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Use of Captive Starlings to Determine Effects of Environmental Contaminants on Passerine Reproduction: Pen Characteristics and Nestling Food Requirements

Christian E. Grue and Lynn P. Franson

U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, MD 20708

Pollutants including organochlorine, organophosphate, and carbamate pesticides, polychlorinated biphenyls, and heavy metals can affect behavioral or physiological processes essential for reproductive success in birds (e.g., see Stendell 1976; Brown 1978:219-227, 233-239; Ohlendorf et al. 1978). Most of these studies dealt with effects on waterfowl, birds of prey, or colonial waterbirds. Relatively little is known about the effects of environmental contaminants on the reproduction of songbirds, although about 60 percent of all living species of birds are passeriforms (Austin 1971).

Field studies on the effects of a variety of contaminants on the reproduction of songbirds are difficult because of the limited number and accessibility of nests of most species. The development of a methodology for the reproduction of a North American passeriform in captivity would facilitate hazard assessment. A similar approach was used successfully by Jefferies (1971) to study the effects of DDT and DDE on reproduction of the Bengalese finch (Lonchura striata).

In a study by Grue and Christian (1981), European starlings (Sturnus vulgaris) reproduced successfully in captivity. Clutch size and hatching and fledging success in birds given Nebraska Brand bird[1] of prey diet (Central Nebraska Packing Co., North Platte, NB)[1] and frozen or live meal worms (Tenebrio molitor; Rainbow Mealworms, Compton, CA) and crickets (Acheta domestica; Ghann's Cricket Farm, Inc., Augusta, GA) were similar to that reported for free-living starlings. These results suggested that starlings could be used as a model for examining the effects of contaminants on reproduction of captive songbirds.

Answers to several questions, however, are needed before the practicality of such experiments can be assessed. First, will starlings reproduce in captivity when pairs are housed individ-

[1] Use of trade names or names of suppliers is for identification purposes only and does not constitute endorsement by the Federal government.

ually? Grue and Christian (1981) used 4 or 10 pairs per pen, but suggested that the use of single pairs would reduce problems associated with asynchronous breeding and excessive interactions among individuals. Use of single pairs per pen would also improve statistical comparisons because pairs, and not pens, would be the sampling unit. Second, what quantity of nestling diet is needed for one pair of starlings to raise a brood? These data would permit determination of the cost of future experiments, and facilitate selection of methods for contaminating nestling diets. And third, what are the pen characteristics required? The objective of the present study was to provide answers to these questions.

MATERIALS AND METHODS

Forty-one pairs of adult ($\geq$ 1 year old) European starlings were weighed, banded, and randomly assigned to individual pens of different dimensions and construction (Table 1). Birds were placed in pens on 11 and 12 March 1981 and had been previously housed in large outdoor pens since their capture in October or November 1980. All pens contained a wooden nest box similar to that described by Kessel (1957), a perch, and a water source (15.2 liter stainless steel pot with nipples or a 3.8 liter plastic fount). Commercial turkey starter (Turkey Starter AP [medicated] Crumpels, Beacon Milling Co., Cayuga, NY) and water were available ad libitum to adults and fledglings. Green alfalfa hay and dry grass were provided as nesting material. The poultry netting located behind the nest boxes in adjoining pens was covered with plywood or opaque acrylic panels to reduce aggression between males.

Reproductive activity of each pair was monitored three times per week between 1300 and 1600 h. Pairs within pens in Groups A and D (the largest and smallest pens, respectively; Table 1) were allowed to raise their young and each pair was provided bird of prey diet and frozen mealworms and crickets in covered aluminum pans (suppliers of nestling diets were those previously mentioned). Nestling diets were available to adults 5 days before young hatched. Consumption of nestling diets by adults and their young was monitored from hatching through 28 days of age, three times daily (0800, 1200, 1600 h), by weighing the diet remaining in the pans and replacing it with a weighed quantity of fresh diet in excess of that consumed during the same time period on the previous day. We did not quantify the amount of each nestling diet consumed by adults vs their nestlings, or the amount of water in the diets lost through dehydration. Clutch size and hatching success were determined for each nesting attempt within each pen. Fledging success was determined for pairs within pens in Groups A and D. Once young hatched (Groups B and C) or young were 28 days old (Groups A and D), nests were removed and pairs allowed to renest. Hatchlings in Groups B and C were sacrificed by CO_2 asphyxiation. Nestlings in Groups A and D were weighed at 18^2 days of age (1-3 days before fledging, Kessel 1957), and were removed from the pens when 30 days of age

Table 1. Pen characteristics.

