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Results from a long-term nest-box program for American Kestrels: implications for improved population monitoring and conservation

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ABSTRACT. A long-term, volunteer-based nest-box program for American Kestrels (*Falco sparverius*) breeding in eastern Pennsylvania was evaluated to identify ways to increase the efficiency of the program and to identify general principles that can be used to improve long-term conservation efforts for other nest-box programs. Between 1993 and 2002, Hawk Mountain Sanctuary volunteers maintained and monitored approximately 270 kestrel nest boxes. Reproductive parameters of kestrels in these nest boxes were similar to those reported in other studies, and kestrels attempted nesting twice in a single year on 11 occasions. Nesting success varied among nest boxes, and productivity was consistently high at some nest boxes and consistently low at others. As a result, approximately half of all nestlings came from the 25% of nest boxes that were used most frequently, and fewer than 7% of kestrels fledged from the 25% of the nest boxes that were used least frequently. Our analysis suggests that volunteer field effort could be reduced by 25% with minimal impact on overall kestrel productivity. Managing for increased conservation efficiency is not inconsistent with effective conservation monitoring and management of kestrels. Our findings have important implications for conservation efforts in which substantial benefits can accrue from more efficient use of limited conservation resources.

SINOPSIS. **Resultados sobre un estudio a largo sobre *Falco sparverius*: implicaciones para mejorar la monitoría y conservación del ave**

Un estudio a largo alcance sobre un programa de proveer con cajas de anidamiento a falcones (*Falco sparverius*) fue evaluado para identificar las formas de incrementar la eficiencia del programa e identificar principios generales que puedan ser utilizados para la conservación de la especie. El trabajo se llevó a cabo entre 1993 y 2002 en Hawk Mountain Santuary, Pennsylvarnia, utilizando voluntarios los cuales monitorearon aproximadamente 270 cajas utilizadas para anidar por el falcón. Los parámetros reproductivos del ave, en dichas cajas, fue similar al informado en otros estudios. En un año en particular, las aves intentaron reanidar en once ocasiones. El éxito de los nidos varió entre las cajas, y la productividad fue consistentemente alta en algunas cajas y consistentemente bajas en otras. Como resultado, aproximadamente el 50% de los pichones provinieron del 25% de las cajas que fueron utilizadas con mayor frecuencia, y menos de un 7% del 25% de las cajas utilizadas con menor frecuencia. Nuestro análisis sugiere que el uso de los voluntarios se puede reducir en un 25% con impacto mínimo sobre la productividad de los falcones. El manejar para incrementar la eficiencia en la conservación del ave, no resultó inconsistente con la efectividad del monitoreo (rastreo) y manejo de los falcones. Nuestros hallazgos tienen implicaciones importantes

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en los esfuerzos por conservar el ave, con beneficios sustanciales y con el uso más eficiente de recursos limitados para su conservación.

Key words: American Kestrels, conservation efficiency, *Falco sparverius*, nest box, volunteers

Many populations of raptors are threatened by direct persecution, pesticide use, and habitat loss (del Hoyo et al. 1994; Zalles and Bildstein 2000). Because of this, birds of prey often are used as "flagship," "umbrella," or "indicator" species, and are regularly the object of intensive conservation efforts (Meyburg and Chancellor 1994; Bildstein 2001). Breeding populations of raptors are sometimes limited by availability of nest sites (del Hoyo et al. 1994), and the use of artificial structures to bolster such populations is widespread (Millsap et al. 1987; Toland and Elder 1987). This conservation strategy has benefited many species including Ospreys (*Pandion haliaetus*), several types of hawks and buzzards (*Buteo* spp.), Golden Eagles (*Aquila chrysaetos*), and Common, Lesser, and Mauritius kestrels (*Falco tinnunculus*, *F. vespertinus*, and *F. punctatus*), as well as many owls (Millsap et al. 1987; Cade and Jones 1993). Maintaining and monitoring these artificial structures also often provides a framework for population monitoring.

