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NESTING OF THE DOUBLE-STRIPED THICK-KNEE (*BURHINUS BISTRIATUS*) IN A HOT ENVIRONMENT

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Nidificación del Alcaraván (*Burhinus bistriatus*) en un ambiente caluroso.

Key words: Costa Rica, flushing behavior, Guanacaste, nest crypsis, nesting ecology, thermal environment.

Many shorebirds (Charadrii) nest in sites with no vegetative cover, so that they can quickly detect approaching predators (Maclean 1967, Koivula & Rönkä 1998, Amat & Masero 2004a). In these sites, the lack of shade could lead to heat stress for the incubating bird (Grant 1982, Amat & Masero 2004b), and this may be especially critical for species nesting in tropical environments because of intense solar radiation. This may lead to situations in which the thermal needs of the adults conflict with those of eggs (Carey 2002, Amat & Masero 2007). To breed successfully in hot environments, adult shorebirds have several strategies to protect the eggs from overheating, such as egg-shading or belly-soaking (Grant 1982, Downs & Ward 1997, Carey 2002; Amat & Masero 2004b, 2007). Because incubating shorebirds normally depart from nests when predators approach nests (e.g., Koivula & Rönkä 1998, Amat & Masero 2004a), leaving the eggs exposed to solar radiation while the nest in unattended may be critical for embryos under hot conditions. The thermal environment may affect the distance at which the incubating adult flushes from the nest, or the returning time to nest following disturbance, so that birds will remain on the nests longer when approached by a predator and return to nests faster after a disturbance at temperatures above 30ºC (Maclean 1967, Brown & Brown 2004, Yasué & Dearden 2006). Thus, to protect their eggs from overheating, incubating adults may expose themselves to greater risks of predation when ambient temperatures are > 30ºC. However, short flushing distances of incubating adults from predators may facilitate nest finding by predators. To avoid this, shorebirds may make their nests and eggs cryptic (Summers & Hockey 1981, Solís & de Lope 1995). Moreover, diurnal variations in nest/egg color appearance due to changes in illumination (see Endler 1991, Endler & Thery 1996) may determine changes in nest crypticity throughout the day. This may also affect the distance from predators at which incubating adult birds depart from nests during a disturbance, so that incubating birds may depart at shorter distances from predators during those parts of the day when the nest is more cryptic.

Therefore, decisions of incubating adults to depart from nests during a disturbance may depend not only on the thermal risks incurred by embryos when the nests are left unattended, but also on diurnal changes in nest crypticity due to changes in illumination. As a result, both ambient temperature and nest crypsis may determine the flushing behavior of incubating adults.

In this paper we report some breeding strategies of the Double-striped Thick-knee *Burhinus bistriatus* in a hot environment. This species is restricted to tropical dry regions of America (Hayman *et al.* 1986), and at least in Costa Rica, it breeds during the dry season of the year (Stiles & Skutch 1989). We present data on diurnal variations in ambient temperatures (T_a) beside nests, flushing behavior of incubating adults in relation to T_a, and diurnal differences in coloration between eggs and nest sites. Because there are few studies on the nesting biology of the Double-striped Thick-knee (Freese 1975, Stiles & Skutch 1989) we also present data on nest characteristics and eggs size.

METHODS

We searched for thick-knee nests in sites up to 30 km around Liberia (Guanacaste Province, NW Costa Rica, 10º38'N, 85º26'W) during 5–14 February 2008. The site is located in the Pacific lowlands, and the habitat is characterized by pastures, stubble fields and patches of tropical dry forest. Along the watercourses there is an evergreen, gallery forest.

We drove along roads and tracks, and stopped every time we spotted thick-knees or where habitat appeared suitable, in which case we searched using binoculars. Once thick-knees were located in a site, we found nests by observing their behavior with binoculars from 50-100 m. Distances of nests to nearest tree or scrub (> 1 m tall) were estimated by pacing, and later transformed to the nearest metre. We estimated these distances because trees or scrubs provide potential sites for the off-duty adult to remain under shade (Maclean 1967). All five nests found contained a single egg, which was measured [maximum length (*L*) and maximum width (*W*)] to the nearest 0.1 mm using vernier callipers. Egg volumes (V_e) were estimated according to Douglas (1990) as $V_e = K_v LW^2$, where K_v corrects for variation in shape and is calculated as $K_v = 0.5236 - [0.5236 \times 2(L/W)/100]$. We also measured the internal diameter of nest scrapes to the nearest cm, using a tape.

