The Effect of Supplemental Feeding on the Known Survival of Reintroduced Aplomado Falcons: Implications for Recovery

Authors: Sweikert, Lily, and Phillips, Mike

Source: Journal of Raptor Research, 49(4) : 389-399

Published By: Raptor Research Foundation

URL: https://doi.org/10.3356/rapt-49-04-389-399.1

J. Raptor Res. 49(4):389–399

THE EFFECT OF SUPPLEMENTAL FEEDING ON THE KNOWN SURVIVAL OF REINTRODUCED APLOMADO FALCONS: IMPLICATIONS FOR RECOVERY

LILY SWEIKERT[1] AND MIKE PHILLIPS
Turner Endangered Species Fund, 1123 Research Drive, Bozeman, MT 59718 U.S.A.

ABSTRACT.—The northern Aplomado Falcon (*Falco femoralis septentrionalis*) inhabited the inland and coastal grasslands of Texas, New Mexico, and Arizona until about 1930, when records of aplomados in the United States decreased. In 1986, the species was classified as endangered under the Endangered Species Act. Among other recovery efforts, 102 birds were released from 2006 through 2011, in its former range in New Mexico at the Armendaris Ranch in the south–central portion of the state. To promote their survival, an extended supplemental feeding program was conducted. From 2006 through 2008, supplemental food was provided daily, whereas from 2009 through 2011 food was provided every other day. Providing food once daily corresponded with an increase in the known survival of the aplomados, where known survival was obtained from the recorded observations of falcons at feedings, and the establishment of nearby nesting pairs. Unfortunately, this increase in known short-term survival and reproduction did not seem to lead to long-term survival or retention. This may be attributable to a lack of available prey throughout the Chihuahuan Desert as a result of ongoing drought, significant brush encroachment caused by historic overgrazing by cattle, the eradication of prairie dogs, and decreased summer and increased winter precipitation, as well as a possible increase in predation influenced by brush encroachment and the fact that the Armendaris Ranch sits at the northernmost edge of the aplomados' historical range. If the reintroduction on the Armendaris Ranch, and other areas with similar levels of prey, is to continue, our research supports the incorporation of an extended daily supplemental feeding program and efforts to improve access to prey, possibly by removing brush and restoring grasslands.

KEY WORDS: *Aplomado Falcon*; Falco femoralis; *brush encroachment*; *endangered species*; *restoration*; *supplemental feeding*.

EFECTO DE LA ALIMENTACIÓN SUPLEMENTARIA EN LA SUPERVIVENCIA CONOCIDA DE *FALCO FEMORALIS SEPTENTRIONALIS*: SOBRE SU RECUPERACIÓN

RESUMEN.—*Falco femoralis septentrionalis* habitó los pastizales tierra adentro y costeros de Texas, Nuevo México y Arizona hasta cerca de 1930, cuando los registros de individuos de esta especie en Estados Unidos comenzaron a disminuir. En 1986, la especie fue clasificada como en peligro bajo la Ley de Especies en Peligro. Entre otros esfuerzos de recuperación, 11 halcones fueron liberados en 2006 en su antigua área de distribución en Nuevo México, en el Rancho Armendaris ubicado en la parte centro-sur del estado. Durante 2011, 102 halcones fueron liberados en el Rancho Armendaris. Para promover su supervivencia, se llevó a cabo un programa prolongado de alimentación suplementaria. De 2006 a 2008, se proporcionó alimentación suplementaria diariamente, mientras que de 2009 a 2011 la comida fue proporcionada cada dos días. El suministro de alimento diario se correspondió con un aumento de la supervivencia conocida de los halcones, donde la supervivencia conocida se obtuvo en base a las observaciones registradas de individuos alimentándose y al establecimiento de parejas reproductoras cercanas. Desafortunadamente, este aumento de la supervivencia conocida y de la reproducción a corto plazo no pareció dar lugar a un incremento en la supervivencia o la retención a largo plazo. Esto puede atribuirse a la falta de presas disponibles en todo el Desierto Chihuahuense como resultado de la sequía en curso, la invasión significativa de plantas arbustivas causada por el sobrepastoreo histórico del ganado, la erradicación de roedores del género *Cynomys*, la disminución de las precipitaciones de verano y el aumento de las precipitaciones de invierno, así como un posible aumento en la depredación influenciada por la invasión de plantas arbustivas y el hecho de que el Rancho Armendaris se encuentra en el límite septentrional de distribución histórica

[1] Present address: South Dakota State University, Department of Natural Resource Management, Box 2140B, SNP 138, North Campus Drive, Brookings, SD 57007 U.S.A.; email address: Lily.Sweikert@gmail.com

de *F. f. septentrionalis*. Si se pretende continuar con la reintroducción en el Rancho Armendaris y en otras áreas con niveles similares de presas, nuestra investigación apoya la incorporación de un programa prolongado de alimentación suplementaria diaria y los esfuerzos para mejorar el acceso a presas, posiblemente mediante la eliminación de plantas arbustivas y la restauración de pastizales.

[Traducción de los autores editada]

The northern Aplomado Falcon (*Falco femoralis septentrionalis*; hereafter "aplomado") occurs in open savanna grasslands with scattered tall tree-yuccas (principally *Yucca elata*) and other woody vegetation in the Chihuahuan Desert (Ligon 1961, Keddy-Hector 1988, Macías-Duarte et al. 2004). Historically, this medium-sized raptor ranged from Nicaragua to southeastern Arizona, southern New Mexico, western Texas, and the south Texas coastal plain (Bailey 1928, Ligon 1961, Phillips 1964, Oberholser 1974, Hector 1987).

Aplomados generally require the presence of available abandoned stick nests built by similar-sized birds because they do not build their own nests (Keddy-Hector 2000). In all areas, aplomados rely heavily on small birds as their primary source of dietary biomass (Hector 1985, Montoya et al. 1997, Macías-Duarte et al. 2004), but spend most of their time hunting and consuming insects (Hector 1985, Brown et al. 2004). They also prey upon small mammals and shellfish occasionally (Lawrence 1874, Bendire 1892, Bailey 1928, Ligon 1961, Clark et al. 1989, Brown et al. 2004). Aplomados are resourceful foragers, being in the minority of falcons that successfully use kleptoparasitism (Cade 1982, Clark et al. 1989, Brown et al. 2003). Additionally, several researchers report aplomados snatching frantic prey from the edge of wildland fires (Brooks 1933, Oberholser 1974, Brown et al. 2004).