The American Kestrel (*Falco sparverius*) is a small falcon whose populations have declined recently in the northeastern United States (Bildstein 1996; National Audubon Society 2002; Sauer et al. 2002). Nest-box programs for this species date from the 1950s when several efforts were established in eastern Pennsylvania (Nagy 1963; Heintzelman and Nagy 1968). Since then, similar programs have been initiated in many other U.S. states including California, Colorado, Florida, Georgia, Idaho, Iowa, Missouri, New Jersey, Pennsylvania, Utah, West Virginia, and Wisconsin and in at least two Canadian provinces (Saskatchewan and Ontario; Toland and Elder 1987; Smallwood et al. 1999; Dawson and Bortolotti 2000). Historically, nest boxes have been used to increase kestrel densities and to augment populations regionally, as well as to increase the number or accessibility of birds for study (Nagy 1963; Hamerstrom et al. 1973; Apanius 1991; Bortolotti 1994; Bechard and Bechard 1996). Today, nest-box programs are considered effective tools for long-term conservation and monitoring of the species.

Successful natural resource conservation depends upon the effective use of limited human and financial resources. Long-term conservation monitoring efforts in particular need to be as efficient as reasonably possible, not only to reduce resource wastage, but also to increase the likelihood that they will continue to be carried out. One way to increase the efficiency of conservation efforts is to monitor the costs and the effectiveness of ongoing programs and to manage these programs adaptively (Primack 1998). Here we evaluate a 10-yr American Kestrel nest-box dataset from a program in eastern Pennsylvania that is largely maintained by volunteers (Bildstein 1996). Our goals are to evaluate general data and the effectiveness of this approach for long-term population monitoring, and based on this analysis, to identify generalized mechanisms to increase the efficiency of the program. Such mechanisms may have application for other long-term conservation efforts to increase populations of avian species. In the second analysis, we take the natural variability within this population as a given and, after discussing likely sources of that variability, focus on the variability itself in the context of the efficiency of our conservation effort. Specifically, we address to what extent would maintaining a subset of the current nest boxes promote more efficient use of limited conservation resources, including volunteer time and money? We follow this analysis by discussing the potential benefits, costs, and implications to kestrels and to population monitoring of such a scaled-down approach to conservation.

STUDY AREA AND METHODS

Study area. The study area consists of approximately 1500 km^2 of partly wooded farmland in the Appalachian Mountains of east-central Pennsylvania, centered about 30 km north of Reading and 30 km west of Allentown, Pennsylvania, in Berks, Lehigh, and Schuylkill counties. The region has a temperate continental climate. Mean maximum July temperature is 30°C, mean minimum January temperature is −7°C, and average annual precipitation is

110 cm with 75 cm of snow (Yarnal 1989). Local topography includes lowlands and rolling hills with a maximum elevation of 490 m above sea level. The site is part of the Eastern Forest Biogeographical Province and native vegetation is primarily Appalachian oak forest composed of mostly second- and third-growth mixed-deciduous trees (Udvardy 1984; Utech 1989). High vegetative diversity is due in part to extensive timber harvests, charcoal production, and burning to increase native blueberry (*Vaccinium* spp.) productivity (Braun 1950). Primary dominants include red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), red maple (*Acer rubrum*), tulip-tree (*Liriodendron tulipifera*), sassafras (*Sassafras albidium*), and black gum (*Nyssa sylvatica*). Most lowlands are privately held livestock, grain, and Christmas-tree farms, interspersed with low-density suburban areas. See Apanius (1991) and Rohrbaugh (1994) for details.

The American Kestrel is a partial migrant in Pennsylvania. Most of the breeding population departs in September or October of each year and returns in March and April. Winter populations of year-round residents are bolstered by an influx of migrants from farther north (McWilliams and Brauning 2000). Based on relative abundances in areas without nest-box programs, we estimate that less than 25% of the local birds nest in natural cavities.

Nest boxes and monitoring. Wooden nest boxes were made from 2.54-cm thick pine or cedar, had internal dimensions of 26 × 24 × 33 cm with 7.6-cm diameter entrance holes centered 26 cm above the floor of the box. Boxes, which were placed in open areas that kestrels frequented regularly, were mounted 3–6 m from the ground, usually on trees or utility poles, but sometimes on sheds and barns. Most boxes were within 50 m of a road, adjacent to or within open farmland or meadows. Box openings usually faced away from the road, and boxes were separated from each other by at least 500 m.

All boxes were cleaned, repaired and, if necessary, replaced each March before migrant kestrels establish territories. The floor of each box was covered with a 2.5–5-cm layer of fresh woodchips. Boxes were then rechecked from a ladder at 2-wk intervals and breeding status and reproductive parameters noted at each visit. All nestlings were banded at 10–25 d of age, and some adult kestrels also were banded when captured opportunistically in the nest box or were trapped near the box.