To record the flushing distances of incubating thick-knees, one of us observed the incubating bird through binoculars while the other researcher walked, at constant pace, directly toward the nest. At the moment at which the incubating bird left the nest the first observer started a stopwatch, which was stopped once the second observer arrived at the nest. These times were used as surrogates of flushing distances. We made three recordings for each nest [early morning (up to 1 h after sunrise), midday (11:00–13:00 h), and late afternoon (during the last hour before sunset)]. These recordings were made either on the same day or on two consecutive days, and the order of visits to nests was not time dependent.

About 5 min after each recording of flushing distances, we recorded T_a (to the nearest 0.1ºC) 5 cm above ground level about 1 m from each nest scrape, using a 20-gauge copper-constantan probe connected to an Omega HH21 microprocessor thermometer (Omega Engineering, Inc., Stamford, CT, USA). To avoid egg overheating while T_a was recorded, we shaded the eggs when temperatures could be critical for embryos.

To quantify the coloration of eggs, nest scrapes, and nest surroundings we photographed the nests, using a Canon EOS400 digital camera equipped with Canon EFS 18-55 mm macrozoom lens. From each nest we took photographs on sunny days at early morning, midday, and late afternoon. Photographs were taken directly from above the nests so that the outer edges of the nest filled the frame. We did not record ultraviolet (UV) reflectance of eggs, which could have affected nest detectability, since birds are able to detect wavelengths in the UV spectrum (Bennett & Cuthill 1994). However, eggshells reflect little UV (Bakken *et al.* 1978).

We quantified the coloration of eggs, nest scrape, and ground in the immediate surroundings of the nests with Photoshop Elements, version 2.0 (Adobe, San José, California, USA). The eyedropper was set at 5 × 5 pixels, and values in the RGB (red, green, blue) color space were recorded. We took readings at spaced points on the images, noting whether the readings were on eggs, nest scrape, or substrate of the nests' surroundings. Five metric values were obtained for each category (egg, nest scrape, and surroundings), which were averaged for each one of these categories for each photograph. We transformed the RGB color space to the CIE (Commission Internationale d'Eclairage) $L^*a^*b^*$ color space (see Nguyen *et al.* 2007), where L^* defines lightness, a^* denotes the red/green value and b^* the yellow/blue value (X-Rite 2000). The color transformations were done using the CIE Color Calculator (Lindbloom 2009). Color differences (ΔE^*) between eggs, and either nest scrape or surroundings, were defined by the equation (X-Rite 2000) $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$. The larger ΔE^*, the lower is the similarity in coloration between two substrates.

Because the study involved repeated measurements of the same individual nests, differences in temperatures at nest sites throughout the day were analyzed using repeated measures ANOVA, while the Student's paired *t*-test was used to compare flushing distances from nests during midday and afternoon. A general linear mixed model (GLMM) approach was used to test the effect of time of day (three fixed levels: morning, midday, afternoon) on color differences (ΔE^*) between eggs and either nest scrape or surroundings. Nest identity was included as a random factor in the GLMM. Mean values are presented with ± 1 SD.

RESULTS

Of the five nests found, three were in short grass pastures, one in an opening in woodland of *Guazuma ulmifolia* (Malvaceae), and another in a stubble sugar cane field. Mean values of nest and egg dimensions were: 17 ± 3 cm (internal diameter of nest scrape), 58.0 ± 1.0 mm (egg length), 41.4 ± 0.8 mm (egg width), and 50.5 ± 2.5 cm^3 (egg volume). The nests were located at 15 ± 15 m from the nearest tree or scrub. During daytime, the off-duty adult was under the shade of the nearest tree or scrub to the nest on 8 out of 10 visits to nests in midday and afternoon while its mate was incubating.