Historical records indicate the aplomado was once a common species in the United States until the early 1930s, when records became sparse (Ligon 1961, Hector 1985, Truett 2002). Factors that potentially contributed to the decline of the species, and/or possibly hamper its recovery, include specimen collection; habitat loss, fragmentation, and degradation; drought; disease; genetic disorders; pesticides; prairie dog extirpation; lead ingestion; electrocution; collisions with fences and power lines; drowning in livestock watering tanks; a lack of suitable nests; and a decrease in available prey (Hastings and Turner 1965, Hector 1987, Kiff et al. 1980, Keddy-Hector 2000, Truett 2002).

Between the early 1950s and 1990, few aplomados were seen in New Mexico and no nests were documented from 1952 until the early 2000s, when pairs were found nesting intermittently in southwestern New Mexico (Ligon 1961, Truett 2002, Meyer and Williams 2005). In 1986, the Aplomado Falcon was listed as endangered under the Endangered Species Act (U.S.D.I. 1986) and a recovery plan was completed in 1990 (U.S.F.W.S. 1990). Although the recovery plan did not include criteria for removing the falcon from the Endangered Species list, it did include criterion for downlisting the bird to "threatened" status: the establishment of a self-sustaining population of 60 breeding pairs (U.S.F.W.S. 1990). To satisfy this criterion, releases of captive-raised juvenile aplomados were conducted in areas of historical occurrence (Hunt et al. 2013). The broad food habits and resourceful nature of the Aplomado Falcon suggested that food would not be a limiting factor and it was assumed that suitable habitat still existed.

The objective of this study was to evaluate the effect of extending the provision of supplemental food after the standard release period, on the known survival of Aplomado Falcons (derived from observations of falcons at feeding stations) released on and around the Armendaris Ranch in New Mexico. Although breeding-season prey biomass in the New Mexican Chihuahuan Desert was approximately an order of magnitude lower than in the higher-rainfall areas of eastern Mexico and south Texas (Truett 2002), where reintroduced aplomados then thrived (Jenny et al. 2004), it was similar to other areas of the Chihuahuan Desert where wild aplomados then flourished. However, in all areas, prey biomass is highly variable, influenced by the amount of precipitation and other climatic conditions, and human-induced changes to habitat structure (Macías-Duarte et al. 2004); fluctuations in prey availability could affect the survival of released aplomados. We hypothesized that providing food more frequently, i.e., every day, would increase known survival among released juvenile aplomados.

METHODS

Study Area. The Armendaris Ranch comprises approximately 1439 km^2 in Sierra and Socorro counties in south-central New Mexico, east of the Rio Grande. The ranch lies within the Jornada del Muerto basin

in the northern Chihuahuan Desert. Topography consists mostly of an open valley plain, bordered by the Fra Cristobal Mountains to the west, the Jornada del Muerto Volcano and lava fields to the north, the White Sands Missile Range to the east, and the Jornada Experimental Range to the south. Ranch habitats consisted primarily of Chihuahuan Desert scrub and desert grassland as classified by Dick-Peddie (1993).

The Armendaris is privately owned and managed by Turner Enterprises, Inc., for livestock production of plains bison (*Bison bison*). The bison herd includes approximately 500 individuals, mostly cows and calves, which are managed to have minimal impact on the grasslands. To promote high quality hunting for several quail species, water and grain stations are common throughout the ranch. Despite the presence of these water and grain stations, avifauna surveys conducted at the Armendaris (Henry 1995, 1998) revealed an apparent breeding-season avian prey biomass not significantly different than other areas of the Chihuahuan Desert (Truett 2002). A habitat suitability model based on vegetative characteristics indicated that the Armendaris contained highly suitable habitat for Aplomado Falcons (Fig. 1; Young et al. 2002, 2005). This included areas of open savannah scattered with tree-yucca (Fig. 2).

Falcon Releases. In 2006, the U.S. Fish and Wildlife Service, New Mexico Department of Game and Fish, The Peregrine Fund, Turner Endangered Species Fund, and Turner Enterprises, Inc., initiated a reintroduction project as part of a larger effort to restore the Aplomado Falcon to New Mexico. The Armendaris was chosen as the first release site because it offered secure and extensive suitable habitat (Young et al. 2005), seemingly sufficient prey populations compared to other areas of the Chihuahuan Desert (Truett 2002), and had historically supported a small breeding population of aplomados (Ligon 1961).

The Peregrine Fund employed standard raptor hacking (reintroduction) procedures for releasing 102 captive-bred Aplomado Falcons at the Armendaris Ranch from 2006 through 2011 in June, July, and August (Hunt et al. 2013). This procedure involved holding juvenile aplomados, with color VID (visual identification) and aluminum U.S.G.S. bands, in a hack box, for 7–10 d, on an elevated platform erected in suitable habitat, and then releasing them at an age when they would naturally fledge (Mutch et al. 2001). On release day, the box was opened remotely allowing the birds to emerge

Figure 1. Habitat suitability model for Aplomado Falcons on the Armendaris Ranch. Map subset from model detailed in report (Young et al. 2002).

on their own, thus simulating natural fledging conditions. To promote survival and encourage the aplomados to establish residency near the release site, site attendants provided supplemental food (freshly thawed Japanese quail [*Coturnix japonica*]), twice a day for approximately 40 d post-release.

Monitoring. During and after the release period, Turner Endangered Species Fund personnel conducted three to seven driving surveys per week to locate Aplomado Falcons on the Armendaris and environs (L. Sweikert unpubl. data and J. Truett pers. comm.). Widespread nesting surveys were conducted during the spring of each year, occasionally with the use of airplanes, to determine the existence of any aplomado nests. Additionally, trail cameras were deployed in 2010 to monitor activity at nest platforms and feeding sites.