Group	Number	Construction	Dimensions (m)[a]
A	5	open-wire, on ground	3 x 6 x 2
B	5	open-wire, on ground	3 x 3 x 2
	5	covered[b], above ground	1.8 x 3.7 x 2
C	8	open-wire, above ground	1.5 x 1.5 x 1.8
	8	covered[b,c], above ground	1.7 x 1.8 x 2
D	10	open-wire, above ground	1 x 1 x 0.8

[a] Width x length x height.
[b] Pens covered with aluminum roofs.
[c] Pens also visually isolated by plywood partitions.

(adults continue to feed their young for about 1 week after they leave the nest, Kessel 1957). Reproductive success in our captive starlings (clutch size, hatching and fledging success, and pre-fledging weights) was compared with that of free-living starlings nesting in wooden boxes on the Patuxent Wildlife Research Center during the same time period.

RESULTS AND DISCUSSION

Reproductive success of captive pairs of starlings varied among pen types (Table 2). Nest box utilization (percentage of pairs that laid eggs), clutch size, and hatching success were greatest in the large, open-wire pens on the ground (pen groups A and B-open). Reproductive success was consistently lowest in covered, above ground pens in which pairs of adults were visually isolated (pen group B-covered). Nest box utilization and clutch size in pen group D (smallest pens) during the first nesting period and pen group C-open during the second nesting period were similar to that in pen groups A and B-open, but hatching success was lower. Of the two pen types (A and D) in which adults were allowed to raise their young, fledging success was greater in the large, open-wire pens (pen group A). Average body weights of captive 18-day old nestlings were similar to weights of young from nests in the wild (Table 3).

Clutch size and hatching and fledging success in our captive starlings were generally lower than average values for first and second broods of free-living starlings in New York (clutch size = 5.1 and 4.1, hatching success = 90.5 and 80.3%, fledging success = 81.4 and 68.3%, respectively; Kessel 1957), a combination of first and second broods of free-living starlings on the Patuxent Wildlife Research Center in 1981 (clutch size = 4.7, hatching success = 91.1%, fledging success = 85.6%, n = 24), and pairs of

captive starlings housed in large (width = 3 m, length = 12 m, height = 2.4 m), open-wire pens containing four pairs per pen and a similar nestling diet (clutch size = 4.7 - 4.9, hatching success = 88.8 - 90.4%, fledging success = 63.1 - 100%; Grue and Christian 1981). Clutch size and hatching success in our most successful pens (A and B-open) were similar to that reported by Risser (1975) and Schafer et al. (1981) for pens containing 10 pairs of starlings. Risser reported an average clutch size of 4.2 eggs and hatching success of 70 percent, and Schafer et al. (1981) reported values of 3.6 and 81.5 percent, respectively, about 25 percent lower than that of free-living starlings nesting nearby.

Reasons for the observed differences in reproductive success among our pen groups, between our study and that of Grue and Christian (1981), and between captive and free-living starlings are not known. Reproductive success in captive starlings was greatest in large, open-wire pens on the ground that permitted

Table 2. Reproductive success of pairs of adult (≥ 1 year-old) European starlings within different types of pens.

