
						χ^2	df	P
Reaction	Noticed	11.7	5.6	20.0	11.3	8.60	2	0.014*
	Approached	0	2.8	6.7	3.3	2.22	2	0.330
	Touched	0	1.4	2.2	1.3	–	–	–
Distance first noticed	< 5 m	14.7	1.4	4.4	5.3*	–	–	–
	< 10 m	8.8	2.8	0	3.3	2.76	2	0.251
	< 20 m	2.9	1.4	4.4	2.7	1.65	2	0.438
	< 50 m	0	0	0	0*	–	–	–

Table 3. Comparative shelter construction costs ($AUD), construction times (where wood is already pre-cut), storage volume (for 10 shelters, which reflects stacking), weight and placement time (to bury in sand and fill to guidelines). Data are presented as means with standard error (construction occurred in batches, so no SEs are presented).

Design	Cost (per unit)	Construction Time (mins)	Storage Volume (m^3)	Weight (kg)	Placement Time (secs)
A-frame	$9.20	15	0.12	1.5 ± 0.07	63.4 ± 6.4
Square	$18.00	30	0.40	3.4 ± 0.07	488.6 ± 63.7
Rectangle	$29.10	35	0.31	8.9 ± 0.03	291.4 ± 29.1

Benefits conferred by the optimal shelter

Criterion 1. Use of shelters

Of 14 observations of broods where an artificial shelter was available, broods used these shelters during three observation sessions (21.4% of observations; see Table 4). Additional sightings were made of chicks using shelters outside the formal observation sessions (see Table 4), accounting for evidence of shelter use in 38.4% of broods presented with shelters. In the 2007/2008 breeding season, as part of the community-based conservation programme, 33.3% of broods used shelters when these were available ($n = 12$) and were observed using shelters on multiple occasions.

Criterion 2. Potential energetic benefits

Brood age had no effect on the proportion of time spent on different levels of the beach nor the activity budget of broods (all $P > 0.05$, see Table 5), with the exception of resting behaviour, where older broods spent more time resting (GLMM, effect size = 0.015 ± 0.005). The number of encounters experienced by broods approached significance for hiding behaviour, with the more encounters experienced, the more time spent hiding (Table 5; GLMM, effect size = 0.008 ± 0.004). The presence of a shelter had no effect on brood activity budgets or the level of beach occupied (Table 5).

During observations of chicks, 288 encounters with potential threats were recorded; 5.3 ± 0.7 encounters per hour. On only one occasion did an encounter end in mortality of a chick. The likelihood of a brood reacting to an encounter was not influenced by the presence of an artificial shelter at the site (GLMM, Wald Statistic = 1.90, df = 1, $P = 0.168$). The escape distance of chicks was also unrelated to the presence of an artificial shelter (GLMM, Wald statistic = 0.41, df = 1, $P = 0.521$; chick age, Wald statistic = 0.52, df = 1, $P = 0.473$).

Criterion 3. Fledging success

Fledging rates for broods that we observed with access to artificial shelter versus those that only had access to natural shelter varied significantly (logistic regression, shelter $\chi^2_1 = 10.612$, $P < 0.001$; age $\chi^2_1 = 0.782$, $P = 0.377$). Of 10 broods with access to only natural shelter, 10.0% fledged, while of 11 broods with access to an artificial shelter, 81.8% fledged successfully. Fledging success data from additional broods in the 2006/2007 and 2007/2008 breeding season, revealed that 22.4% that did not have access to artificial shelter survived to fledge, while 65.2% that had access to artificial shelters survived to fledge ($n = 81$; GLMM, Wald Statistic = 10.17, df = 1, $P = 0.001$). When the number of chicks surviving within a brood is considered, the average number surviving when they had access to artificial shelter was 0.87 ± 0.82 chicks versus 0.33 ± 0.71 for those with only natural shelter ($n = 81$ broods, 39 chicks; Mann Whitney $U = 387.5$, df = 1, $P < 0.001$).

