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Implications of radio-tracking for the survival of Masked Lapwing chicks

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Monitoring survival of free-living, precocial avian young is difficult. Perhaps the most promising method available is a combination of radio-tracking and frequent investigator brood visits. The aim of this study was to determine if the process of radio-tracking negatively impacts chick survival by comparing survival of tagged chicks with that of their untagged siblings. We radio-tracked 50 Masked Lapwing *Vanellus miles* chicks and compared within-brood mortality of tagged and untagged chicks to examine whether attaching radio-transmitters influenced chick survival. There was no difference in survival between the two categories of chicks, so the survival of lapwing chicks was not affected by radio-tracking. However, members of smaller, less robust and possibly less habituated species may still be negatively affected by radio-tracking. Radio-tracking seems to be an ethically acceptable and practical method for obtaining an improved understanding of cryptic life history stages, such as brood-rearing, in waders.

INTRODUCTION

The flightless, precocial young of ground-nesting birds experience substantial mortality (Weston and Elgar 2007; Maguire *et al.* 2009, 2013; Tan *et al.* 2015). Intraspecific variation in reproductive success is heavily influenced by the survival of young (Bradley *et al.* 1990; Rogers *et al.* 1995; Hedrick 2005; Nisbet and Dann 2009; Anteau *et al*. 2014). Thus mortality of young may influence evolutionary trajectories and, in some cases, even population viability (Loegering and Fraser 1995; Göth and Vogel 2003).

Determining chick survival rates and the fate of altricial young is made easier by their pre-fledging attachment to the nest vicinity (Williams and Wood 2002). In contrast, data on the survival of precocial chicks to fledging is often difficult to obtain because they are highly mobile, cryptic and respond to investigators evasively, as they would to predators (McGowan *et al.* 2009; Sharpe *et al.* 2009; Ekanayake *et al*. 2015) The small size and cryptic plumage of precocial chicks can also make determining the causes of death difficult. Chicks are small enough to be carried substantial distances or eaten entirely by avian or mammalian predators, leaving no evidence. Even if intact, the carcass's small size and camouflage may make it difficult to locate and for the investigator to infer a cause of death (Keedwell 2001; Wegge and Kastdalen 2007).

Whilst the use of equipment such as miniature video cameras has provided valuable information about altricial chicks' fate (Williams and Wood 2002; Schaefer 2004; Bulit *et al.* 2008), there are currently few effective methods for determining the fate of mobile, precocial chicks. Many studies rely on focal brood visits (*e.g.* Chokri *et al*. 2011; Maguire *et al*. 2011), an approach especially appropriate for precocial species that do not venture far from their nest (e.g. *Sternidae* spp.) or use a well-defined territory in open habitat (e.g. some *Charadrius* spp.). Few studies combine radio-tracking and frequent brood visits, although such investigations are especially suitable when studying precocial and highly mobile chicks living in complex habitats (e.g. *Charadriidae* and *Megapodiidae* spp.) (Pearce-Higgins and Yalden 2002; Göth and Vogel 2003). The combination of radio-tracking and brood visits (henceforth 'radio-tracking') can provide data for precocial species on mortality and fledging, but also additional information on movement and habitat use (Kenward 2001; Whittier and Leslie 2005; Sharpe *et al.* 2009).

However, one prominent concern is that radio-transmitters may provide biased survival estimates because they may influence mortality, perhaps through reduced body condition resulting from comprised thermoregulation or an additional energy expenditure associated with an increased weight burden (Mattsson *et al.* 2006; Sharpe *et al.* 2009). In extreme cases, radio-transmitters may precipitate the rejection of young by parents (Kenward 2001; Mattsson *et al.* 2006; Zenzal *et al.* 2014).

The frequency of visits to broods that are being radio-tracked will often depend on the perceived (or actual) rate of chick mortality, the attainment of additional information (e.g. on movements), and logistical issues such as the number of broods to be radio-tracked (Millspaugh and Marzluff 2001). However, the frequent disruptions to normal behaviour caused by the need to visually locate chicks may be detrimental. Specifically, frequent visits elicit anti-predator behaviour and may potentially cause more disturbance than a mere passer-by (Duffy and Ellison 1979; Price 2008), possibly as a result of repeated interruptions of normal behaviours (feeding and brooding) and the additional energy expenditure involved in repeated fleeing and hiding (Keedwell 2001; Weston and Elgar 2005; Sharpe *et al*. 2009; Drietz *et al*. 2011)

As radio-tracking equipment has become smaller and cheaper, its application to ornithological studies has grown (Zenzal *et al.* 2014). Nevertheless, for the vast majority of species the lethal and sub-lethal effects of radio-tracking remain relatively untested compared with those associated with other options, such as focal brood visits. Therefore there is a need to further quantify the effects of radio-tracking on the survival and fitness of tracked young (Sharpe *et al*. 2009; Dreitz *et al.* 2011). In this study we examine whether the attachment of a radio-transmitter influences chicks' survival by comparing chicks of the same brood with and without radio-transmitters. Given that retention of distinguishing marks (e.g. leg bands, leg flags, collars and wing tags) is a critical assumption of many survival analyses (Anderson and Green 2009; Dann *et al.* 2014), we also document the rate of retention of radio-transmitters on free-living chicks and report on the unexpected loss of standard Australian Bird and Bat Banding Scheme (ABBBS) metal, tarsal bands.

