SHORT COMMUNICATIONS

THE EFFECT OF PHOTOPERIOD AND TEMPERATURE ON TESTICULAR GROWTH IN CAPTIVE BLACK-BILLED MAGPIES[1]

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The gradual increase in daylength each winter and spring in the Northern Hemisphere has been established as the primary proximate stimulus for reproduction in numerous north-temperate bird species. Photoperiodic induction of the secretion of gonadotrophins in advance of the breeding season, which in turn causes increased gonadal hormone secretion and gametogenesis, ensures that a bird will be physiologically and behaviorally prepared for reproduction when food and weather conditions become favorable (see reviews by Murton and Westwood 1977, Farner and Gwinner 1980, Wingfield and Farner 1980). Variation in the timing of breeding can often be correlated with annual variation in the vernal increase in ambient temperature (e.g., Lack 1950, Goodacre and Lack 1959, Slagsvold 1976, Wingfield et al. 1983). The delayed breeding commonly observed in years with periods of cold spring weather may be the result of a decreased rate of accumulation of the nutrients and energy necessary for egg formation by females, owing to increased thermoregulatory demands and scarcer food during cold weather (Perrins 1970, O'Conner 1978, Dhondt and Eyckerman 1979). The delay may also be a result of a modifying effect of temperature on the neuro-endocrine control system of either or both males and females. Modification of photoperiodic responses by temperature presumably could synchronize the annual reproductive effort with environmental conditions that maximize the probability of success. This modifying effect has been most thoroughly studied in Gambel's White-crowned Sparrows (*Zonotrichia leucophrys gambelii*). Farner and Mewaldt (1952), Farner and Wilson (1957), and Lewis and Farner (1973) demonstrated that low temperatures exert a slight inhibitory effect on testicular development in this subspecies when birds were maintained on LD 15:9 or LD 18:6. Additionally, plasma levels of luteinizing hormone, testosterone, and dihydrotestosterone did not change significantly when birds maintained at LD 20:4 and 23°C were exposed to 5°C for four days (Wingfield et al. 1982).

The slight effect that temperature has on testicular growth in a relatively long-range migrant such as *Z. l. gambelii* is not surprising. Modification of testicular development by temperature would not appear to be adaptive for a migratory species, because temperatures encountered at the wintering ground and during migration (during the initial stages of testicular growth) are of little value as

indicators of the food supply or weather conditions at the breeding ground. An early-breeding resident species, however, might profitably utilize temperature, in addition to the primary stimulus of photoperiod, as a more precise indicator of the most favorable breeding period. To test the hypothesis that the inhibitory effect of low temperature on photoperiodically induced testicular growth is greater in an early-breeding resident species than in a migratory one, I examined the effect of temperature on testicular growth in the Black-billed Magpie (*Pica pica*), an early-breeding resident species of northern Utah.

Black-billed Magpies were trapped near Logan, Utah (42°N), from September through December 1979 using circular funnel-entrance traps (Alsager et al. 1972) baited with cattle bones and pig hearts. Before the experiments the magpies were maintained in a large outdoor pen (5 × 7 × 2 m). Age was determined according to Erpino (1968a), and sex was determined by laparotomy as described by Risser (1971) except that the birds were anesthetized with methoxyfluorane during the procedure. Only adult birds were used in the experiments because first-year males often do not breed (Erpino 1968b).

Twelve adult male magpies were removed from the outdoor pen on 15 December and randomly divided into three equal groups. Two of these groups were housed indoors in 3 × 3 × 2.5 m environmental chambers in which two 300-W incandescent bulbs, one Duro-test Vita-lite fluorescent tube, and one Champion Cool-white fluorescent tube provided an intensity of 280 lux on the floor in the middle of the chamber and 670 lux at perches most often occupied by the birds. One of these groups was exposed to a photoregime of LD 12:12 and a temperature of 20 ± 2°C, and the other group was exposed to LD 12:12 and 2 ± 2°C. The third group was housed indoors in a 2 × 2.5 × 3 m environmental chamber in which one Duro-test Vita-lite fluorescent tube and one Champion Cool-white fluorescent tube provided an illuminance of 240 lux on the floor in the middle of the chamber and 490 lux at perches most often occupied by the birds. This third group was exposed to LD 9:15 and 20 ± 2°C. All of the illuminances were substantially above the minimum that other species required for maximal testicular growth rates at stimulatory photoperiods (see review by Farner 1959). In northern Utah Black-billed Magpies lay eggs in late March and early April, thus a photoregime of LD 12:12 represents the approximate daylength to which magpies are exposed during the month prior to egg laying. The lights were turned on at 0700 for all groups.

