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Authors: Hunt, W. Grainger, Brown, Jessi L., Cade, Tom J., Coffman, John, Curti, Marta, et al.

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RESTORING APLOMADO FALCONS TO THE UNITED STATES

W. GRAINGER HUNT,¹ JESSI L. BROWN,² TOM J. CADE, JOHN COFFMAN,³ MARTA CURTI,
ERIN GOTT, WILLIAM HEINRICH, J. PETER JENNY, PAUL JUERGENS, ALBERTO MACÍAS-DUARTE,⁴
ANGEL B. MONTOYA,⁵ BRIAN MUTCH, AND CAL SANDFORT
The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709 U.S.A.

ABSTRACT.—Captive-bred fledgling Aplomado Falcons (*Falco femoralis*) were released along the coastal plain of southern Texas (839 birds from 21 sites during 1993–2004) and in the Chihuahuan Desert of western Texas (637 birds from 11 sites in 2002–2011) and southern New Mexico (337 from 10 sites during 2006–2012). The Texas coastal releases yielded two nesting populations: 15–18 pairs near Brownsville and 15 pairs on two islands near Rockport. Habitat in these areas is extensive open savanna, the ancestral condition over most of the region. Today, it is almost entirely dominated by farmland and brushland, the latter harboring the Great Horned Owl (*Bubo virginianus*), a major predator of the falcons. Conversely, releases in the Chihuahuan Desert have been unsuccessful in establishing a wild population in either area. Although 8–10 pairs were present in West Texas in 2009, by 2011 only one pair remained, and none were found in 2012, the apparent consequence of severe drought. A single pair documented in New Mexico in 2011 was associated with artificial feeding of prey birds. We concluded that the conservation and expansion of Aplomado Falcon populations on the Texas coastal plain will require the protection and management of existing breeding territories, and the creation and management of more brush-free savanna. Persistent drought, the reduction of prey populations, and high rates of mortality from raptor predation appear to preclude the reestablishment of Aplomado Falcons in western Texas or New Mexico.

KEY WORDS: *Aplomado Falcon*; *Falco femoralis*; *captive breeding*; *hacking*; *species restoration*.

DEVOLVIENDO A *FALCO FEMORALIS* A LOS ESTADOS UNIDOS

RESUMEN.—Se liberaron volantones de *Falco femoralis* criados en cautiverio a lo largo de las planicies costeras del sur de Texas (839 aves de 21 sitios durante 1993–2004) y en el desierto de Chihuahua del oeste de Texas (637 aves de 11 sitios durante 2002–2011) y del sur de Nuevo México (337 aves de 10 sitios durante 2006–2012). Las liberaciones en la costa de Texas produjeron dos poblaciones que anidaron: 15–18 pares cerca de Brownsville y 15 pares en dos islas cerca de Rockport. El hábitat de esta área se compone de una extensa sabana abierta, lo que representa la condición ancestral de casi toda la región. Actualmente se encuentra casi completamente dominada por tierras de labranza y matorrales; este último alberga a *Bubo virginianus*, uno de los mayores depredadores de halcones. Por el contrario, las liberaciones en el desierto de Chihuahua no fueron exitosas en el establecimiento de poblaciones silvestres. Aunque se encontraron 8–10 pares en el oeste de Texas en 2009, para el 2011 sólo se registró un par y no se encontró ninguno en 2012, como consecuencia aparente de una sequía severa. Una sola pareja documentada en Nuevo México

¹ Email address: grainger@peregrinefund.org

² Current address: Office of Undergraduate and Interdisciplinary Research, 202 Ross Hall, MS 0436, University of Nevada, Reno, NV 89557 U.S.A.

³ Department of Biology, New Mexico State University, Las Cruces, NM 88003 U.S.A.

⁴ Current address: Universidad Estatal de Sonora, Ley Federal del Trabajo S/N, Col. Apolo, Hermosillo, Sonora 83100, Mexico

⁵ Current address: Partners for Fish and Wildlife Program, U.S. Fish and Wildlife Service, 1800 Marquess Street, Las Cruces, NM 88005 U.S.A.

en 2011 estuvo asociada con la alimentación artificial de aves de presa. Concluimos que la conservación y la expansión de poblaciones de *F. femoralis* en las planicies costeras de Texas requerirán de la protección y el manejo de los territorios de cría existentes, y de la creación y manejo de sabanas libres de matorrales. La sequía persistente, la reducción de las poblaciones de presas y las altas tasas de mortalidad debidas a la depredación por parte de rapaces parecen impedir el restablecimiento de poblaciones de *F. femoralis* en el oeste de Texas o Nuevo México.