Pen group[a]	Dates[b]	Number of nest boxes with eggs n (%)	Clutch size $\bar{X} \pm SD$	Number of young [$\bar{X} \pm SD$ (%)] Hatched[c]	Fledged[c]
			FIRST NESTING		
A	11 Mar - 16 May	5 (100)	3.8 ± 0.4	2.8 ± 0.8 (73.7)	2.0 ± 0 (71.4)
B-open	11 Mar - 15 Apr	5 (100)	3.2 ± 0.8	3.0 ± 1.2 (93.8)	--
B-covered	11 Mar - 23 Apr	2 (40.0)	2.0 ± 0	1.0 ± 0.7 (50.0)	--
C-open	11 Mar - 26 Apr	5 (62.5)	3.6 ± 1.1	2.3 ± 1.7 (63.9)	--
C-covered	11 Mar - 19 Apr	4 (50.0)	2.8 ± 1.3	2.5 ± 1.7 (89.3)	--
D	11 Mar - 20 May	10 (100)	3.8 ± 0.4	2.6 ± 1.1 (68.4)	0.7 ± 1.1 (26.9)
			SECOND NESTING		
A	9 May - 16 May	5 (100)	3.5 ± 1.3	--[d]	--
B-open	16 Apr - 12 May	5 (100)	4.2 ± 0.4	3.2 ± 0.8 (76.2)	--
B-covered	23 Apr - 17 May	3 (60.0)	4.0 ± 1.0	2.7 ± 0.6 (67.5)	--
C-open	27 Apr - 20 May	8 (100)	3.5 ± 1.4	2.3 ± 1.4 (65.7)	--
C-covered	20 Apr - 16 May	5 (62.5)	3.8 ± 0.8	2.8 ± 0.8 (73.7)	--
D	21 May - 13 Jun	7 (70.0)	4.1 ± 0.9	1.8 ± 1.7 (43.9)	0
			THIRD NESTING		
A	16 May - 15 Jun[e]	5 (100)	3.8 ± 1.1	3.0 ± 1.7 (78.9)	0
B-open	13 May - 7 Jun	4 (80.0)	4.0 ± 0.8	2.0 ± 1.8 (50.0)	--
B-covered	18 May - 6 Jun	2 (40.0)	2.0 ± 1.4	0	--
C-open	21 May - 7 Jun	4 (50.0)	4.0 ± 0.8	2.3 ± 2.1 (57.5)	--
C-covered	17 May - [f]7 Jun	2 (25.0)	3.5 ± 0.7	1.5 ± 2.1 (42.9)	--
D	--	--	--	--	--

[a] Pen characteristics are described in Table 1.
[b] From placement of birds in pens or removal of nests and hatchlings (B-D) or fledglings (A and D).
[c] For pairs that laid eggs.
[d] Nests and eggs removed because fledglings (< 28 days old) interferred with incubation behavior of adults.
[e] Fledglings from first nesting removed from pen.
[f] End of reproductive activity.

Table 3. Body weights (g) of 18-day old European starlings from nests of captive and free-living adults.

	n	Mean	SD	Range
Captive	16[a]	75.4	7.6	60 - 88
Free-living	88[b]	70.3	6.5	54 - 82

[a] From 8 nests.
[b] From 24 nests located on the Patuxent Wildlife Research Center in 1981.

interaction (visual and auditory) between birds within adjoining pens and normal foraging behaviors. Age of captive starlings selected for study may account for the differences between the reproductive success of our birds and that of Grue and Christian (1981) and between the reproductive success of captive and free-living individuals. In those studies in which reproductive success of captive starlings was lowest (Schafer et al. 1981, and our study), many of the test birds were probably breeding for the first time. In the wild, only a small number of starlings breed their first year, and those that do, produce first clutches that are smaller than those of older birds; second clutches are similar in size to those of older birds (Kessel 1957; Collins and de Vos 1966; Flux and Flux 1982). The greater number of eggs in the second clutches of our starlings compared to their first clutches was probably due to the presence of birds about 1 year old. Our study suggests that starlings are capable of breeding their first year, but in the wild, their reproductive activity is probably limited by competition with older birds for nesting cavities.

Differences in the onset of breeding activity and diet do not appear to account for the lower reproductive success of captive starlings compared with free-living individuals. Captive starlings in our study (first egg laid on 29 March) and those of Risser (1975) and Grue and Christian (1981) initiated egg laying 16 to 21 days before free-living starlings in the same vicinity, probably in response to the greater availability of nesting material and cavities, and food, and greater social stimulation (Risser 1975). Early initiation of breeding could reduce reproductive success due to the adverse effects of harsh early spring weather on gonadal development and reproductive activity. However, the reproductive success of captive starlings that initiated egg laying a few days after free-living individuals was still lower than that observed in the wild (Schafer et al. 1981). Although Risser (1975) suggested that the smaller clutch sizes in his pens may have been a result of an inadequate diet for maximum egg production, Grue and Christian (1981) reported clutch sizes in captive starlings given a similar diet to be comparable to that of their free-living counterparts. We also do

not believe that differences between the basal areas of the nest boxes used by our captive starlings (252 cm^2) and those used by their free-living counterparts (252 - 813 cm^2) account for the observed differences in reproductive success. Reproductive success of free-living starlings appears to be inversely related to basal area (Moeed and Dawson 1979).