Hawk Mountain Sanctuary, a raptor conservation organization that maintains a 1000-ha preserve near the center of the study area, oversees the nest-box effort. Since the early 1990s, more than 200 nest boxes have been maintained on the study area. Most of these have been monitored by volunteers for at least five years between 1993 and 2002. Maintaining and monitoring each box involves two to five visits of 10–30 min each, or about 1.5 h and 32 km (20 miles) of travel annually. Across the 10-yr time frame of this study, we estimate that volunteers spent a minimum of 3000 hours in the field and traveled more than 60,000 km to maintain and monitor nest boxes.

Data analysis. For each nest box we calculated averages of the number of eggs laid, their hatch date based on age when monitored (Griggs and Steenhof 1993), the maximum number of nestlings observed, and the number of fledglings (i.e., birds banded at 10–25 d of age). We also calculated average nesting success for each box (successful nesting attempts were those in which at least one chick fledged) and the average proportion of fledglings that were male (following Smallwood 1989). We refer to these summary data as “productivity measures.” We also calculated the frequency with which each nest box was occupied (i.e., eggs were laid) during the years it was monitored.

We analyzed our data in three ways. First, because data were generally not normally distributed, we used a nonparametric Wilcoxon rank-sum test to compare productivity measures between boxes that were occupied in less than half of the years monitored (“low-use boxes”) with those that were occupied in more than half of the years monitored (“high-use boxes”). Second, to evaluate the extent to which kestrel use of nest boxes was random, we generated expected frequencies of nest box occupancy from a binomial distribution and compared observed and expected values with a *G*-test for goodness of fit (Sokal and Rohlf 1981). Third, we correlated average kestrel productivity with average nest box use frequency by evaluating average productivity measures at boxes in 10 use-frequency classes (i.e., 0–10%, 10–20%, . . . 90–100%). We used a *G*-test for goodness of fit with Williams correction for a two-cell

Table 1. Reproductive output (mean ± SD (*N*)) by kestrels in eastern Pennsylvania (a) on the 11 occasions when nesting was attempted twice during a single breeding season and (b) on the five occasions where second nesting followed an initially successful attempt.

	No. eggs	No. nestlings	No. fledglings	Proportion of males	Percent successful
(a) All second nesting attempts					
First attempt	3.80 ± 1.4 (10)	0.64 ± 0.81 (11)	0.64 ± 0.81 (11)	0.10 ± 0.22 (5)	45
Second attempt	3.90 ± 0.37 (10)	3.00 ± 1.18 (11)	2.55 ± 1.51 (11)	0.46 ± 0.42 (10)	91
(b) Second nesting attempts following a successful first attempt					
First attempt	3.75 ± 1.26 (4)	1.40 ± 0.55 (5)	1.40 ± 0.55 (5)	0.10 ± 0.22 (5)	100
Second attempt	3.75 ± 0.5 (4)	3.20 ± 1.30 (5)	2.40 ± 1.82 (5)	0.58 ± 0.29 (4)	80

case to evaluate nest-box switching by banded kestrels that nested in more than one year of the study (Sokal and Rohlf 1981). Data were analyzed with SAS software (version 8.01, 1999).

RESULTS

Nest boxes. Between 1993 and 2002, Hawk Mountain volunteers maintained and monitored a total of 270 kestrel nest boxes. On average, 85.6 ± 9.4 (± SD) nest boxes were used each year, eggs were recorded at 83.6 ± 10.6 nests in each year, nestlings were observed at 63.5 ± 7.9 nests in each year, and fledglings were observed at 61.5 ± 8.8 nests in each year. Our analysis focused primarily on the 201 boxes that were maintained for at least five years during this period. However, because some analyses may be impacted by differences in the amount of time monitored, we conducted some of our statistical tests on both those 201 boxes and the subset of boxes monitored for all 10 years of the study. The average box was monitored for 8.8 ± 1.7 years (± SD; *N* = 201), and 112 (56%) were monitored for all 10 years of the study. Kestrels nested twice during a single breeding season 11 times, once each at eight boxes, and once in three consecutive years at a single box.

Kestrels produced an average of 4.56 ± 0.04 eggs per box (± SE; *N* = 171). Average hatch date of eggs was 153 ± 0.95 days after the start of the year (i.e., 01–02 June; *N* = 158). On average, 2.90 ± 0.10 nestlings and 2.73 ± 0.10 fledglings were produced at each box (*N* = 171). The proportion of successful first nesting attempts was 0.69 ± 0.02 (*N* = 171). Mean proportion of offspring that were male averaged 0.50 ± 0.01 (*N* = 154).