[Traducción del equipo editorial]

The Aplomado Falcon (*Falco femoralis*; hereafter “aplomado”) is a colorful, agile, fast-flying, savanna-dwelling bird-predator that ranges from Argentina to the border region of northeastern Mexico; the endangered subspecies *F. f. septentrionalis* extends northward from Guatemala to the United States (Keddy-Hector 1990). The basis for The Peregrine Fund’s 25-yr effort to restore the species to the United States lies in what is known of its historical occurrence on the Texas coastal plain and the Chihuahuan Desert region of western Texas, southern New Mexico, and southeastern Arizona (Fig. 1). Evidence of former distribution is based on the records, narratives, and collections of those who traveled these areas during the late 1800s and early 1900s (see Oberholser 1974, Hector 1987), and on inference of habitat conditions that supported species of similar requirement. Even after these had largely disappeared, the preeminent Texas naturalist J.D. Strecker commented in 1930 that the “... Aplomado Falcon has always been a much commoner bird in southern and western Texas than it has been credited.”

The hypothesis that aplomado habitat still existed in the United States when The Peregrine Fund (TPF) began releasing captive-bred fledglings in

the 1990s was influenced by the chronology of the last reports of nesting: the 1940s in coastal Texas and 1952 in southern New Mexico (Hector 1987). These dates corresponded with the introduction of DDT and dieldrin to agriculture and the consequent near-total loss of Peregrine Falcons (*Falco peregrinus*) throughout temperate North America, as well as with the less-well-documented declines of other bird-eating species, including Cooper’s Hawks (*Accipiter cooperii*; Schriver 1969). Those regions in the southwest where aplomados had persisted supported agriculture consisting largely of cotton, a crop receiving heavy applications of DDT beginning in 1947 (Hunt et al. 1986, 1988). Following the banning of DDT in agriculture by the United States government in 1972, TPF was able to repopulate the eastern United States with peregrines (Cade and Burnham 2003). It was plausible that organochlorines had likewise eliminated aplomados in remnant habitat that had otherwise supported them, that this habitat still existed, even though diminished, and that the species could, like the peregrine, be restored in such areas by means of captive breeding and release (Kiff et al. 1980, Keddy-Hector 2000, Jenny et al. 2004).

Far in advance of the DDT era, however, the structure of vegetation in the American southwest had undergone a vast transformation (Schmidly 2002), and those changes corresponded with a reduction in sightings of aplomados over time (Hector 1987). A contributing event was likely the completion of two railway systems: the Southern Pacific in 1883 and the St. Louis, Brownsville, and Mexico Railway in 1904. Trains brought well-drilling equipment to the northern Chihuahuan Desert and southern Texas, and facilitated the export of commodities to eastern markets. The development of irrigation wells enabled farmers to convert prairies to croplands, and the new economics of livestock grazing led to overexploitation that transformed the remaining open savannas into brushlands (Hastings and Turner 1965, Archer 1989). Even before the arrival of the railroads, the land had long been overgrazed. South Texas prairies, for example, held from 500 000 to over 2 million sheep and goats during 1870–1890, greatly

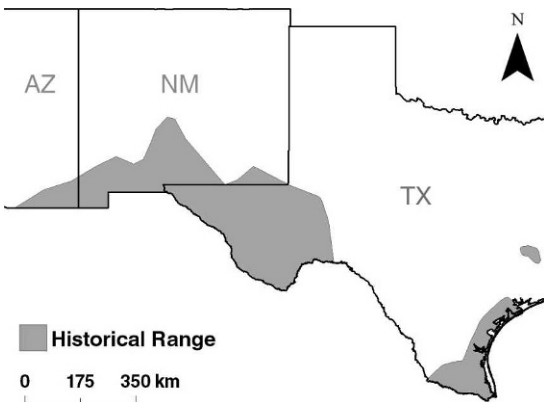


Figure 1. Historical range of the Aplomado Falcon in the United States (after Oberholser 1974, Hector 1987). The isolate in southeastern Texas represents an adult male collected in Bellville (Austin County) in 1900 (Hector 1987).

reducing the carrying capacity for all livestock (Lehmann 1969). Sheep ranching reached southwestern New Mexico in the 1500s and was prevalent until the mid-1800s when cattle began to dominate the industry. The number of cattle present in New Mexico increased from 300 000 to 2 300 000 from 1870 to 1890; and in 1906, New Mexico supported 7 250 000 head of livestock (Dick-Peddie 1993).