The total amount of nestling diet consumed and the proportion of each component varied with age of our captive nestlings (Figs. 1 and 2). The pattern of consumption of nestling diets corresponded closely to the growth curve of free-living starlings (Kessel 1957). Our nestlings appeared to be fed two to four times their body weights (estimated from Kessel 1957) when 1 to 4 days old and 0.7 to 1.4 times their body weight between 4 and 18 days of age (Fig. 1). Consumption of nestling diets reached its peak at about day 13 and decreased until fledging (days 18 - 24), and then increased as young became independent of adults and fed at the feeders. When nestlings were 1 to 7 days old, they were fed primarily mealworms (54 - 83% of the diet removed by adults, Fig. 2). From day 8 to day 24, the proportion of the nestling diet removed by the adults consisting of crickets increased to a high of 58 percent while the proportion consisting of mealworms decreased to as low as 35 percent. The amount of mealworms adults and nestlings consumed relative to crickets increased after day 23 when young started feeding at the feeders. The proportion of the nestling diet removed consisting of bird of prey diet remained relatively constant during nestling development (Fig. 2). We estimate that, in the presence of adults, about 1,465 g of nestling diet (150 g bird of prey diet, 675 g mealworms, 640 g crickets) are necessary for adults to raise one young to 28 days of age. This is in addition to the turkey starter available to the adults, but which is not fed to the nestlings by their parents.

To our knowledge, our study and that of Grue and Christian (1981) are the first successful attempts to induce starlings to lay eggs and rear young in captivity; previous attempts (Miller 1969) failed. Since most captive-bred passerines are exotic to North America and attempts to breed native species in captivity have been only partially successful (Knos and Stickley 1974), the results of our study and others (Risser 1975, Grue and Christian 1981, Schafer et al. 1981) suggest that captive starlings may be a suitable model for determining the potential effects of environmental contaminants on North American passerines. Single pairs within pens may be used which improves statistical designs, avoids problems in the interpretation of results due to polygamy, and reduces interaction between pairs which may lead to mortality of adults and interfere with parental care. We observed no mortality in our study, whereas others with more than one pair per pen (Risser 1975, Grue and Christian 1981, Schafer et al. 1981) reported mortality of 18 to 31 percent in males and 7 to 14 percent in females, due primarily to aggression during nest-box and mate selection. Unfortunately, optimum pen characteristics do not appear to vary with the number of pairs per pen;

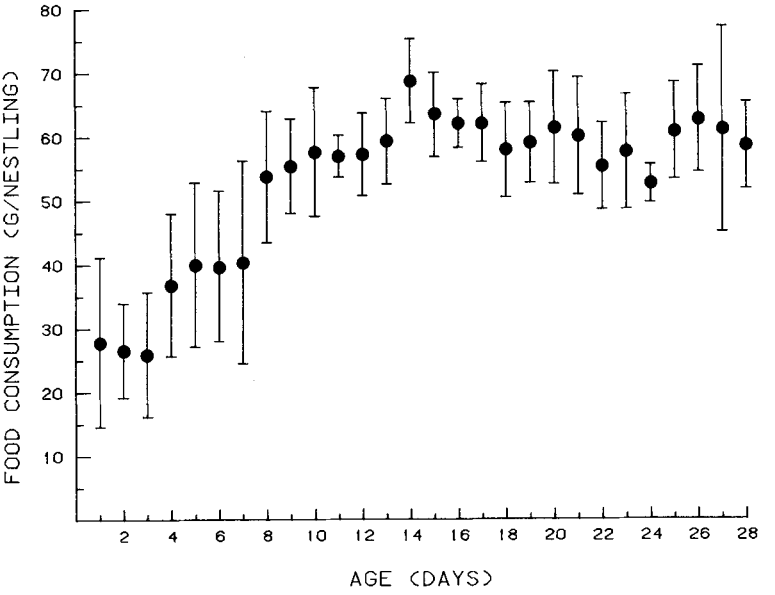

Figure 1. Total consumption of nestling diets by 1- to 28-day old starlings and their parents expressed as g per nestling per day. Dots = means; vertical lines = one standard deviation; sample size = 5-8 pens, 2-4 young/pen.