Extended Supplemental Feeding Program. We hypothesized that known survival of recently released aplomados on the Armendaris would increase if the supplemental feeding program was extended beyond the standard 40-d period. We surmised that the aplomados were still relatively naïve, even after

Figure 2. Open grassland savanna with scattered tree yuccas in the central portion of the Armendaris Ranch.

40 d of free-flying experience, owing to their captive origins. We proposed that extending the feeding program would allow these birds to gain more experience, without being food-stressed, which could increase their survival.

The extended supplemental feeding programs varied in length from year to year. Each year feeding continued until late spring of the first year following release, as long as falcons visited the feeding station or unless there was evidence of falcons being targeted by predators at the stations. In an attempt to improve the cost-effectiveness of the program, the schedule of feedings was changed from every day, during 2006 through 2008, to every other day, during 2009 through 2011. For each feeding, one fewer quail than the number of expected falcons was provided in the evenings. Very infrequently, scheduled feedings were missed due to weather or other circumstances.

We recorded which birds attended feedings through direct observations. Observations were continued for the duration of the time the aplomados were eating at the station during a feeding. In 2007, of the total 88 d that food was provided, identifications of birds attending feedings were made only on 43 d, beginning on the fourteenth day food was provided. In all other years, barring technical difficulties, birds were identified on all days that food was provided.

Known Survival. We defined "known survival" as the number of days up to the last day a bird was recorded attending a feeding station, or was known to be alive by some other monitoring method. Given the naïveté of the released birds, those who ceased to attend feedings, and were not found via other monitoring methods, were assumed to be dead. This assumption was consistent with The Peregrine Fund's conclusion that "excessive mortality is implicit, however, in the current lack of a breeding population and in the overall rarity with which the species is seen and reported" (Hunt et al. 2013). However, it is possible that these birds persisted in unknown

Table 1. Number of Aplomado Falcons released in New Mexico, on the Armendaris Ranch, and White Sands Missile Range, and the duration, participation, and percent of time food was available during the extended supplemental feeding program (2006–2011).

Year	Birds Released in New Mexico (*n*)	Birds Released at Armendaris Ranch (*n*)	Birds Released at White Sands Missile Range (*n*)	Birds that Participated in the Feeding Program (*n*)	Length of Feeding Program (*d*)	Days Food was Provided (*n*)	Time Food was Available During the Feeding Program (%)
2006	11	11	0	8	159	148	93.08%
2007	39	17	22	13	92	88	95.65%
2008	70	38	32	21	257	219	85.21%
2009[a]	71	14	15	7	39	20	51.28%
2010[b]	67	12	22	9	54	27	50.00%
2011	47	10	12	7	37	18	48.65%

[a] The 2009 extended supplemental feeding program was terminated prematurely when it appeared that an avian predator killed an aplomado at the feeding station.

[b] The 2010 extended supplemental feeding program was terminated when only one seemingly wild, unbanded, adult aplomado attended feedings at the feeding station.

locations. Unfortunately, we were unable to differentiate between likely mortality and actual mortality because no birds were radio-tagged until 2011. In 2011, 10 aplomados released at the Armendaris were equipped with VHF radio transmitters to document movements and mortality as part of a larger study by The Peregrine Fund (Hunt et al. 2013).

Statistical Analysis. All data were analyzed using Microsoft Excel (version 14.4.1) and Minitab (version 16) (Microsoft 2010, Minitab, Inc. 2014). We used logistic regression to predict the probability of known survival of aplomados that participated in the every-day feeding programs versus the every-other-day feeding programs and males versus females. A two-proportion hypothesis test was used to determine if the proportion of birds known to survive to day 30, out of the total number of birds known to participate in every-day feedings, was significantly different than the proportion known to participate in every-other-day feedings. A two-proportion hypothesis test was also used to compare the proportion of males that survived to day 30 to females that survived to day 30. Because the length of the feeding programs varied a great deal from year to year (Table 1), we considered only the known survival of birds for 30 d following the standard 40-d feeding period for logistic regression and hypothesis test of two proportions.

Survival analysis, a class of statistical method for studying the occurrence and timing of events, was used to compare the amount of time an aplomado was known to be alive, when fed every day compared to every other day. In this case, the event of interest was the last day the falcon was known to be alive and the response variable was the number of days of known survival up to that last day. Falcons still attending feedings at day 60 were right-censored. Despite its name, researchers frequently use survival analysis to analyze events other than death, such as the time to entry into marriage or divorce (Diekmann 1989, Goldstein 1999). The Log-Rank and Wilcoxon methods of comparison were used for this survival analysis. Because we were comparing the amount of time each individual bird was known to take advantage of the feeding program, we considered the periods of known survival of birds for 60 d following the standard 40-d feeding period.

Finally, a weighted regression was used to determine whether there was a significant difference between feeding-program usage by birds that were offered food every day versus every other day. For this analysis, the response variable was the proportion of times an aplomado fed out of the total number of times food was available while that individual was known to be alive. Because the number of feeding opportunities available to each individual varied by the frequency of feeding and the year, the response variable was weighted by the square root of the number of feeding opportunities while the bird was known to be alive.

RESULTS

Extended Supplemental Feeding and Falcon Reproduction. Annual spring surveys revealed that releases at the Armendaris led to the formation of single nesting pairs at the ranch in 2007, 2009, and

2011. These were the only recorded nesting pairs in New Mexico from 2006 through 2011, despite the release of 102 birds at the Armendaris and 203 more birds elsewhere in the state during that time. All nesting individuals had previously attended the extended supplemental feeding programs. Indeed, one bird that attended 124 feedings out of 148 feeding opportunities, during the 2006 feeding program, was part of the 2007 nesting pair, the first nesting pair resulting from the reintroduction effort in New Mexico.

The 2007 pair fledged two young, the 2009 nesting attempt failed, and the 2011 pair fledged three young. Because none of the fledglings were banded, it is difficult to speculate on their survival. However, from 2007 to October 2010, an unbanded female Aplomado Falcon resided at the Armendaris and regularly attended extended supplemental feedings. Circumstantial evidence suggested that this female was one of the young fledged in 2007 and, as an adult, was a part of the failed nesting attempt in 2009 (T. Waddell, Turner Enterprises, Inc. pers. comm.).