Mechanisms underlying the transformation of open grasslands to brushlands included the erosive impact of monsoonal rains upon soils no longer stabilized by the roots of perennial grasses, and the curtailment of natural fires by the widespread exposure of bare ground (Archer 1989, Truett 2010). The degree and extent of vegetation change cannot be quantified, but may be inferred from historical commentary (Cook 1908, Bartlett 1854, see Buffington and Herbal 1965), the geography of present-day croplands, livestock shipping records, photographs, local descriptions, casual comparisons of erosion profiles among ranches, and accounts of faunal occurrence in areas where conditions are no longer suitable. Consider, for example, that pronghorn (*Antilocapra americanus*) were noted as abundant within <1 d of horse travel from Corpus Christi, Texas, in 1853 (Bartlett 1854; see map of historical pronghorn distribution in Schmidly 2002), and that the Attwater's Prairie Chicken (*Tympanuchus cupido attwateri*) was reported as far south as the Brownsville region in the 1800s (Merrill 1878, Lehmann 1941). Neither of these areas is suitable for these species today. Strecker (1930) found aplomados nesting near Midland, Texas, in an area described as "... open plain," but now a virtual sea of mesquite brush (*Prosopis* spp.).

With the assumption that habitat still existed, TPF released captive-bred aplomados for 9 yr from various sites in southern Texas (1993–2004), 10 yr in West Texas (2002–11), and 7 yr in New Mexico (2006–2012). TPF also made field observations, performed nest occupancy surveys, and gathered data on reproduction and survival. One goal of the releases was that the limiting factors could then be detected in the subsequent distribution of breeding birds, and, where possible, these factors could be addressed. Territory monitoring provided insight into the ecology of aplomados in the United States and a greater understanding of the degree to which the species could be reestablished. We here update Cade et al. (1991) and Jenny et al. (2004) by describing (1) progress in restoring aplomados, (2) our understanding of the factors influencing their

demographics, and (3) potential strategies for population management and increase.

METHODS

Preparation for reintroducing aplomados began with the collection during 1977–1988 of eight wild nestlings from eastern coastal Mexico by the Chihuahuan Desert Research Institute (CDRI) and 17 more by TPF in 1987–1988. CDRI, using methods developed for peregrines, produced the first captive-bred aplomado in 1982 (Weaver and Cade 1983, Cade et al. 1991). These efforts were continued by the Predatory Bird Research Group, University of California, Santa Cruz, until 1987, when TPF assumed responsibility. By the 1990s, following some earlier small-scale releases in southern coastal Texas, we were able to produce numbers of captive-bred fledglings sufficient for beginning a reintroduction program (Cade et al. 1991, Jenny et al. 2004).

Texas Coast. During 1993–2004, and in 2012, TPF hacked (liberated) 874 captive-bred fledglings from 23 locations (Fig. 2) at various sites along the coast of Texas (see Jenny et al. 2004 for details). Release sites initially included open areas in moderate proximity to mesquite and live oak (*Quercus virginianus*) woodland, but losses of released falcons to avian predators in these associations suggested that open prairie with widely scattered woody vegetation was more suitable (Jenny et al. 2004). TPF typically placed 6–8 VID-banded (visual identification) fledglings ca. 36 d old in a large predator-proof box affixed to the top of a platform (hack tower) approximately 3 m in height. Attendants regularly provided freshly thawed Japanese Quail (*Coturnix japonica*), taking care to prevent the falcons from associating food with humans. Hack boxes were discreetly opened after 7–10 d of acclimation, after which 2–3 attendants continued monitoring and provisioning the falcons for at least 6 wk following release, during which time birds began catching prey and venturing from the release site for increasing periods (Mutch et al. 2001, Jenny et al. 2004).

