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Thermal Aspects of Nest Placement in the Orange-tufted Sunbird (*Nectarinia osea*)

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During early development, most birds are ectothermic and must rely entirely on their parents for maintaining their thermal needs. Parents invest time and energy to incubate their eggs (see review in Walsberg 1983) and are compelled to restrict their other activities, most importantly foraging. Therefore, any adaptation, behavioral or physiological, that might reduce this conflict becomes an advantage. Selecting a nest site that is sheltered from the extreme elements may benefit the parent and the egg or nidicolous young. The parent could benefit from a prolonged incubation season and through savings of incubation energy and time. Young (or eggs) could benefit from the reduced time needed for development, during which they are most vulnerable to predation. This in turn may increase the overall reproductive success of the parent.

Selection for a favorable nest microclimate apparently is particularly significant for small birds, where thermal capacities of adults, eggs, and young are low, specific maintenance metabolism is high, and the capacity to store food energy is limited (Calder 1984). Indeed, selective nest placement relative to the thermal environment has been documented for many small birds (e.g. Hadley 1969, Orr 1970, Austin 1976, Carpenter 1976, Hogstedt 1978, Walsberg 1981, Zerba and Morton 1983, for review see Collias and Collias 1984), but quantitative data required for energetics analysis are nevertheless sparse (e.g. Ricklefs and Hainsworth 1969, Calder 1973a, b, Walsberg and King 1978b).

The Orange-tufted Sunbird (*Nectarinia osea*, Nectariniidae) is a very small (5-7 g) passerine in which only the female incubates. In Israel, this Paleotropic species was originally confined to arid tropical-type habitats along the Rift Valley region, but it has been dramatically expanding its range into new man-made habitats in the temperate zone of the country (Paz 1986). Given its small body size and its tropical origin, one might predict some form of nest-site selection for thermal advantage, especially in the cooler parts of its range.

We studied the interaction of nest microclimate, nest structure and parental behavior, and their effects on incubation energetics of this bird in the coastal plain of Israel. We report here on the role of various thermal factors in nest placement and on the effect of season.

Methods.—In the temperate parts of its range, the Orange-tufted Sunbird is most prevalent in man-made parks and gardens, where it feeds mainly on nectar from a variety of introduced plants. In this region the breeding season usually extends from March through August, during which the birds are monogamous and highly territorial (pers. obs., Goldstein and Yom-Tov 1988). A single pair will usually make multiple nesting attempts, and may raise up to three successful broods per season (unpubl. data). The female alone builds a domed, suspended nest and incubates the two- to three-egg clutch for about 13 days (Goldstein and Yom-Tov 1988).

Our study was conducted during the 1986 and 1987 breeding seasons in a northern suburb of Tel-Aviv (32°06'N, 34°47'E), which is located in the temperate-coastal-lowland-climate region of Israel. The mean daily temperatures in this region range from 11° to 13°C in January to 26°C in August. The mean minimal temperature of 5° to 7°C occurs in January and February, and the mean maximal temperature is 29° to 31°C in August. Extreme maximal daily temperatures exceeding 40°C are frequent during heat waves in the transitional seasons. Annual rainfall ranges between 500 to 600 mm and is confined mainly to November through March (Jaffe 1988).

We located 86 nests by following female sunbirds carrying nesting material. Of these, 42 were dated to the early nesting season (March to mid-May) and the remaining nests (44) to the late season (mid-May to August) based on the date of the laying of the first egg (=nesting date). The following variables were evaluated for each nest: (1) vertical distance from ground to bottom of nest; (2) horizontal distance and orientation of nest to nearest vegetation mass or artificial structure; (3) entrance orientation; (4) exposure to direct sun radiation; and (5) protection from rain. Nest orientation relative to the nearest structure and nest-entrance orientation were determined using a magnetic compass (thus, relative to magnetic north). For statistical analyses, nest orientations in relation to the nearest structure were grouped into four azimuth classes (N, E, S, or W). In order to test the possible role of wind, nest-entrance orientations were grouped into two uneven groups—"away from the wind" (including N, NE, E, SE, and S) and "into the wind" (including SW, W, and NW)—based on the direction of prevailing winds. Sheltering from direct sun radiation was evaluated in terms of total time per

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TABLE 1. Orientation of *Nectarinia osea* nests relative to nearby protective structures at different times of nesting season.[a]

Position relative to structure	Season Early	Late	Total
North	5	11	16
East	19	15	34
South	10	9	19
West	6	4	10
Total	40	39	79

[a] Significantly ($P < 0.005$) more nests oriented to east in early season and for total than expected by chance.

TABLE 2. Orientation of *Nectarinia osea* nest entrances and effect of season.[a] Percentage of nests located on eastern side of protective structure for each group given in parentheses.