Radiotelemetry Study. Unfortunately, eight of the ten VHF transmitters placed on aplomados released at the Armendaris malfunctioned, by failing to emit a signal, turning off and on sporadically, or emitting an incorrect signal (i.e., signaling that the aplomado was alive when it was dead). Six aplomados were re-trapped and their transmitters adjusted or replaced with a new VHF transmitter or satellite transmitter. Although the majority of the VHF transmitters continued to malfunction, three fatalities were recorded by tracking two signals, one in mortality mode and one not, and one satellite transmitter. Two of these mortalities were attributed to avian predators and one to a mammalian predator.

Participation in Extended Supplemental Feeding Programs. Of the 102 Aplomado Falcons released at the Armendaris, 56 birds participated in the extended supplemental feeding program (Table 1). An additional nine falcons released at the White Sands Missile Range, about 48 km from the Armendaris feeding stations, also participated in the extended supplemental feeding program. Of the 65 total birds that used extended supplemental feedings, 42 were involved in every-day feedings and 23 were involved in every-other-day feedings.

The length of the feeding programs varied every year, from 257 d in 2008 to 37 d in 2011. Most falcons attended feedings in the beginning of the extended supplemental feeding program; however, one falcon, ID 2008-6, did not begin attending feedings until the 82nd day (Fig. 3). The length (number of days) of falcon attendance at feedings varied greatly.

Effect of Frequency of Feeding on Known Survival. The frequency of feeding, i.e., every day or every other day, was a significant predictor of whether the recently released aplomados were known to be alive at day 30 (logistic regression, $P = 0.020$, $\chi^2 = 5.41$, df = 2), but the sex of the falcons was not a significant predictor no matter the frequency of feeding ($P = 0.378$, $\chi^2 = 0.78$, df = 2). Specifically, the probability of a known falcon surviving to day 30, when provided food every day, was 3.6 times greater (95% CI: 1.173, 11.064) than the probability of known survival to day 30 for a falcon that was provided food every other day. The probability of a male falcon surviving to day 30, regardless of the feeding frequency, was 1.6 times higher than a female's (95% CI: 0.566, 4.466).

When food was provided daily, 57% of the recently released aplomados were known to be alive at day 30, compared to only 26% of the aplomados when food was provided every other day. A two-proportion hypothesis test indicated the proportion of birds known to be alive at day 30 when food was provided every other day was significantly lower (−0.31, 95% CI: −0.544, −0.077) than those provided food every day ($P = 0.009$, $Z = -2.60$).

A two-proportion hypothesis test showed no significant difference (−0.142, 95% CI: −0.382, 0.098) between the proportion of female falcons known to be alive at day 30, compared to the proportion of male falcons known to be alive at day 30 ($P = 0.245$, $Z = -1.16$). Specifically, 39% of the females were known to survive to day 30 and 53% of the males were known to survive.

Survival analysis revealed a significantly greater percentage of birds were known to survive to day 60 when fed every day, compared to birds fed every other day ($P < 0.001$, Fig. 4, $M = 16.27$, 95% CI: 10.47, 22.07). The Log-Rank method of comparison had $\chi^2 = 24.96$ and the Wilcoxon method of comparison had $\chi^2 = 19.84$. Specifically, none of the birds that were offered food every other day were known to survive to day 60, whereas about 50% of the birds fed every day survived to day 60. Longer-term monitoring revealed that although some of these birds persisted into the first and second years following their initial release, most disappeared