We conducted ground-based surveys of known falcon territories and adjacent habitat during March through May in all years except 2007, beginning near the onset of the nesting cycle. We searched for and observed falcons to determine territory occupancy, breeder age (juvenile or adult), nest location, and whether pairs were incubating. At minimum, we identified a nesting attempt as a pair attending a nest just prior to, or during, the incubation period. We revisited territories in May and June in some years to count the young; we defined the reproductive rate as

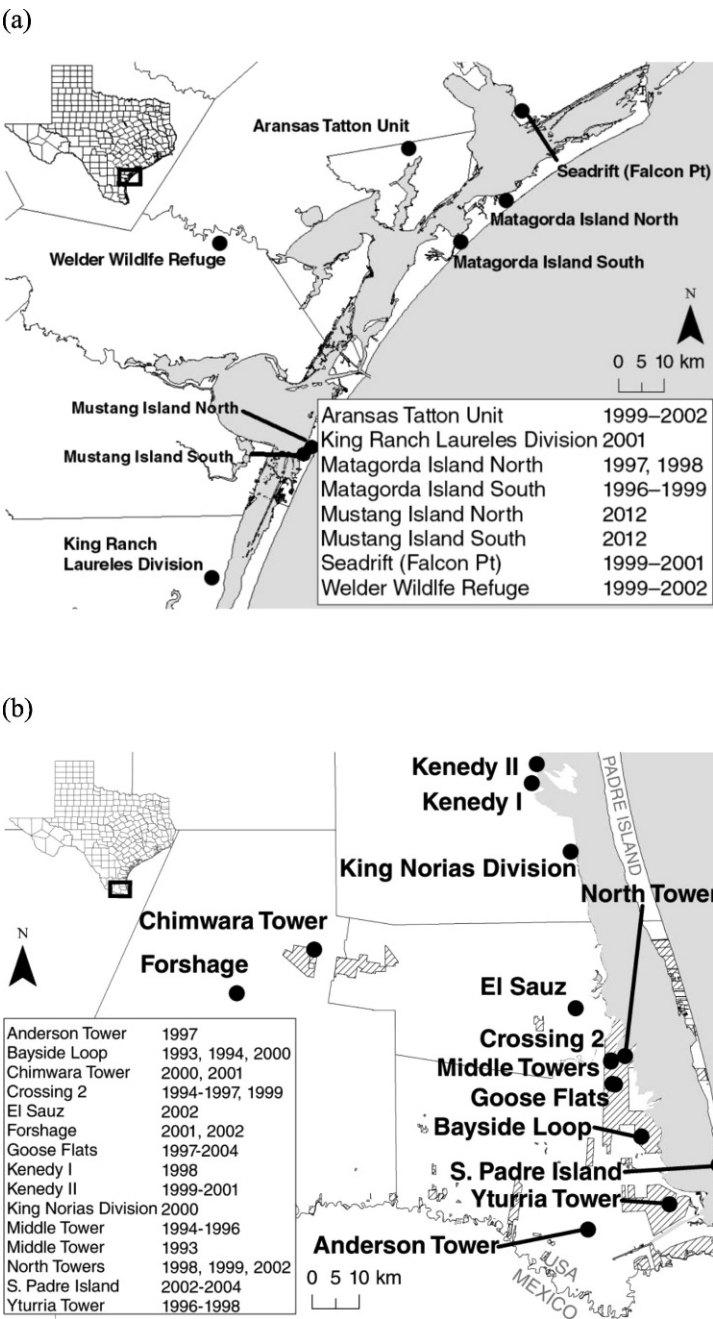


Figure 2. (a) Sites where The Peregrine Fund released Aplomado Falcons along the mid-coast of Texas during 1996–2002 and in 2012. (b) Aplomado Falcon release sites in southern coastal Texas during 1993–2004. Hatched areas show national wildlife refuge boundaries.

the number of fledglings (large young) per nesting attempt (or territorial pair). We approached nests only to band nestlings, obtain blood samples, or to investigate the cause of nest failure. We determined productivity for all known pairs during 1995–2006, and again in 2012 and 2013.

Efforts to locate falcons in areas where territory occupancy had not yet been recorded focused in large part on mainland prairie habitat between Brownsville and Corpus Christi, and in the area south and west of Rockport. Survey areas included habitat identified during two flights in fixed-wing aircraft, as well as places where falcons had previously been released. Coastal Texas surveys included Laguna Atascosa National Wildlife Refuge (NWR), Lower Rio Grande Valley NWR, Port of Brownsville properties, Buena Vista Ranch, South Padre Island, El Sauz Ranch, King Ranch Norias Division, King Ranch Laureles Division, Kenedy Ranch, North Padre Island, Mustang Island, San Jose Island, Matagorda Island NWR, Aransas NWR, Mad Island Marsh Preserve (The Nature Conservancy), Falcon Point Ranch, and the Goliad Prairie.