Entrance orientation	Season Early	Late	Total
Away from wind[b]	36 (44)	32 (41)	68 (43)
Into wind[c]	6 (50)	12 (33)	18 (39)
Total	42 (45)	44 (39)	86 (36)

[a] Difference between number of nests with away-from-wind and into-wind orientations significant ($P < 0.005$) for early-season and total nests.

[b] Includes N, NE, E, SE, and S.

[c] Includes SE, W, and NW.

day the nest received direct sunlight. This was determined by multiplying the fraction of open sky above the nest along the solar path (estimated by stretched hand units) by the number of daylight hours on the nesting date. Periods of diffuse radiation penetrating through the foliage canopy were not included. Subsequently, nests were categorized into one of three groups: always shaded; less than 2 h exposure; and exposure of 2 h or more. With regard to rain, nests were divided into two groups (sheltered and unsheltered) depending on the presence or absence of a solid roof above them.

Nest microclimate was studied in 12 occupied but unattended nests (during egg-laying phase) at different locations (seven shaded, three exposed up to 2 h, and two exposed for 2 h or more) on various dates. Air temperature (T_a), nest temperature (T_n), egg temperature (T_e), and total radiation were measured continuously for at least 24 h and averaged over 1-h intervals using a computerized data logger (Electronic Engineering M11-001). T_a was measured in the shade at nest level and at a distance of 1 m from the nest using a white-painted PT 100 sensor. T_n and T_e were measured by Cu-Cn thermocouples placed in the center of the nest cavity and an egg, respectively. All temperatures were accurate to within 0.2°C. Total radiation was measured simultaneously by a LI-COR piranometer (LI-200SZC). Wind velocity was sampled at sites of nine active nests, and at an adjacent open area of each site, using a hot-wire anemometer with an omnidirectional probe (TSI model 1640). For each site, wind measurements were taken every 1 to 3 h over a period of one to five days and recorded as the average of 10 actual readings measured over a 5-min period. Wind velocities and air temperatures collected at the nest sites were compared with corresponding data reported by the Israeli Meteorology Service for a nearby meteorological station (Sede-Dove).

The birds in our study were not individually marked, but judging from the distinct location of each observed nest and the monogamous, territorial nature of this species, we assumed each nest was independent for the purposes of statistical analysis. Results are cited as means and standard deviations. Samples were compared using a two-tailed Mann-Whitney U-test. Frequency distributions were tested using chi-square goodness-of-fit tests and tests of independence (Sokal and Rohlf 1981).

Results.—Nests typically were suspended from a twig above an open stretch of ground at a mean height of 2.1 ± 0.59 m (range 0.8-3.5 m, $n = 86$). No significant difference was found in nest height between the early and late seasons ($P = 0.118$, Mann-Whitney U-test). Most nests (> 90%) were placed next to a protective structure, usually near the side of a building. The distance from the nearest structure averaged 1.2 ± 1.2 m (range 0.1-4.0 m, median 0.7 m, $n = 79$); no differences were found for this variable relative to season ($P = 0.244$, Mann-Whitney U-test). Table 1 summarizes the orientation of early- and late-season nests with respect to a nearby structure. Eastern orientation was more common in both subseasons, but only in the early season was this trend statistically significant ($P < 0.005$, df = 1, goodness-of-fit test).

Nests that faced away from the wind were significantly more frequent ($P < 0.005$, df = 1, goodness-of-fit test) than were those that faced into the wind. Although this tendency appeared more predominant in early season nests, there was no statistical link between entrance direction and season ($P = 0.224$, df = 2, test of independence; Table 2). Similarly, no interaction was found between entrance direction and nest orientation in either season ($P > 0.8$, df = 1, goodness-of-fit test; Table 2).

We found 67% of the nests studied were fully shaded during all daylight hours, 27% were exposed to direct sunlight for up to 2 h per day, and only 2% were exposed for longer periods of time (Fig. 1). The maximum exposure time observed was 6 h. Although exposure to sun radiation occurred during morning and late-afternoon hours for some nests (e.g. Fig. 2), this pattern was not prevalent, nor was there any statistically significant relationship between the duration of sunlight exposure and season ($P = 0.304$, df = 2, $n = 86$; test of independence).

Only seven of the nests studied were placed under

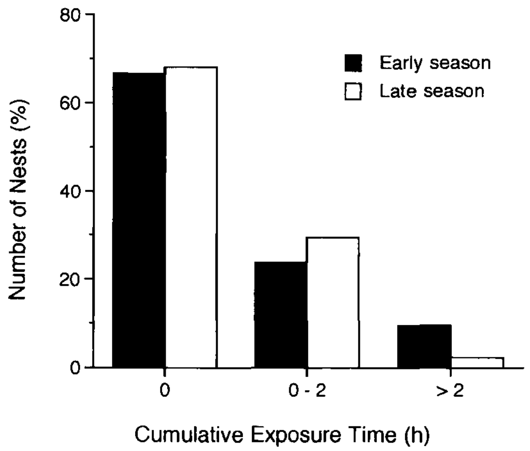

Fig. 1. Distribution of *Nectarinia osea* nests (n = 86) relative to duration of direct sunlight exposure. Early season is March to mid-May, and late season is mid-May to August.

a solid roof, usually in a doorway or a porch of a private home, that would provide full shelter from rain. Although six of these nests were found in the early season, the link between site and season was not statistically significant ($P = 0.101$, df = 1, $n = 7$, goodness-of-fit test).