Table 4. Details of observations of broods that used artificial shelter including number of chicks in the brood, age of the brood, temperature during observation session, type of observation ('obsv' refers to within the observation session, 'outside obsv' refers to observations made by rangers or volunteers monitoring breeding pairs) and the context of shelter use. One brood was observed on two occasions. Data in brackets refers to conditions during shelter use outside the observation session. Eight additional broods had access to artificial shelter but were not observed using this shelter during observation sessions (age range 2–24 days, mean 10.9 days; temperature range 19–32° C, mean 23.1° C).

Brood identifier	Brood size	Brood age (days)	Air temp. (° C)	Provenance of observation	Context of shelter use
Point Impossible	3	14	32	Obsv	A flock of ravens flew over the brood; all reacted by running from water's edge into shelter. All remained there until the ravens had passed, then two emerged and returned to forage at the water's edge, while one chick sat inside the shelter, resting for the remainder of the observation session (15 minutes).
Venus Bay	1	5	16	Obsv	An adult and chick were seen to take refuge inside the shelter as light rain began to fall. No disturbance event triggered use.
Fingal, MPNP	2	5	22	Obsv	Two chicks were seen to regularly enter the shelter to rest before emerging after a few minutes to forage. No disturbance events triggered use.
London Bridge, MPNP	1	3, 20 [11, 12, 32]	18 [>30]	Outside obsv	Chick sighted on three occasions sitting in shelter for several hours on hot (30+ °C) days, as well as running to shelter when people walked by along the water's edge. The parents would stand either directly outside shelter or a few metres away.
Rye West, MPNP	1	6 [2]	21 [20]	Outside obsv	Chick seen taking refuge inside a shelter in response to multiple human encounters, remaining there each time until the people had left the vicinity.

Table 5. GLMM output for the proportion of time broods spent in different activities and on different beach zones according to the number of encounters experienced, the presence of an artificial shelter and age of the chicks. Asterisks indicate significant results (*, $P < 0.05$, **, $P < 0.01$).

		Percentage of time (mean ± se)	Number of Encounters		Shelter Presence		Chick age	
			Wald Statistic (df = 1)	P	Wald Statistic (df = 1)	P	Wald Statistic (df = 1)	P
Activity	Foraging	43.6 ± 4.4	0.58	0.448	0.13	0.719	0.02	0.889
	Resting	26.4 ± 3.9	0.00	0.976	0.03	0.861	8.68	0.003*
	Hiding	10.4 ± 1.7	3.43	0.064**	0.12	0.727	0.89	0.346
	Brooding	15.5 ± 4.3	0.60	0.437	0.01	0.932	1.30	0.254
Zone	Dune	8.4 ± 2.5	0.07	0.786	0.33	0.569	0.02	0.886
	Upper-Beach	29.5 ± 5.4	0.05	0.825	0.32	0.570	0.22	0.642
	Lower-Beach	13.8 ± 3.1	0.06	0.811	0.21	0.649	0.50	0.480

Discussion

Despite artificial shelters being used in shorebird conservation efforts worldwide, we are unaware of researchers who have quantified and analysed the performance of different artificial shelter designs before their use (Mueller 1982, Burness and Morris 1992). This study confirms the contention (Mueller 1982, Burness and Morris 1992) that artificial shelters confer potential thermal benefits to chicks and that designs differ in their insulative properties, in particular in their ability to remain cool in hot conditions (presumably because of ventilation properties). Shelters differed in their conspicuousness to people, and hence their exposure to unwanted and potentially damaging interference. All three shelter designs persisted equally well in coastal conditions, albeit in the context of a relatively short exposure period. Inundation led to the destruction and displacement of a number of shelters, although no particular shelter design appeared more or less prone or resistant to this damage. While there was no significant difference in sand accumulation or erosion between designs, a small percentage (8.6%) of shelters are likely to become inaccessible to chicks due to sand movement, regardless of design.

While we selected a shelter design most appropriate for the prevailing conditions and threats, it is possible that other designs may be more appropriate under other circumstances. For example, in South Australia, one of the major threats to Hooded Plover chicks is crushing by vehicles (Buick and Paton 1989). The rectangle design was more conspicuous and may be more likely to be avoided by vehicles. Its sturdiness may also be more resistant to crushing. We did not measure the degree of protection shelters offered from predators (though our data on survival probably means they were effective to some extent), and this may be particularly important where predators are active or abundant. We also acknowledge that there are variety of shelter designs which we did not test (we focused on three designs judged *a priori* to hold the greatest promise), and which may offer refinements in effectiveness.