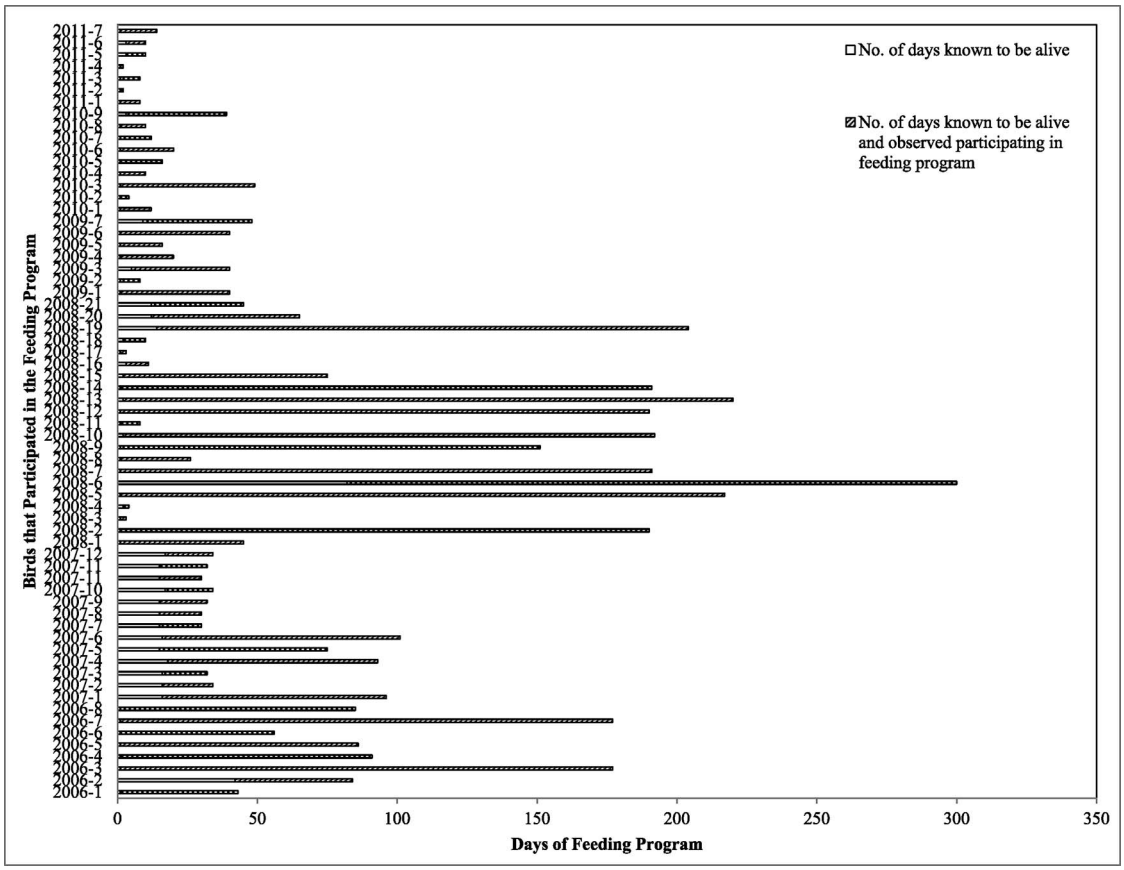

Figure 3. The number of days released juvenile Aplomado Falcons were known to be alive and the number of days each individual participated in the feeding program on the Armendaris Ranch in New Mexico after the conclusion of the standard 40 d supplemental feeding period from 2006–2011.

within a few months of release (L. Sweikert and M. Phillips unpubl. data, Hunt et al. 2013).

Effect of Frequency of Feedings on Aplomado Falcon Attendance at Feeding Stations. A weighted regression showed that falcons, during the years when food was offered every day, attended more feedings than falcons during the years when food was offered every other day ($P = 0.001$, $t = -3.37$). This result supports the rationale for providing food every day as opposed to every other day.

DISCUSSION

Known Survival Trends as a Function of Feeding Frequency. The results suggest that when daily supplemental feeding was extended, following the end of the standard 40-d supplemental feeding protocol, survival of recently released juvenile Aplomado Falcons increased through at least day 60. Furthermore, when food was provided more frequently, aplomados used the feeding program more. Therefore, it appears that aplomados derived greater benefit from a daily food source than from an every-other-day food source, demonstrating a possible reliance on the feeding program. All outcomes indicate that the extended supplemental feeding program promoted known survival of recently released juvenile Aplomado Falcons. However, as a caveat, we note that because the practice of providing food every day versus every other day occurred in different years, it is possible that variations in weather, naturally available prey, and presence of predators also contributed to these results.

Effect of Extended Supplemental Feeding on Population Establishment. Nearly all of the 102

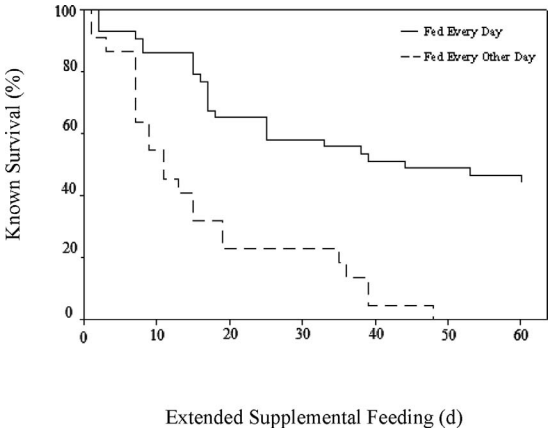

Figure 4. Known survival (%) of released juvenile Aplomado Falcons fed every day (n = 42 birds) and every other day (n = 23 birds) on the Armendaris Ranch in New Mexico over a 60-d period after the conclusion of the standard 40-d supplemental feeding period from 2006–2011.

birds released at the Armendaris, with the exception of the members of the nesting pairs and a few others, did not become permanent or even infrequent residents. Similarly, of the aplomados that used the ranch in the year following their release, only a few were known to inhabit the ranch during the second year following their release. Although the final fates of the released birds were largely unknown, there was no evidence that they established themselves elsewhere (Hunt et al. 2013, U.S. Fish and Wildlife Service unpubl. data). In agreement with the Peregrine Fund's conclusion, it seems likely that most did not survive to reproduce, although it is possible they dispersed to areas with limited human populations or were unobserved (Hunt et al. 2013).

Supplemental feeding programs for other reintroduced, captive-born, carnivores, including the red wolf (*Canis lupus rufus*; Phillips et al. 2003), Mexican wolf (*Canis lupus baileyi*; Romo et al. 2013), and the black-footed ferret (*Mustela nigripes*; L. Sweikert unpubl. data), have promoted increased survival rates for recently released individuals. Unfortunately, and in contrast to these other species, improved short-term prospects for Aplomado Falcons did not appear to translate into improved long-term survival or retention in the general area of the releases for population establishment.

Given the success of the extended daily supplemental feeding program, it remains unclear why the release of over 100 Aplomado Falcons did not lead to the establishment of at least a few birds on the Armendaris Ranch. Releases elsewhere in New Mexico were similarly unsuccessful. What is clear is that the daily-extended supplemental feeding program increased known short-term survival at the Armendaris. These results suggest that a lack of available food is a primary limiting factor to the survival of released aplomados in this area.

Implications for Recovery. Hunt et al. (2013) emphasized the importance of drought, and its effects on prey populations, as a principal cause for the lack of success in New Mexico and west Texas. Furthermore, a decrease in prey due to drought might encourage predators to target aplomados as an alternate prey source; continuous yearly drought would cumulatively contribute to a decline in habitat quality (Steenhof and Kochert 1988, Macías-Duarte et al. 2004). Moreover, another applicable factor that may have affected the long-term success of reintroduced Aplomado Falcons at the Armendaris Ranch is that the ranch is at the northernmost edge of the aplomados' known historical range. Although historical records of breeding aplomados exist for the area around ranch headquarters (Ligon 1961), it is reasonable to conclude that populations of any species at the edge of their range might naturally expand and contract over time (Peterson 2001, Laliberte and Ripple 2004). In addition to the above possible limiting factors at the Armendaris and environs, we propose that changes to the structure of habitat are sufficiently substantial to affect the hunting success of recently released aplomados, in effect, further reducing the amount of food locally available.