MATERIALS AND METHODS

Study Site

Masked lapwings (hereinafter 'lapwings') are abundant on Phillip Island, Victoria, Australia (38°29.112'S, 145"13.787'E) where they thrive in a matrix of urban and rural environments (Chambers *et al.* 2008; Cardilini *et al.* 2013; Lees *et al.* 2013b; Roche *et al.* 2016). Fieldwork was conducted between June and November, 2014 (Dann 1981; Chambers *et al.* 2008). Lapwing chicks leave the nest and commence feeding within hours of hatching, and rely on their parents for protection (alarm and defence) and thermoregulation (brooding) until fledging (Lees *et al.* 2013a).

Data Collection

Systematic searches for nests occurred throughout the breeding season. After all eggs in a nest had hatched, chicks were captured and one chick in the brood was randomly chosen for radio-transmitter attachment. This chick had a radio-transmitter (Sirtrack PicoPip™; 1.05 g, ≤ 5% of the bird's weight at hatching; estimated operating life of 132 days) attached using the 'glue-on' method of attachment (Göth and Jones 2001). Briefly, this method involves trimming a small amount of down from the chick's back and using a combination of eyelash glue and superglue to attach the radio-transmitter and cotton gauze 'comfort layer' to the chick's skin and down. Chicks fitted with a radio-transmitter were then banded with a uniquely coded ABBBS metal band on the left tarsus to aid identification, whilst the other chicks in the brood were banded on the right tarsus.

We radio-tracked 50 chicks (from 50 broods) and recorded two GPS location data points a minimum of five hours apart daily per tagged chick, as well as noting whether or not their siblings were alive (Millspaugh and Marzluff 2001). The location of chicks was determined by visually identifying the radio-tagged chick from afar, then walking to the position where it was first observed and recording a GPS location data point. Parent birds responded to the approach with anti-predator defence (calling, false brooding, injury feigning and swooping), while chicks fled and/or hid (Ristau 1983; Lees *et al.* 2013a). Brood monitoring ceased on the death of the radio-tagged chick, shedding of the radio-transmitter or loss of the radio-transmitter signal. When radio-transmitters were visually identified as having fallen off, the radio-tagged chick was re-captured and a new radio-transmitter was attached.

When chicks died, we attempted to confirm the cause of death by locating and examining the carcass and, in many cases, by talking to local residents who witnessed the death. Carcasses were examined to distinguish between those hit by vehicles or killed by predators and those that died from starvation or exposure. When signals were lost and the parents were located on three consecutive occasions without the accompanying radio-tagged chick, the chick was assumed to have died and monitoring of the brood ceased. Adults without chicks were confirmed as the parents through the observation of uniquely engraved leg flags placed on adult birds throughout this and previous breeding seasons. If all chicks in a brood disappeared at once, they were all coded as deceased; however, the disappearance of all members of a brood simultaneously only occurred twice. The retention rate of standard-sized ABBBS metal bands was determined by frequently visiting chicks with radio-transmitters.

Statistical Analysis

Each brood was treated as an independent datum; broods were > 100 m, and generally kilometres, apart. As brood monitoring ceased after the radio-tagged chick died, we analysed survival of chicks up to this time, excluding the data on untagged chicks from that point onwards. To determine if the presence of the radio-transmitter influenced the radio-tracked chick's survival, data from the chicks that died before the radio-tracked chick did were analysed using a Cox proportional hazard regression (47 of 50 broods; two broods with single chicks and one with five chicks were removed from the model). This survival analysis was run with the binomial status of all chicks at the time of death as a response variable (0 = alive, 1= deceased) and the presence of a radio-transmitter and brood size as fixed factors, whilst brood identity was considered a mixed effect. Chicks were of known age, except for seven (in seven broods) whose age was calculated using a linear regression based on 20 chicks (not part of the radio-tracking study) of known age which estimated age from weight:

$$Log_{10}\text{ (chick age [days])} = (434.57 * \text{chick weight [g]}) - 520\text{ ; } R^2 = 0.773$$

Two independent samples t-tests explored whether chicks that lost their bands weighed less or had shorter tarsi than newly-hatched, radio-tagged chicks that retained their bands. Seven of the 50 broods were encountered opportunistically and so were removed from this analysis. Summary statistics are cited as the coefficient ± one standard error, unless otherwise indicated. All statistical tests were conducted in R (2015), with the Cox proportional hazard regression being conducted in the package 'survival' (Therneau 2015).

RESULTS

Chicks with a radio-transmitter (47 chicks from 47 broods which contained 156 chicks in total; one radio-tracked chick per brood) were no more or less likely to die than their siblings (Table 1). All radio-transmitters on chicks that survived to at least 39 days old were shed and replaced or re-attached. Radio-transmitters of chicks surviving to the shedding of their transmitter (n = 13) remained attached for 33.3 ± 2.4 days (range 17 – 44 days) before falling off on the emergence of feathers.