Ambient temperature varied significantly throughout the three periods of the day. Temperature was higher during midday (39.8 ± 3.75 ºC, n = 5) than during the morning (26.5 ± 1.44 ºC) or afternoon (33.3 ± 2.03 ºC) (ANOVA for repeated measures, $F_{3,2} = 1162.8$, $P < 0.001$).

We did not find adults incubating at three of five nests in the early morning, and for this reason we compared flushing times only during midday and late afternoon. Although

TABLE 1. Differences in coloration (ΔE^*) (mean ± 1 SD) between eggs (EG) and both nests (NE) and surroundings (SU) in Double-striped Thick-knee nests (n = 5), during the early morning, midday and late afternoon. Coloration was recorded from digital photographs in the RGB (red, green, blue) color space and then transformed to the Comission International d'Eclairage $L^*a^*b^*$ color space. A generalized linear mixed model was used to test the effect of time of day on color differences (see Methods for further details).

	Morning	Midday	Afternoon	$F_{2,8}$	P
ΔE*EG-NE	25.5 ± 13.40	13.4 ± 7.99	27.0 ± 16.71	3.71	0.073
ΔE*EG-SU	35.6 ± 9.41	16.7 ± 7.75	25.4 ± 10.69	8.51	0.010

there was a trend for incubating adults to flush at shorter distances from observer during midday (14.9 ± 5.60 sec, n = 5) than in the late afternoon (28.9 ± 9.18 sec), the difference was not statistically significant (Student's paired *t*-test, $t = 2.57$, df = 4, $P = 0.062$).

GLMMs indicated that the color differences (ΔE^*) between eggs and nest scrapes did not vary throughout the day ($F_{2,\,8} = 3.71$, $P = 0.073$), although there were color differences between eggs and nests surroundings according to time of day ($F_{2,\,8} = 8.51$, $P = 0.010$). In this last case, the color differences between eggs and nest surroundings were less obvious during midday than in the other periods (Table 1).

DISCUSSION

Although our sample size was small, some patterns emerged from our results. High ambient temperatures (> 35°C) may limit the ability of incubating shorebirds in exposed sites to maintain homeostasis. In the case of the Double-striped Thick-knee, lack of water bodies near nests may preclude the regulation of adult body temperature using belly-soaking (Amat & Masero 2009), and would predispose incubating birds to desert their nests during stressful thermal conditions (Amat & Masero 2004b). Therefore, nesting near trees or scrubs likely facilitated that the off-duty parent could stay under shade, and that it may approach quickly the nest when its mate stops incubating, so that the eggs are almost continuously attended during stressful conditions. Some nests were found unattended in the early morning. This has also been found in other shorebird species in hot environments when T_a is between 20°C and 30°C (Maclean 1967, George Kainady & Al-Dabbagh 1976, Grant 1982).

There were diurnal variations in T_a beside nests, and this may have affected the distance at which incubating thick-knees departed from predators. Indeed, when we approached nests, incubating adults took longer to depart from nests in midday (when T_a was higher) than in the late afternoon, although likely due to small sample size the difference in departure times was marginally non-significant.

We found that the difference in coloration between eggs of the Double-striped Thick-knee and their nest scrapes did not vary throughout the day. The congeneric Stone Curlew *B. oedicnemus* lines the nest scrapes with materials collected from the surroundings, and this makes the eggs more cryptic (Solís & de Lope 1995; see also Mayer *et al.* 2009). It is interesting to note that despite of not adding materials to the scrape, there are no diurnal differences in coloration between the eggs of the Double-striped Thick-knee and their nest scrapes, in spite of diurnal variations in illumination. Nevertheless, differences in coloration between eggs and nest surroundings varied according to time of day, with such differences being smaller around midday, i.e., when adults took longer to depart from nests when observers approached. Thus, incubating adults allow predators to approach their nests at shorter distances during midday before flushing because nests may be better camouflaged under the light conditions of midday. This may shorten the periods in which eggs are exposed to critical temperatures.

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