Historically, the Aplomado Falcon inhabited open grasslands with prominent widely scattered tall woody vegetation (Ligon 1961, Keddy-Hector 1988, 2000). Nearby woodland, shrubland, and wetland areas may be important for providing aplomados with sufficient prey, species that construct suitable nesting platforms, and suitable roosting locations (Keddy-Hector 2000, Macías-Duarte et al. 2004, C. Perez pers. comm.). Most of the formerly open grasslands have, however, undergone significant vegetation changes in the last century (Grover and Musick 1990). In southern New Mexico, grass cover declined 70% during the preceding century (York and Dick-Peddie 1969). Brush increased proportionately with the decrease in grass cover, in the Jornada Basin, directly south of the Armendaris Ranch (Gibbens et al. 2005). Indeed, on the Armendaris Ranch, grasslands are interspersed with

thick patches of brush cover, primarily creosote (*Larrea tridentate*), that support abundant populations of quail (Baxter and Wolfe 1972, Rollins et al. 2006). Factors contributing to this vegetation shift throughout the grasslands include overgrazing by cattle, fire suppression, and changes in climate (Brown et al. 1997, Curtin et al. 2002, Truett 2010). Additionally, the once common prairie dogs that maintained large brush-free areas are now functionally extinct (Truett et al. 2006).

Regardless of the mechanism, despite the high suitability of the Armendaris according to the habitat suitability model (Young et al. 2002, 2005) and the historical occurrence of breeding aplomados on the ranch (Ligon 1961), portions of grasslands at the Armendaris and elsewhere in the Chihuahuan Desert now support a more obvious brush component that may hinder successful hunting by aplomados. Indeed, although brush encroachment can increase the abundance of prey birds (Macías-Duarte et al. 2009), it may also decrease their availability (Truett 2002). "Aplomados may be sensitive both to the spacing of woody vegetation (because of its effect on feasible pursuit speeds), and the density of ground cover (because of its effect on impenetrability of prey refugia)" according to Keddy-Hector (1988). A dense vegetation structure may provide obstacles for prey to use to avoid capture, mid-chase, and may also provide cover for escape (Janes 1985). These changes in vegetation structure may also promote an increased presence of large avian predators (Hunt et al. 2013). It is noteworthy that reintroduced aplomados released in coastal Texas appeared to avoid even small live oaks (*Quercus virginianus*), a type of large spreading oak, associated with avian predators such as the Great Horned Owl (Hunt et al. 2013).

Unfortunately, drought, climate change, and historical range contraction are all factors possibly limiting the establishment of aplomados in New Mexico that cannot be easily controlled; however, providing daily supplemental food and reducing the shrub component of desert grasslands might improve prospects for restoring the species. The latter could be achieved through prescribed fire, mechanical removal, and/or chemical application (Fisher 1950, Westoby et al. 1989). The Bureau of Land Management has treated over 400 km^2 of brush-infested land nearby in the Jornada Basin since 2007 through the application of herbicides, deferred grazing for 5 yr, and prescribed fire (B.L.M. 2009). It is probable aplomados, and other grassland species, would benefit from expanding these restoration efforts throughout the Chihuahuan Desert.

Because of the failure of released aplomados to persist at the Armendaris Ranch, no falcons were released there, or elsewhere in New Mexico for the same reason, in 2013. No releases are planned for the state in 2014 and beyond. The U.S. Fish and Wildlife Service is currently conducting a comprehensive review of the New Mexico reintroduction program, and a similar program in west Texas, to determine if one or both should be permanently terminated. Such terminations would focus recovery efforts on the coastal plains of south Texas where notable challenges exist to further improve circumstances for the species (Hunt et al. 2013). Although much progress has been achieved there on behalf of the species, after 11 yr of reintroductions involving over 800 birds (Jenny et al. 2004), population growth has stalled at 30 or so nesting pairs, likely due to a lack of suitable habitat (Hunt et al. 2013). These results stand in contrast to those conducted in New Mexico (Hunt et al. 2013). Even though far fewer aplomados (337) were released in New Mexico over a shorter period of time (7 yr), not a single known pair persisted.

Even if conditions for aplomados along the south Texas coastal plains improve sufficiently to support 60 nesting pairs, thus satisfying the current criterion for downlisting the species to Threatened status, such a population would almost certainly fall short of that needed for recovering the species in a significant portion of its range and removing it from the Endangered Species List entirely. Though the current Aplomado Falcon recovery plan does not present delisting criterion (U.S.F.W.S. 1990), such criterion would be more demanding than the downlisting criterion.

Prospects are dim for restoring a population of aplomados to the Armendaris Ranch and environs unless those factors responsible for limiting the survival of recently released birds are eliminated or substantially ameliorated. Considering it took 11 yr to establish the existing populations of aplomados in coastal Texas, where prey biomass is much greater, we recommend that the U.S. Fish and Wildlife Service complete a comprehensive assessment of reintroductions in New Mexico before officially terminating restoration work there. If future reintroductions are scheduled at the Armendaris and/or areas with a similar prey biomass, our work supports the inclusion of an extended daily supplemental feeding program through spring following a falcon's

release year if possible, to promote known survival. Additionally, a concerted effort to reduce the abundance of brush in the grasslands, to improve access to prey, may be valuable.

ACKNOWLEDGMENTS

We thank Tom Waddell, Joe Truett, Trish Cutler, Jonathan Reuning-Scherer, and Kevin Honness for support, advice, and inspiration. We also thank Cheryl Dykstra, Grainger Hunt, Christopher J. Perez, and one anonymous reviewer for their comments, which greatly improved an earlier version of this report. Furthermore, we are grateful to Alberto Macías-Duarte for translating the abstract. Our work relied on collaboration with The Peregrine Fund, the White Sands Missile Range, the U.S. Fish and Wildlife Service, the New Mexico Department of Game and Fish, and the Bureau of Land Management. Research was conducted under U.S. Federal Fish and Wildlife Permit number TE069184.

LITERATURE CITED

BAILEY, F.M. 1928. The birds of New Mexico. New Mexico Department of Game and Fish, Santa Fe. Albuquerque, NM U.S.A.