Because of widespread nest predation, we developed an artificial nesting structure called the “barred box” which substitutes for tree-yuccas (principally *Yucca treculeana*) in discouraging access by ground predators (Fig. 3), and provides the added benefit that birds in the box are safe from most avian predators (see Brown and Collopy 2008, 2012). The bars are spaced just close enough (7.62 cm) that birds larger than aplomados cannot squeeze through them. Inside each box we place an artificial nest of grapevine wreaths and wood-chips that aplomados readily accept. A typical box measures 122-cm square and 31 cm in height, and is supported ca. 2.3 m aboveground atop a 16-cm-diameter treated pole, wrapped with a 60-cm-wide band of metal flashing to thwart climbing mammals.

Chihuahuan Desert. TPF also released 637 aplomado fledglings (19–138 per year) in the desert grasslands of western Texas from 11 hack sites from 2002 to 2011 (Fig. 4), and 337 individuals from ten sites in southern New Mexico during 2006 to 2012 (Fig. 5). We chose hack sites in yucca savanna that appeared similar to habitat where the species had been studied in nearby Chihuahua, Mexico, by Montoya et al. (1997) and Macías-Duarte et al. (2004). Aplomados in Chihuahua nested primarily in tree-yuccas (*Y. faxoniana* and *Y. elata*) in very open grassland usually dominated by black grama (*Bouteloua eriopoda*) or tobosa (*Pleuraphis mutica*) grasses (Montoya



Figure 3. A newly constructed barred box for nesting Aplomado Falcons on Matagorda Island.

et al. 1997). The nests used by aplomados were most often built by Chihuahuan Ravens (*Corvus cryptoleucus*), Swainson's Hawks (*Buteo swainsoni*), and Red-tailed Hawks (*Buteo jamaicensis*).

Survey methods in the Chihuahuan Desert were similar to those utilized in South Texas. West Texas surveys were mostly limited to properties enrolled in the Safe Harbor program (Bean et al. 2001), although some landowners not enrolled in that program granted access for falcon surveys. Other surveys in the region followed public roads through the grasslands of Pecos, Brewster, Fort Davis, Presidio, Culberson, and Hudspeth counties. In New Mexico, we surveyed the broad vicinities of the release sites and examined areas where aplomados were reported by other observers. We searched for aplomados in the White Sands Missile Range, adjacent public lands, Bosque del Apache NWR, Nutt Grassland, Armendaris Ranch, grasslands south and west of Deming, and in the “boot heel” region of southwestern

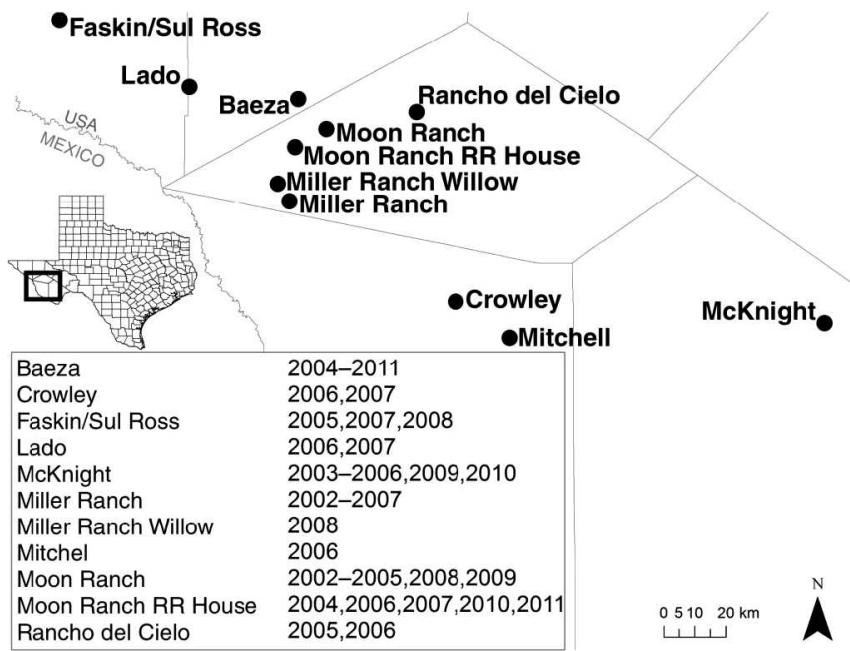


Figure 4. Aplomado Falcon release sites in West Texas, 2002–2011.