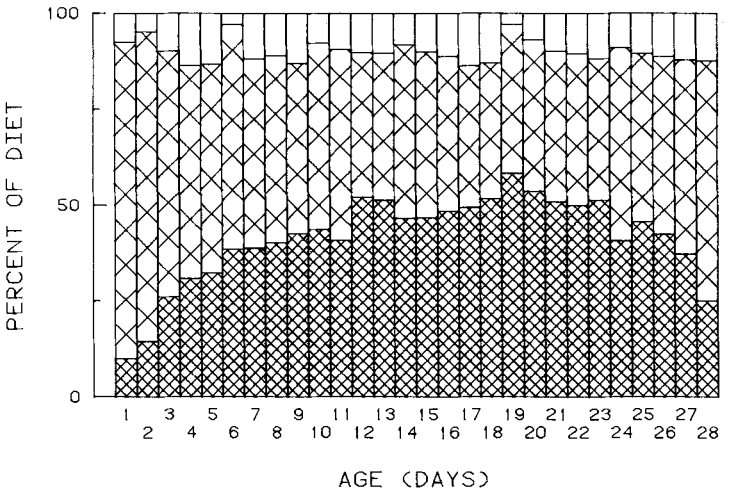

Figure 2. Composition of nestling diets consumed by 1- to 28-day old starlings and their parents expressed as the average percentage of the total diet consumed (Fig. 1). Closely cross-thatched bars = frozen crickets, open cross-thatched bars = frozen mealworms, and the open bars = bird of prey diet.

relatively large, adjacent open-wire pens on the ground appear to be necessary to maximize reproductive success. That single pairs reproduced in our smallest above-ground pens, although not as successfully as those in larger pens on the ground, suggests that additional development of methods with birds at least 2 years old could improve reproductive success in small pens.

Given adequate pen facilities, the use of captive starlings to determine the effects of contaminants on egg production, incubation behavior, and egg fertility would be relatively inexpensive because birds need to be housed in test facilities only during the breeding season, and nestling diets do not need to be provided. This approach was used by Schafer et al. (1981) to determine the effects of avian chemosterilants on starlings within pens containing 10 breeding pairs. Although studies on the effects of contaminants on the growth and survival of captive nestlings are feasible, the costs associated with purchasing, preparing, and presenting nestling diets to an adequate number of breeding pairs may be prohibitive.

Few techniques appear to be practical to contaminate the large number of insects needed for a full reproductive trial. Insects could be given a contaminated food source for a specified period of time or until they died. Producing a range of concentrations of a contaminant in insects may be difficult using this technique and would depend on the sensitivity of the insects to the contaminant. Alternatives include spraying insects with, or dipping insects into, solutions containing different concentrations of a test substance. With any of these techniques, contaminated insects can be frozen, although they must be thawed before starlings will readily consume them.

We do not know the minimum amount of time starlings must be acclimated to captivity before they will breed. In all of the studies in which reproduction has been successful, starlings had been previously housed in outdoor holding pens; attempts (Miller 1969) to breed recently captured starlings have failed. Periods of acclimation reported by Risser (1975), Schafer et al. (1981), and our study were similar; starlings captured in late summer to late fall, and housed together in outdoor aviaries until January or March of the following year, laid eggs and hatched young.

Differences between the sensitivity of starlings and other passerines to contaminants must be considered when designing reproductive tests. Starlings do not appear to be as sensitive to organochlorine and cholinesterase (ChE)-inhibiting compounds as some other songbirds (Schafer and Brunton 1979). This, however, does not reduce the utility of starlings as a model for other species of songbirds, as long as exposure indices (e.g., brain ChE activity) are used to extrapolate results. Although greater exposure to a particular contaminant may be necessary to induce effects in starlings compared with some other songbirds, we assume that similar effects would be expected among species in which these indices indicate a similar degree of intoxication.

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