BAXTER, W.L. AND C.W. WOLFE. 1972. The interspersion index as a technique for evaluation of Bobwhite Quail habitat. White papers, conference presentations, and manuscripts Paper 18. Nebraska Game and Parks Commission, Lincoln, NE U.S.A.

BENDIRE, C. 1892. Life histories of North American birds, with special reference to their breeding habitats and eggs. Smithsonian contributions to knowledge 840. Government Printing Office, Washington, DC U.S.A.

BROOKS, A. 1933. Some notes on the birds of Brownsville, Texas. *Auk* 50:59–63.

BROWN, J.H., T.J. VALONE, AND C.G. CURTIN. 1997. Reorganization of an arid ecosystem in response to recent climate change. *Proceedings of the National Academy of Science USA* 94:9729–9733.

BROWN, J.L., A.B. MONTOYA, E.J. GOTT, AND M. CURTI. 2003. Piracy as an important foraging method of Aplomado Falcons in southern Texas and northern Mexico. *Wilson Bulletin* 115:357–359.

———, W.R. HEINRICH, J.P. JENNY, AND B.D. MUTCH. 2004. Development of hunting behavior in hacked Aplomado Falcons. *Journal of Raptor Research* 38:148–152.

BUREAU OF LAND MANAGEMENT (B.L.M.). 2009. Restoring desert grasslands: creosote treatments in southern New Mexico. Las Cruces, NM U.S.A.

CADE, T.J. 1982. The falcons of the world. Comstock/Cornell Univ. Press, Ithaca, NY U.S.A.

CLARK, W.S., P.H. BLOOM, AND L.W. OLIPHANT. 1989. Aplomado Falcon steals prey from Little Blue Heron. *Journal of Field Ornithology* 60:380–381.

CURTIN, C., N. SAYRE, AND B. LANE. 2002. Transformations of the Chihuahuan borderlands: grazing, fragmentation, and biodiversity conservation in desert grasslands. *Environmental Science and Policy* 5:55–68.

DICK-PEDDIE, W.A. 1993. New Mexico vegetation, past, present, and future. Univ. New Mexico, Albuquerque, NM U.S.A.

DIEKMANN, A. 1989. Diffusion and survival models for the process of entry into marriage. *Journal of Mathematical Sociology* 14:31–44.

FISHER, C.E. 1950. The mesquite problem in the Southwest. *Journal of Range Management* 3:60–70.

GIBBENS, R.P., R.P. MCNEELY, K.M. HAVSTAD, R.F. BECK, AND B. NOLEN. 2005. Vegetation change in the Jornada Basin from 1858 to 1998. *Journal Arid Environments* 61:651–668.

GOLDSTEIN, J.R. 1999. The leveling of divorce in the United States. *Demography* 36:409–414.

GROVER, H.D. AND H.B. MUSICK. 1990. Shrubland encroachment in southern New Mexico, USA: an analysis of desertification processes in the American Southwest. *Climatic Change* 17:305–330.

HASTINGS, J.R. AND R.M. TURNER. 1965. The changing mile. Univ. Arizona Press, Tucson, AZ U.S.A.

HECTOR, D.P. 1985. The diet of the Aplomado Falcon (*Falco femoralis*) in eastern Mexico. *Condor* 87:336–342.

———. 1987. The decline of the Aplomado Falcon in the United States. *American Birds* 41:381–389.

HENRY, A.L. 1995. Inventory of a northern Jornada del Muerto grassland for the Aplomado Falcon *Falco femoralis septentrionalis*. Report by New Mexico Heritage Program, The Nature Conservancy, to the Turner Foundation, Bozeman, MT U.S.A.

———. 1998. BLM grassland bird study: draft summary. Report from Arid Lands Project, Santa Fe, New Mexico, to U.S. Bureau of Land Management, Socorro, NM U.S.A.

HUNT, W.G., J.L. BROWN, T.J. CADE, J. COFFMAN, M. CURTI, E. GOTT, W. HEINRICH, J.P. JENNY, P. JUERGENS, A. MACÍAS-DUARTE, A.B. MONTOYA, B. MUTCH, AND C. SANDFORT. 2013. Restoring Aplomado Falcons to the United States. *Journal of Raptor Research* 47:335–351.

JANES, S.W. 1985. Habitat selection in raptorial birds. Pages 159–188 *in* M.L. Cody [ED.], Habitat selection in birds. Academic Press Inc., New York, NY U.S.A.

JENNY, J.P., W.R. HEINRICH, A.B. MONTOYA, B.D. MUTCH, C.E. SANDFORT, AND W.G. HUNT. 2004. From the field: progress in restoring the Aplomado Falcon to southern Texas. *Wildlife Society Bulletin* 32:276–285.

KEDDY-HECTOR, D.P. 1988. Vegetative cover, small bird abundance and patterns of Aplomado Falcon habitat quality in eastern Mexico. Pages 157–164 *in* R.L. Glinski, B.G. Pendleton, M.B. Moss, M.N. LeFranc, Jr., B.A. Millsap, and S.W. Hoffman [EDS.], Proceedings Southwest Raptor Management Symposium and Workshop. National Wildlife Federation, Washington, DC U.S.A.

———. 2000. Aplomado Falcon (*Falco femoralis*). *In* A. Poole [ED.], The birds of North America online, No. 549. Cornell Lab of Ornithology, Ithaca, NY U.S.A. http://bna.birds.cornell.edu/bna/species/549 (last accessed 13 August 2014).

KIFF, L.F., D.B. PEAKBALL, AND D.P. HECTOR. 1980. Eggshell thinning and organochloride residues in the Bat and Aplomado falcon in Mexico. *International Ornithological Congress* 17:949–952.

LALIBERTE, A.S. AND W.J. RIPPLE. 2004. Range contractions of North American carnivores and ungulates. *BioScience* 54:123–138.

LAWRENCE, G.N. 1874. The birds of western and northwestern Mexico: based upon the collections made by Col. A.J. Grayson, Capt. J. Xantus, and Ferd. Bischoff. *Memoirs of the Boston Society of Natural History* 2:265–319.