Second nesting attempts. Six of the 11 second nesting attempts occurred after the first nesting attempt failed at the egg stage (Table 1). The other five occurred after a successful first nesting attempt. Although our sample size is small, in those five cases first breeding was early (mean hatch date = 131 ± 5; 11–12 May), productivity was low, and a greater proportion of chicks were female. Ten of the 11 second nesting attempts produced fledglings, and productivity values were similar to average values for successful first attempts (Table 1).

Frequency of nest box use and nesting success. On average, nest boxes were used by kestrels in 4.0 ± 2.9 years (± SD; *N* = 201) or 44% ± 30% of the years monitored. Of the 201 boxes monitored for at least five years, four were used in all 10 years of the study, 114 were used in fewer than five years, and 30 were never used. The nine nest boxes at which second nesting occurred were more heavily used (in 68% of years) than was the average box, which was used in 44% of years monitored.

Nesting success varied among nest boxes. At the 112 boxes that were monitored for 10 yrs, all nesting attempts were successful at 25 nest boxes (22%), and all were unsuccessful at nine boxes (8%). For all 201 boxes, there was no difference in the average number of eggs in clutches at high- and low-use boxes (high-use boxes were used in more than 50% of years monitored, low-use boxes were all other boxes; $P_{94,77}$ = 0.1), but average hatch date was earlier ($P_{94,64}$ = 0.0008) in high-use boxes (Table 2). Kestrels breeding in low-use boxes produced fewer chicks ($P_{94,77}$ = 0.001) and had fewer

Table 2. Reproductive output (number of eggs, chicks, and fledglings, ratio of males in brood, hatching date, and success rates; mean ± SE) at kestrel nest boxes that were used in at least 50% of the years monitored ("high-use boxes") and in boxes that were used in fewer than 50% of years monitored ("low-use boxes"). *F*-tests for equality of variances are shown. Statistical significance is indicated with an *.

	High-use	Low-use	*F*	*P*
No. eggs	4.6 ± 0.04	4.5 ± 0.08	$F_{76,93} = 3.92$	< 0.0001*
No. nestlings	3.2 ± 0.08	2.5 ± 0.18	$F_{76,93} = 3.59$	< 0.0001*
No. fledglings	3.0 ± 0.09	2.4 ± 0.19	$F_{76,93} = 3.50$	< 0.0001*
Male ratio	0.51 ± 0.01	0.48 ± 0.03	$F_{59,93} = 2.76$	< 0.0001*
Hatching date	150 ± 0.9	157 ± 1.8	$F_{63,93} = 2.99$	< 0.0001*
Success rate	0.75 ± 0.02	0.62 ± 0.05	$F_{76,93} = 3.92$	< 0.0001*

fledglings ($P_{94,77} = 0.03$) than birds breeding in high-use boxes. However, nesting success (successful nesting attempts were those in which at least one chick fledged) and the proportion of male chicks did not differ between high- and low-use boxes ($P_{94,77} = 0.30$, $P_{94,60} = 0.14$). Variability in every productivity measure was greater at low-use boxes than at high-use boxes (Table 2).

Kestrels used certain boxes more than expected and other boxes less frequently than expected if use of boxes was random (for all 201 boxes, $G = 25.6 > \chi^2_{0.005,9} = 23.6$; for the 112 boxes monitored for 10 years, $G = 111.7 > \chi^2_{0.001,9} = 27.9$). Mean numbers of eggs laid, numbers of nestlings and fledglings produced, and success rate all were correlated linearly with the frequency with which nest boxes were used ("use frequency"; Figs. 1a, b, c, Fig. 2a). Mean sex ratios of nestlings were not linearly correlated with frequency of use (Fig. 2b). In general, mean hatch date was earlier in frequently used boxes, but there was no statistically significant linear correlation in these data (Fig. 2c).