A unilateral laparotomy was performed on each bird at the beginning of the experiments and after 21 and 28 days of exposure to the experimental daylengths and temperatures. During the laparotomy the length and width of the left testis was measured to the nearest 0.2 mm with vernier calipers inserted into the body cavity. The volume of the left testis was estimated by the formula for an ellipsoid, $V = 4/3\pi ab^2$, where $a = 0.5 \times$ (length of the testis), and $b = 0.5 \times$ (width of the testis). Mink food, canned cat food,

TABLE 1. Mean volume of the left testis of Black-billed Magpies exposed to three different treatments of daylength and temperature for 28 days.

Treatment[a]	Mean volume of the left testis (mm³) ± SE		
	Day 0	Day 21	Day 28
9L:15D 20°C	8.5 ± 1.2	9.6 ± 1.5	7.7 ± 0.7
12L:12D 20°C	10.8 ± 2.1	122.0 ± 5.8	283.4 ± 24.1
12L:12D 2°C	9.4 ± 2.6	27.1 ± 1.6	44.9 ± 1.2
df and F-ratio[b]	$F_{2,9} = 1.48$	$F_{2,9} = 187.1$	$F_{2,8} = 548.7$
	NS	$(P < 0.001)$	$(P < 0.001)$

[a] $n = 4$ for all groups, except 12L:12D; 20°C; Day 28, where $n = 3$ because one bird died during the laparotomy on Day 21.
[b] The data were $\log_{10}$-transformed before the statistical analysis.

bread, and water were freely available throughout the experiments. Weights of the birds did not vary more than 5% from initial weights.

Statistical analysis of the data followed procedures outlined by Zar (1974). Testicular volumes were $\log_{10}$-transformed prior to the statistical analysis. The $\log_{10}$-transformed volumes of the three treatment groups were then compared at 0, 21, and 28 days of treatment using a one-way analysis of variance followed by a comparison at each time using the Student-Newman-Keuls multiple range test. The change in testicular volume within each group between 0 annd 21 and between 21 and 28 days was tested with a two-tailed paired t-test. Equations describing testicular volume as a function of time were derived using the least squares regression procedure.

At the beginning of the experiment, the volume of the left testis of all birds was within the range measured in wild adult male magpies in November and December (4.6–11.7 mm³). The mean volume of the left testis did not change after 21 or 28 days in magpies exposed to LD 9:15; 20°C (Table 1; $P > 0.50$). The mean volume did increase, however, in birds exposed to LD 12:12; 20°C or LD 12:12; 2°C for 21 days ($P < 0.001$ in both cases), and increased further after seven additional days of photostimulation ($P < 0.001$ in both cases). Therefore, long daylength and not high temperature is the stimulus that initiates testicular development in Black-billed Magpies. However, low temperature does decrease the rate of photoperiodically induced testicular growth. The left testes of birds exposed to LD 12:12; 2°C were much smaller than those of birds exposed to LD 12:12; 20°C after both 21 and 28 days of photostimulation ($P < 0.001$ in both cases).

Testicular growth in Black-billed Magpies is a linear, logarithmic function of time during the initial growth stages, as it is in most bird species that respond to photostimulation (Murton and Westwood 1977). The regression equation describing the $\log_{10}$ left testicular volume, $\log_{10}V_t$ (mm³), as a function of time, t (day), in the LD 12:12; 20°C group is $\log_{10}V_t = 0.051t + 1.028$ ($r^2 = 0.99$), and the equation for the LD 12:12; 2°C group is $\log_{10}V_t = 0.31t + 0.782$ ($r^2 = 0.97$). The slope of these regression lines is k, the logarithmic testicular growth-rate constant (Farner and Wilson 1957).