The daily mean T_a of 12 nest sites recorded on different dates from April through July (range 16.4°–33.3°C) were not significantly different from the values reported for the same dates by the Sede-Dove meteorology station ($P = 0.124$, $n = 12$, Wilcoxon's signed rank test). The hourly mean temperatures recorded in two representative wind sheltered nests, one shaded and one partially exposed, are shown in Figure 2. Whereas both T_e and T_n closely followed T_a during the night (differences < 0.5°C), these temperatures were higher than T_a during the day as a result of solar radiation. T_e and T_n usually were less than 1.0°C above T_a for the shaded nest (maximum total radiation ca. 80 W/m^2; Fig. 2A), but reached 8° and 3°C, respectively, above T_a for the exposed nest (maximum total radiation ca. 350 W/m^2, Fig. 2B). The maximum gains in T_n and T_e over T_a recorded in this study were 13.5° and 10.5°C, respectively, in a nest that received 6 h of direct sunlight per day. The average pattern of the 12 nests monitored corresponded to that of the individual shaded nest: close agreement between all temperatures (differences < 0.3°C) at night; and a radiation-related mean increase of up to 2°C in T_n and T_e during the day.

Wind velocity at the nest sites ranged from 0.1 to 1.8 m/s and averaged between 0.40 and 0.95 m/s (overall $\bar{x} = 0.54 \pm 0.22$ m/s, $n = 9$; Table 3). Higher wind velocities tended to occur during late afternoon (1400–1700), reflecting the characteristic wind regime of this region. The values recorded at nest sites were

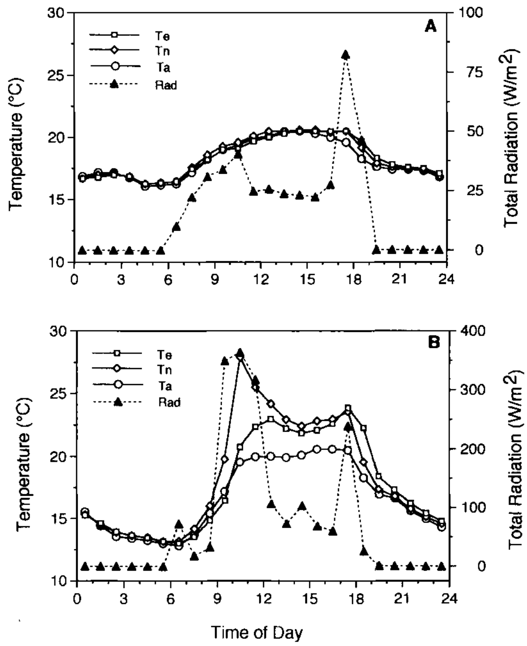

Fig. 2. Hourly means of egg temperature (T_e), nest temperature (T_n), air temperature (T_a), and total radiation (Rad) measured in late April at a fully shaded nest (panel A), and at a nest exposed to sunlight for 4 h (panel B). In both cases, maximal radiation occurred in morning and late afternoon.

2.5- to 5-fold lower than those taken simultaneously in the open and 5- to 10-fold lower than those reported from the Sede-Dove station in both the early and late seasons (Table 3). Wind velocity was usually low during the night; five measurements taken at three different nest sites were all less than 0.15 m/s.

Discussion.—While exploring the new habitats created by man in the temperate region of Israel, Orange-tufted Sunbirds were exposed to ambient temperatures that are 5° to 10°C cooler than those of its original range. We tested the hypothesis that this species should select a thermally ameliorated nest site in its temperate range, particularly during the early portion of the nesting season.

The Orange-tufted Sunbird, like many other members of the family Nectariniidae (Skead 1967), suspends its nest in a relatively open and elevated site. This might reduce predation risks, but potentially increases the exposure of the nest to the elements. The predominant character of the nest sites we observed was the close (< 2 m) association of nests with a sheltering structure, such as the side of a building. Independent of the season, a clear tendency for placing the nest on the eastern side of a sheltering structure was detected. Moreover, most of the nests (ca. 80%), regardless of their orientation toward the sheltering wall, had their entrances directed away from

TABLE 3. Wind velocity ($\bar{x}$ ± SD) at *Nectarinia osea* nest and its ratio to wind velocity at nearby open area and at Sede-Dove Meteorological Station.