A disproportionate number of kestrel fledglings was produced at a relatively small subset of nest boxes. When all 201 monitored boxes were considered, twenty-five percent of all fledglings produced in 10 years came from the 20 most frequently used nest boxes (25% of chicks fledged from 10% of boxes). Fifty-four percent of all fledglings came from the 50 (25%) most frequently used boxes, 84% of fledglings came from the 100 (50%) most frequently used boxes, and 98% of fledglings came from the 151 (75%) most frequently used boxes. Similar trends were observed when we considered only the 112 boxes monitored for all 10 years of the study (Fig. 3): 20% of all fledglings came from the 11 (10%) boxes that were used most frequently, 45% of fledglings came from the 28 (25%) boxes used most frequently, 75% of fledglings came from the 56 (50%) boxes used most frequently, and 93% of fledglings came from the 84 (75%) boxes used most frequently.

Banded birds. Between 1992 and 2003, 413 adult kestrels were banded at or near nest boxes. Of these, 267 were females (65%) and 146 were males (35%). Of the adult females banded, forty-two (16%) were observed in more than one year of the study. They included four birds that nested in three years and one bird that nested in four years. Of the adult males banded, six were observed in multiple years.

Twenty-three female birds (55%) observed in multiple years bred in the same box for at least two years ("single-box breeders") and one bred in a different box in a third year. The 19 remaining females (45%) bred in different boxes in each year ("multiple-box breeders"). There were no significant differences in the productivity rates among years for either single-box breeders or for multiple-box breeders ($P = 0.05$). Also, single-box breeders tended to occupy nest boxes that were used with greater frequency than was the average box (67% use frequency of boxes used by single-box breeders vs. 44% study-wide average use frequency of all boxes). Finally, when they switched boxes, 70% ($N = 14$) of the multiple-box breeders moved from lower-use boxes to higher-use boxes ($G = 9.7 > \chi^2_{0.005,1} = 7.9$; includes one single-box breeder that switched boxes after the first year).

DISCUSSION

Our results indicate that the basic productivity measures of this eastern Pennsylvania pop-

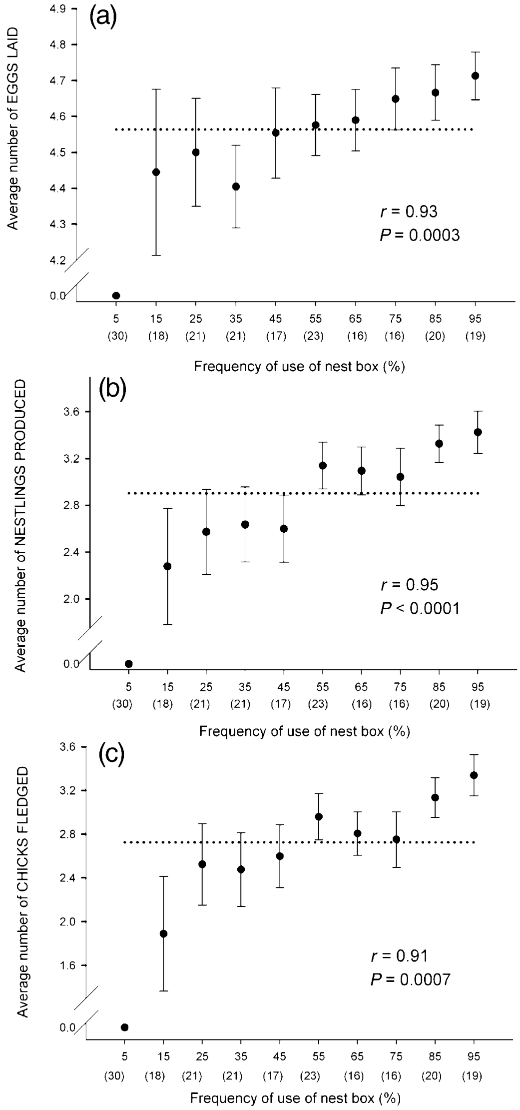

Fig. 1. Relationships between frequency of nest-box use by American Kestrels across 10 yrs in eastern Pennsylvania and (a) average number of eggs laid, (b) average number of nestlings produced, and (c) average number of fledglings produced. Only nest boxes that were monitored for at least five years are included. Dotted lines represent mean values for all boxes. Correlations are of mean values from each category, and data from the 5% use category were not used in the correlation analysis.