When Gambel's White-crowned Sparrows are maintained on LD 18:6, k is a positive linear function of temperature (Lewis and Farner 1973). If it is assumed that a similar linear relationship occurs in Black-billed Magpies at LD 12:12, then the slope, m (day^{-1} °C^{-1}) of the line describing k as a function of temperature at LD 12:12 is 0.00109. This value of m can be used as a basis for interspecific comparisons of the effect of temperature on testicular growth. For a valid comparison, however, the species being compared to magpies at LD 12:12 should have been exposed to daylengths approximately the same as those perceived by that species during the month prior to egg laying and thus are physiologically equivalent to LD 12:12 in Black-billed Magpies. Gambel's White-crowned Sparrows migrate from wintering grounds in the western United States and northern Mexico to breeding grounds in Alaska and northern Canada (DeWolfe 1968), where they are exposed to daylengths ranging from 15 to 20 hr during the final stages of migration and at the breeding grounds. In this subspecies, $m = 0.0004$ at both LD 15:9 and LD 20:4 (Lewis and Farner 1973), which is 37% of the value of 0.00109 determined for Black-billed Magpies. These values of m support the hypothesis that temperature has a greater effect on testicular growth in an early-breeding resident species than in a long-distance migrant.

The modification of photoperiodically induced testicular growth by temperature has apparent adaptive value for Black-billed Magpies. Linsdale (1937) reported that nestling magpies are fed primarily insects; caterpillars, grasshoppers, and fly larvae and pupae represent 18, 11, and 11 percent of the total diet, respectively. If spring weather is cold and the emergence of these insects is delayed, it would be adaptive for magpies to delay their breeding season so that their young could be raised when food is abundant. The inhibitory effect of low temperature on the testicular growth of magpies in this study appeared to be one mechanism to achieve this delay. A delay in testicular development probably delays egg laying, since testicular androgenic hormones stimulate the male courtship and nest-building behaviors that accelerate ovarian growth (Morton et al. 1985) and stimulate ovulation in females (Brockway 1965, Lehrman 1965, Murton and Westwood 1977). Such a sequence of events may partially explain the difference in the mean date of the onset of egg laying noted by Erpino (1968b) in a population of Black-billed Magpies in two consecutive years near Laramie, Wyoming. Egg laying began about a week earlier in the second year, when temperatures averaged 9°C higher than in the first year. The inhibitory effect of cold temperature on testicular growth may have also accounted for the altitudinal variation in the onset of egg laying noted by Holyoak (1967) in northern England. The average date of clutch initiation at 305 to 457 m above sea level was 12 days later than at 152 to 305 m and 18 days later than at 0 to 152 m. These differences may result from differences in photosensitivity of the different populations to photoperiods of equal length, or from responses to factors other than photoperiod or temperature. Nevertheless, an inhibition of testicular growth by temperature at the higher altitudes is an equally plausible explanation.

Modulation of testicular growth by temperature may serve an additional valuable function. Because the energetic cost of thermoregulation increases as the equivalent black-body temperature of Black-billed Magpies decreases below 5°C, as it frequently does in the weeks prior to egg laying (Mugaas and King 1981), a female magpie might not accumulate sufficient energy for ovogenesis as early in a cold spring as in a warm one, and egg laying could be delayed. A concomitant inhibition of testicular growth in the male could be important so that the male and female remain physiologically and behaviorally synchronized throughout the breeding season.

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PREDATORY BIRD BEHAVIOR AND TILLAGE OPERATIONS[1]

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Predatory birds occasionally take the prey flushed by moving machinery and thereby increase their hunting success. For example, Peregrine Falcons (Falco peregrinus) followed a refuge patrol boat to hunt Horned Grebes (Podiceps auritus) in South Carolina (Andre 1978). In Minnesota, Flugum (1975) noted that his farm tractor, being used in tillage work, would flush mice and improve the hunting success of Red-tailed Hawks (Buteo jamaicensis) and, rarely, American Kestrels (F. sparverius). During field work in Isabella County, central Michigan, between 1973 and the summer of 1985, I witnessed other examples of this association between avian predators and farm machinery. This paper further documents the avian predator-machinery association and provides new data on hunting success of avian predators that forage around working farm machinery.

Relative abundance of predator and prey was recorded by summing the number of sightings of each and relating these sightings to the daylight hours spent preparing a field for planting. Capture attempts by avian predators consisted of either a swooping descent from a perch or a rapid