LIGON, J.S. 1961. New Mexico birds and where to find them. Univ. New Mexico Press, Albuquerque, NM U.S.A. and New Mexico Department of Game and Fish, Santa Fe, NM U.S.A.

MACÍAS-DUARTE, A., A.B. MONTOYA, W.G. HUNT, A. LAFON-TERRAZAS, AND R. TAFANELLI. 2004. Reproduction, prey, and habitat of the Aplomado Falcon (*Falco femoralis*) in desert grasslands of Chihuahua, Mexico. *Auk* 121: 1081–1093.

———, C.E. MÉNDEZ-GONZÁLEZ, J.R. RODRÍGUEZ-SALAZAR, W.G. HUNT, AND P.G. KRANNITZ. 2009. Factors influencing habitat use by migratory grassland birds in the state of Chihuahua, Mexico. *Auk* 126:896–905.

MEYER, R.A. AND S.O. WILLIAMS, III. 2005. Recent nesting and current status of Aplomado Falcon (*Falco femoralis*) in New Mexico. *North American Birds* 59:352–356.

MICROSOFT. 2010. Microsoft Excel Version 14.4.1. Microsoft. Redmond, WA U.S.A. www.microsoft.com (last accessed 23 June 2015).

MINITAB, INC. 2014. Minitab 16 statistical software (Version 16). Minitab Inc., State College, PA U.S.A. www.minitab.com (last accessed 23 June 2015).

MONTOYA, A.B., P.J. ZWANK, AND M. CARDENAS. 1997. Breeding biology of Aplomado Falcons in desert grasslands of Chihuahua, Mexico. *Journal of Field Ornithology* 68:135–143.

MUTCH, B.D., J.P. JENNY, W.R. HEINRICH, A.B. MONTOYA, AND C.E. SANDFORT. 2001. The northern Aplomado Falcon: biology, restoration, and hacking procedures. The Peregrine Fund, Inc., Boise, ID U.S.A.

OBERHOLSER, H.B. 1974. The bird life of Texas. Vol. I. E.B. Kincaid, Jr. [ED.], Univ. of Texas Press, Austin, TX U.S.A.

PETERSON, A.T. 2001. Endangered species and peripheral populations: cause for reflection. *Endangered Species Update* 18:30–31.

PHILLIPS, A.R., J. MARSHALL, AND G. MONSON. 1964. The birds of Arizona. Univ. Arizona Press, Tucson, AZ U.S.A.

PHILLIPS, M.K., V.G. HENRY, AND B.T. KELLY. 2003. Restoration of the Red Wolf. Pages 272–288 *in* L.D. Mech and L. Boitani [EDS.], Wolves: behavior, ecology, and conservation. Univ. Chicago Press, Chicago, IL U.S.A.

ROLLINS, D., B.D. TAYLOR, T.D. SPARKS, T.E. WADELL, AND G. RICHARDS. 2006. Species visitation at quail feeders and guzzlers in southern New Mexico. Pages 210–219 *in* S.B. Cederbaum, B.C. Faircloth, T.M. Terhune, J.J. Thompson, and J.P. Carroll [EDS.], Gamebird 2006: quail VI and perdix XII. Warnell School of Forestry and Natural Resources, Univ. Georgia, Athens, GA U.S.A.

ROMO, J.L., R.A. WEBELS, A.G. BERNAL, Z.Y. GONZALEZ, C. AGUILAR, C.G. CHAVEZ, N.E. DIAZ, AND C.A. GONZALEZ. 2013. Re-introduction of the Mexican Wolf in the Sierra Madre Occidental, Mexico. Pages 116–119 *in* P.S. Soorae [ED.], Global re-introduction perspectives 2013: further case studies from around the globe. IUCN/SSC Re-introduction Specialist Group, Gland, Switzerland, and Environment Agency, Abu Dhabi, U.A.E.

STEENHOF, K. AND M.N. KOCHERT. 1988. Dietary responses of three raptor species to changing prey densities in a natural environment. *Journal of Animal Ecology* 57: 37–48.

TRUETT, J.C. 2002. Aplomado Falcons and grazing: invoking history to plan restoration. *Southwestern Naturalist* 47:379–400.

———. 2010. Grass: in search of human habitat. Univ. California Press, Berkeley, CA U.S.A.

———, D.P. GOBER, A.E. ERNST, R. LIST, H. WHITLAW, C.L. HAYES, G. SCHMITT, AND W.E. VAN PELT. 2006. Prairie dogs in the Chihuahuan Desert: history, ecology, conservation. Turner Endangered Species Fund, Bozeman, MT U.S.A.

UNITED STATES DEPARTMENT OF INTERIOR (U.S.D.I.). 1986. February 25, 1986. *Federal Register* 51(37):6686–6690.

UNITED STATES FISH AND WILDLIFE SERVICE (U.S.F.W.S.). 1990. Northern Aplomado Falcon Recovery Plan. Albuquerque, NM U.S.A.

WESTOBY, M., B. WALKER, AND I. NOY-MEIR. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42:266–274.

YORK, J.D. AND W.A. DICK-PEDDIE. 1969. Vegetational changes in southern New Mexico during the past hundred years. Pages 156–166 *in* W.G. McGinnes and B.J. Goldman [EDS.], Arid lands in perspective. Univ. Arizona Press, Tucson, AZ U.S.A.

YOUNG, K.E., B.C. THOMPSON, D.M. BROWNING, Q.H. HODGSON, J.L. LANSER, A. LAFÓN TERRAZAS, W.R. GOULD, AND R. VALDEZ. 2002. Characterizing and predicting suitable Aplomado Falcon habitat for conservation planning in the northern Chihuahuan Desert. New Mexico Cooperative Fish and Wildlife Research Unit, Las Cruces, NM U.S.A.

———, ———, R. VALDEZ, W.R. GOULD, AND A. LAFÓN TERRAZAS. 2005. Assessment of predictive values from the Aplomado Falcon habitat suitability model: validation information for conservation planning in the northern Chihuahuan Desert. New Mexico Cooperative Fish and Wildlife Research Unit, Las Cruces, NM U.S.A.

Received 30 March 2014; accepted 3 February 2015