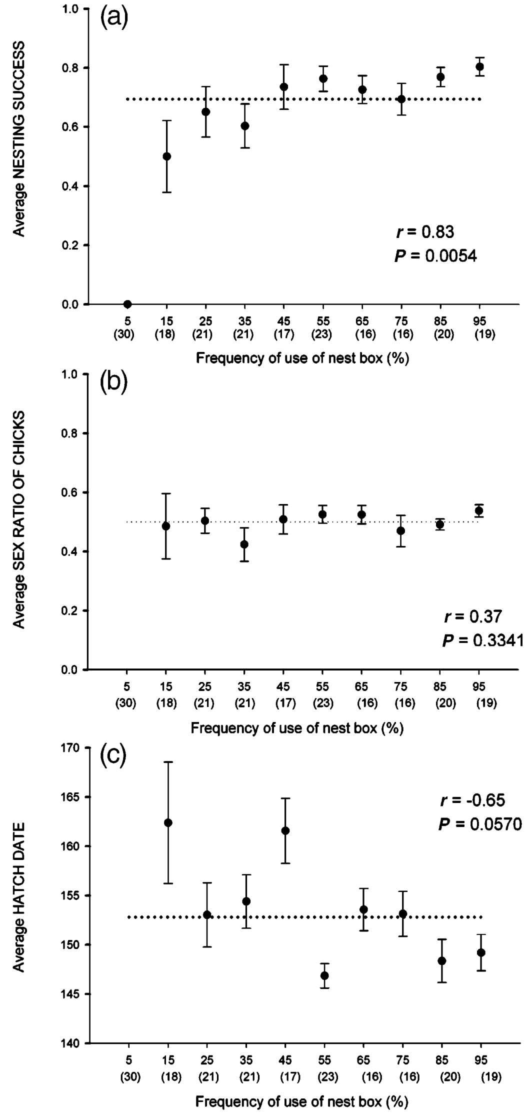

Fig. 2. Relationships between frequency of nest box use by American Kestrels in eastern Pennsylvania and (a) average nesting success, (b) average sex ratio of chicks, and (c) average hatching date of eggs. Only nest boxes that were monitored for at least five years are included. Dotted lines represent mean values for all boxes. Correlations are of mean values from each category, and data from the 5% use category were not used in the correlation analysis.

ulation of American Kestrels (number of eggs, nestlings, and fledglings produced, breeding success, and sex ratios of offspring) are similar to those of kestrels breeding elsewhere in North America (Bloom and Hawks 1983; Varland and Loughin 1993; Breen and Parrish 1997; Jacobs 1995; Dawson and Bortolotti 2000; Sockman and Schwabl 2001). Variability in nesting success among years also was similar to that ob-

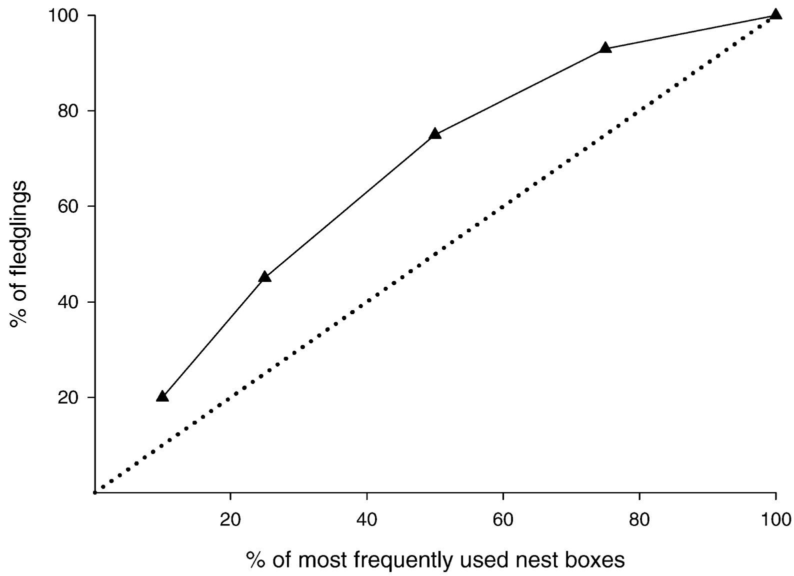

Fig. 3. Contribution of nest boxes used with different frequencies to the total reproductive output of kestrels in a 10-yr study in eastern Pennsylvania (triangles). Data shown are nest boxes that were monitored in all 10 yrs of the study (N = 112). Patterns for the 201 boxes monitored for at least five years are similar. The dotted line represents the expected result if all nest boxes contributed equally to reproductive output.

served in these studies. Frequency of nest-box use by kestrels correlated well with kestrel reproductive success. Kestrels nesting at some nest boxes consistently produced a large number of fledglings, whereas those in other boxes consistently produced fewer fledglings. Because these data are representative for this species, they suggest that our nest box program would be an effective tool for population monitoring.