Season[a]	n	Wind velocity (m/s)	Nest site/ open area	Nest site/ Sede-Dove
Early	5	0.53 ± 0.243	0.24 ± 0.121	0.12 ± 0.054
Late	4	0.55 ± 0.214	0.26 ± 0.046	0.14 ± 0.033
$\bar{x}$		0.54 ± 0.216	0.25 ± 0.097	0.13 ± 0.044

[a] No differences for any of three measures between seasons ($P > 0.4$, Mann-Whitney U-test).

the western winds that prevail in the region. Consequently, wind velocities at the nest sites were reduced by almost an order of magnitude compared with the open (Table 3). A similar amelioration of wind has been reported for nests in dense vegetation (Walsberg and King 1978a) and for ground nests (Kimberly and Webb 1993).

Our observations indicate that wind is a major factor affecting nest-site selection in the Orange-tufted Sunbird. It has been suggested that forced convection is the most important mode of heat loss affecting the thermal budgets of egg or incubating parent (Walsberg and King 1978a, b, Webb and King 1983, Walsberg 1985). Laboratory experiments conducted with the nests of Orange-tufted Sunbirds have shown that wind can increase overall nest-wall thermal conductance by 20%, and cooling rate of an unattended single egg by 10% (Sidis et al. in prep.). When nests were oriented with their opening toward the wind, egg cooling rates were elevated by a further 30%. Wind may play an additional role in the case of suspended nests like those of sunbirds, where strong winds may damage the structure of the nest, dislocate it altogether, or cause the eggs to drop through the entrance (Collias and Collias 1984). Thus, sheltering the nest from wind may have multiple advantages in this species.

While protection from excess wind is crucial for reducing heat loss, protection from overheating is equally important. The ambient temperature at the nest sites of the Orange-tufted Sunbird was about the same as that recorded in the open, suggesting no role for this factor by itself in nest placement. A more pivotal role may be played by direct sun radiation. Unlike some other small passerines of the temperate climate, which utilize solar energy for nest warming at least part of the day (e.g. Walsberg and King 1978a, Yom-Tov et al. 1978, Walsberg 1981), the Orange-tufted Sunbird seems to avoid direct sunlight altogether. The majority (> 90%) of the nests observed in our study were fully shaded or received less than 2 h of direct sunlight during the day (Fig. 1). The significance of this preference can be appreciated from the T_n and T_e data (Fig. 2). These temperatures, which represent an integrated measure of the thermal environment of the incubating bird and of the unattended egg, were only slightly (< 2°C) above T_a in shaded nests (Fig. 2A), but exceeded it by up to 10°C in unshaded nests (Fig. 2B). During hot-weather spells, which are common in spring and early summer in this region, ambient temperatures may exceed 35° to 40°C (Jaffe 1988). Under such conditions, exposure to direct solar radiation may pose a threat of overheating to the egg and the attending parent. Similar unfavorable conditions might develop even during normal midday summer temperatures of 29° to 31°C. Therefore, regardless of the season, placing the nest in a shaded site, in addition to sheltering it from prevailing winds, is apparently important for successful breeding in the Orange-tufted Sunbird. The fact that the availability of suitable nest sites is practically limitless in urban habitats may have promoted the successful occupation of these habitats by the sunbirds.

While the absence of a seasonal effect is reasonable when one considers the thermal role played by wind and direct sunlight as discussed above, it is less clear why there was not a difference in sheltering of nests from rain. Rainfall, which is associated with cold and stormy winter weather, is expected in the study area during most of the early nesting season (March–April; Jaffe 1988). Nest destruction and clutch loss due to heavy rains and stormy weather occasionally have been recorded in the early season (Y.S. pers. obs.). Even though potential roofed sites were abundant in the area, only 16% of the early nests were fully sheltered from rain. The closed-dome structure of the nest itself potentially provides some protection, as is often the case with tropical birds (Collias and Collias 1984); sheltering from prevailing winds and direct sunlight also provides some protection from driving rain. Alternatively, one may speculate that the behavioral patterns associated with nest-site selection in this species are still designed to meet the arid conditions of its original range and have not yet modified relative to the wetter climate of the temperate region. Preliminary observations we made in the Southern Negev desert (in the area of Eilat) suggest that there is no geographical difference in where nests are placed (relative to shelter), but more data on nests in the ancestral populations is needed in order to clarify this possibility.

In conclusion, sheltering the nest from wind to reduce cooling and sheltering from direct sunshine to prevent overheating are the most significant thermal factors involved in nest-site selection of the Orange-tufted Sunbird throughout the nesting season. The anecdotal observations of nest placement inside human habitats, previously reported in this species (Goldstein and Yom-Tov 1988), may represent an extreme form of such selection.

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