Unlike observations of terns where chick survival was increased (Mueller 1982, Burness and Morris 1992), Hooded Plover chicks were very rarely seen using shelters during our observations. However, this is likely to be a product of the short duration and one-off nature of the observation sessions. Anecdotal evidence indicates a substantially higher usage rate, and use of shelters at night is unknown and may be very important. Our tests of the benefits chick shelters offered chicks were equivocal. Our results suggested that shelters did not confer energetic benefits, through more foraging time, shorter commute distances to cover or enhanced foraging habitats (Mueller 1982, Weston and Elgar 2005). Shelters might provide some thermal buffering for chicks that would normally be provided by brooding from adults or by the use of natural shelter (O'Connor 1984, Visser and Ricklefs 1993a,b). Other shorebird chicks commonly use shelters as a source of shade in hot weather (Mueller 1982, Burness and Morris 1992). While temperatures in this study included extremes (sand, 9–48° C), the anticipated reduction in the amount of time chicks were brooded in the presence of shelters was not evident. The failure to detect significant effects of shelters on energetic and thermal behavioural surrogates may reflect observation periods that occurred in mild (22.3 ± 4.8 °C) or energetically unchallenging conditions. Anecdotal observations of chicks using shelters regularly and for prolonged periods during hot days and rain (this study) supports the idea that shelters may be used by chicks under challenging thermal conditions. Certainly, anecdotal observations revealed more extensive shelter use than estimates derived from our observations, suggesting more observational effort may be required before subtle affects of shelters may be detected.

While we were unable to reveal the mechanisms involved, the survival of chicks in this study was greatly correlated with the presence of an artificial shelter. To avoid confusing enhanced survival with other parameters, we randomly allocated the provision of artificial shelter to broods, and the age range of these broods was similar to those with only natural shelter and was included as a covariate in analyses. These broods had a 71.8% greater chance of fledging than broods with only natural shelter available. Additional deployment of artificial shelters to broods over two breeding seasons further validated the effectiveness of shelters, whereby broods with artificial shelter had a 42.8% greater chance of surviving. This implies that shelters mitigate threats which potentially include crushing, avian predation, thermoregulation, or combinations of these, or some other unexplained factor(s), which are major causes of chick mortality. Shelters have been used to enhance chick survival in terns, by reducing and in some cases, eliminating, avian predation of chicks (Jenkins-Jay 1982, Burness and Morris 1992). Kruse *et al.* (2001) used A-frame shelters for Piping Plover and tern chicks but found no increase in fledging success at sites that had an abundance of natural cover. Typically, shelters are provided at sites where vegetation growth is lacking, but chick use of shelters occurs at sites where sufficient vegetation appears to be present (Keane 1998). Hooded Plover broods mostly forage in open beach areas with limited cover; we do not suggest diminished cover is a threat to Hooded Plovers, rather, artificial cover may mitigate the impacts of human disturbance and superabundant predator populations by offering cover that is less prone to trampling, possibly more convenient and more resistant to predators, compared with natural cover, although none of these explanations were confirmed during this study.

In conclusion, we suggest that artificial shelters offer a practical way of dramatically improving survival of threatened shorebird chicks on beaches, although the mechanism via which survival is increased warrants investigation. In combination with other management techniques commonly used for increasing breeding success of threatened shorebirds worldwide, such as exclusion zones, fencing and predator control, chick shelters should make a substantial contribution to population viability.

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GRAINNE S. MAGUIRE*
Birds Australia, Suite 2-05, The Green Building, 60 Leicester Street, Carlton, Victoria 3052, Australia.

ANDREW K. DUIVENVOORDEN, MICHAEL A. WESTON, ROBYN ADAMS
School of Life and Environmental Sciences, Faculty of Science and Technology, Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia.

**Author for correspondence: email: g.maguire@birdsaustralia.com.au*

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