Individual and environmental characteristics can interact to create variability in avian reproductive output (Plesnik and Dusik 1994; Valkama et al. 1995; Korpimaki and Wiehn 1998; Wiebe et al. 1998; Dawson and Bortolotti 2000; Sockman and Schwabl 2001; Valkama et al. 2002). Previous research on American Kestrels suggests that food availability has a strong influence on reproductive output (Toland 1987; Dawson and Bortolotti 2000). The consistency with which some of the nest boxes in our study produced more fledglings than others suggests that at our site either individual-bird variation, habitat-related variables, or both, influenced output in a manner that, over the long-term, may be more important than the impact of weather-related perturbations, which should show study-wide effects. Earlier work in this study area suggests that nest boxes on barns consistently endured less predation and were more heavily used than nests at other sites (Valdez et al. 2000). Ultimately, however, whether or not the variability we observed is due to environmental or bird-specific differences, its presence has important consequences for designing population models and for increasing the efficacy of this conservation monitoring.

Variability in nesting success also can limit the long-term conservation success of projects by reducing their efficacy. This analysis evaluated the impact of maintaining a subset of nest boxes in a kestrel management program to increase the efficiency with which limited conservation resources are used. The extensive inter-site variability in nesting success that we observed suggests that maintaining a subset of nest boxes could be beneficial because it has the potential to increase significantly the efficiency of our field effort. We found that certain boxes were used consistently more frequently by kestrels and that the highest number of offspring was produced at these boxes. As a result, a disproportionately large percentage of kestrels (45–54%) fledged from the 25% of nest boxes that were used most frequently, and disproportionately few kestrels (2–7%) fledged from the 25% of the nest boxes that were used least frequently. Simply put, we could selectively reduce our current field effort (i.e., nest box maintenance and monitoring) by 25%, while decreasing total managed kestrel reproduction by only 2–7%. This relatively small decrease in productivity could be mitigated by redirecting the unused field effort either toward placing additional new boxes in new areas, or in the development of new conservation actions.

That said, we recognize that there may be "costs" associated with the scale-back we advocate. For example, unproductive nest boxes may be important "training sites" for young, inexperienced, or unproductive birds. If true, after first using a poor box, inexperienced breeders may relocate to better sites where they can be more productive; this phenomenon has been observed in some unmanaged populations of birds (Ferrer and Bisson 2003; Hoover 2003). Indeed, the behavior of the banded kestrels in this study, which typically moved from lower-use to higher-use nest boxes, suggests that this may be the case. If low-use boxes are used primarily by inexperienced or unproductive kestrels, removing 25% of the boxes could increase competition for high-use boxes. Increased competition could lead to increased stress or to changes in foraging or nesting behavior by adults, all of which can result in lower productivity. Scaling back on the number of boxes maintained and monitored also may impact the ability of biologists to detect changes in population size, since infrequently used boxes may be those where changes in population parameters are first observed. For these reasons, and because high variability in reproductive output at low-use boxes indicates that it is possible to produce a normal brood of chicks in such a box, we also advocate monitoring the impacts of nest-box reduction on the kestrel populations as an important component of any new management action. We also advocate low-frequency monitoring of a few low-use nest boxes. One way to accomplish this while maintaining the efficiency of our field effort would be to target low-frequency monitoring efforts on low-use boxes that are on routes frequently traversed by volunteers.

Broader implications. It seems reasonable to assume that most conservation efforts do not operate at maximum efficiency. Even so, because conservation resources usually are limited, maximizing efficiency remains an important goal. Our results suggest several ways in which the overall efficiency and effectiveness of conservation efforts can be increased. Specifically, our field data were collected almost entirely by non-professional volunteers. The use of volunteers can be a reasonable and effective way to collect valuable conservation data with relatively low organizational expenditures (Newman et al. 2003; Foster-Smith and Evans 2003). Also, evaluation of conservation programs for birds is relatively simple and can highlight important ways to increase their effectiveness. Unfortunately, such evaluation is rarely attempted or, at least, rarely published. Finally, field efforts and use of scarce resources can be adaptively managed to increase conservation efficiency. Although there may be trade-offs, the benefits derived from adaptive management can increase the efficiency and, in turn, the long-term effects of conservation efforts.

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