Table 1

Outcome of Cox proportional hazard regression investigating the influence of the radio-transmitter on the survival of radio-tracked Masked Lapwing chicks (n = 47) compared to that of their siblings (n = 109). C ± SE = exponential coefficient ± standard error, Log-rank p-value = 0.539. CI = confidence interval. The reason that coefficients and tests for 'brood size (two)' are missing is that 'brood size (two)' is treated as the reference group for the coding of the categorical factor.

Treatment	C ± SE	Lower 95% CI	Upper 95% CI	z-value	p-value
Radio-transmitter presence	1.150 ± 0.214	-0.814	1.623	0.794	0.427
Brood size (three)	0.948 ± 0.361	0.479	1.875	-0.154	0.878
Brood size (four)	0.755 ± 0.356	0.359	1.584	-0.744	0.457

There was no rejection of radio-tracked chicks by their parents. Seven (14%) of the 50 radio-tagged chicks survived to fledge; the other chicks perished from a variety of causes including: predators (n = 6), collisions with vehicles (n = 7), starvation or exposure (n = 3), being run over by a lawnmower (n = 1) and unsubstantiated, inferred depredation (n = 26). Thus, even with radio-tracking, the causes of mortality were robustly determined for only 39.5% of chicks.

Five of the 43 newly-hatched, tagged chicks (12%) lost their metal bands, presumably from the band slipping over the tarsometatarsal joint. Chicks that lost their band were not smaller in mass ($t = -1.811$; $df = 41$; $p = 0.393$) or tarsus length ($t = 0.139$; $df = 41$; $p = 0.399$) than those that retained their bands.

DISCUSSION

Due to the extremely high mortality of Australian Brush-turkey *Alectura lathami* chicks, Göth and Jones (2001) were only able to report one transmitter retention duration (16 days) for a wild chick, although retention times of 14, 29 and 34 days were reported for three captive chicks. Whittier *et al*. (2005) also report short retention times of radio-transmitters (3-17 days) on 26 Least Tern *Sterna antillarum* chicks as a result of the chicks' quick growth and feather development. Here we report longer transmitter retention times (33.3 ± 2.4 days, n = 13) for lapwing chicks, perhaps because their slower growth rate allows the transmitter to remain attached to the skin and down for longer. The fact that all radio-transmitters were shed means that, for lapwings, reasonable periods of monitoring without burdening the birds with lengthy or even life-long device attachments are possible.

We observed no indication of restricted movement or altered behaviours of radio-tracked chicks (i.e. no sign of impaired walking, running, feeding or brooding) or parental abandonment, and we found no effect of transmitter attachment on the survival of chicks compared with that of their untagged siblings. This is consistent with results on other species reported by Göth and Jones (2001) and Pearce-Higgins and Yalden (2002).

The lapwings' modest rate of survival to fledging (14%) is typical of many precocial species. Other studies employing radio-tracking report 2-19% survival rates (Göth and Jones 2001; Keedwell 2001; Pearce-Higgins and Yalden 2002). The cause of death of about half of the radio-tracked chicks could not be determined. Radio-tracking is routinely associated with a modest ability to determine the causes of chick mortality; for precocial chicks, other studies also report up to 60% undetermined causes of death (Whittam and Leonard 2000; Keedwell 2001; Wegge and Kastdalen 2007). This is likely to be the result of the chicks' small size and the high probability that they will be carried some distance away from the capture location or ingested whole by predators (Keedwell 2001). Identification of the threats to chick survival is critical for many wader species, as many of them are in decline, with poor breeding success often being the reason (Garnett *et al.* 2011).

Many Masked Lapwings have adjusted well to the frequent human disturbance associated with living and breeding in highly modified urban and rural environments (Cardilini *et al.* 2013; Lees *et al.* 2013a) and so may be particularly tolerant of investigator interference. Importantly, we acknowledge that sub-lethal impacts of transmitter attachment may occur (e.g. changes in time budgeting, growth and body condition); these possible effects were beyond the scope of this study, but warrant investigation. Other species may be more sensitive to radio-tracking methods. In summary, our results suggest that radio-transmitters are a tractable, unbiased and ethical aid in studying wader chicks. Whilst their use does not guarantee accurate assignment of a chick's ultimate fate, they remain the best way to determine the causes of most deaths.

Retention of bands- a cautionary comment

Using mark-recapture data to estimate species' fecundity is common in ornithological research (Cleminson and Nebel 2012). However, we report here a 12% loss of regulation, standard-sized ABBBS metal bands applied to one-day old lapwing chicks. We suggest that it is likely that the small circumference of the tarsometatarsal joint (not measured in this study) led to the loss of bands. Other studies report similar band loss, but usually as a result of wear (Jovani and Tella 2005) or removal by the bird (Meyers 1995). Neither of these possibilities apply in our study species. Whilst robust statistical models are available to estimate survivorship (Conn *et al.* 2004; Juillet *et al.* 2011), none of them compensate for the early (within days) loss of bands from a substantial percentage of chicks. Were large-scale mark-recapture studies to experience a similar percentage of band loss from chicks, survival could be severely underestimated.

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