New Mexico. Personnel of New Mexico Game and Fish, U.S. Fish and Wildlife Service (USFWS), Department of Defense, and the Bureau of Land Management (BLM), as well as independent contractors surveyed these and other areas, including Otero Mesa.

TPF fitted 66 captive-produced fledglings with radio-transmitters in summer 2011 prior to release in West Texas and New Mexico. The sample included 19 individuals released from two sites near Valentine, Texas (Baeza and Moon RR, Fig. 4) and 47

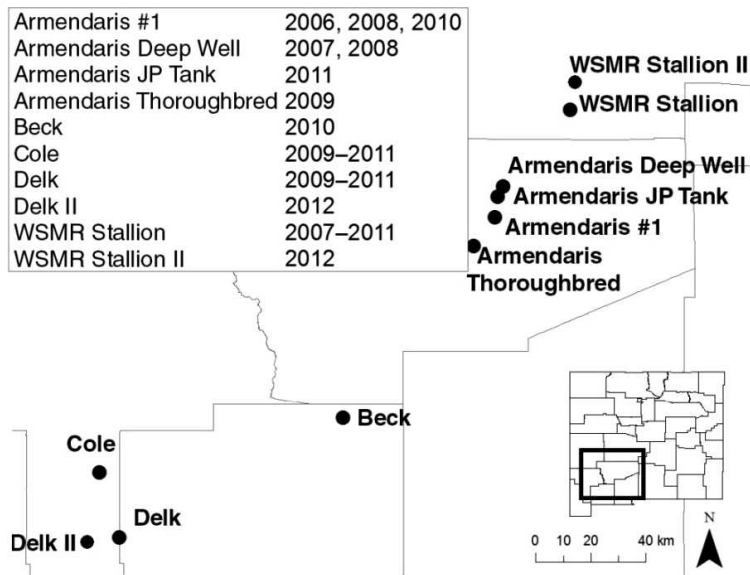


Figure 5. Aplomado Falcon release sites in New Mexico, 2006–2012.

from four sites in New Mexico (Delk, Cole, Armandaris JP, and White Sands, Fig. 5). Transmitters were $<3\%$ of body mass, and all were attached by Teflon ribbons in backpack configuration, including 56 conventional VHF instruments and ten satellite-reporting PTTs. In 2012, we tagged an additional nine falcons at three hack sites in New Mexico; all were satellite-reporting PTTs identical in configuration and application to those of the prior year.

In all years, TPF gauged the success of the hacking process as the proportion of fledglings surviving 21 d from release, as determined by visual observation of falcons returning to the hack site for food (Mutch et al. 2001). Individuals disappearing prior to 21 d were presumed dead for lack of foraging competence, although a few were known to have survived despite early departure from hack sites in coastal Texas. Knowledge of the fates of individuals after leaving the hack sites was largely restricted to those eventually identified on breeding territories.

RESULTS

Coastal Texas. By 1995, two years after TPF began its releases in coastal Texas, the first wild-breeding pair of aplomados appeared near Brownsville, and by 2002, there were 37 nesting territories occupied by pairs, with at least 87 young fledging from wild nests during the 7-yr period (Jenny et al. 2004). Releases were terminated in 2004 when it was clear that the population had stopped increasing. Aplomado pairs had established themselves in two distinct areas—one on Matagorda Island near Rockport and the other just north of Brownsville (Fig. 2). Aplomados failed to establish near mainland hack sites on the mid-coast, including the Aransas Tatton Unit, the Welder Wildlife Refuge, and the Laureles Division of the King Ranch (Fig. 2a). Nor did pairs appear on the Kenedy Ranch or King Ranch further south (Fig. 2b). In general, aplomados settled in open savanna and did not persist in areas of mesquite brush or even in relatively open expanses of ranchland containing live oak clusters (motts).

Brownsville population. The aplomado population near Brownsville currently extends some 55 km northward from the Mexican border through the Laguna Atascosa NWR and beyond (Fig. 6, and see Jenny et al. 2004). All territories lie within a 5–12 km-wide band of prairie and prairie-brushland within 20 km of the Laguna Madre, with the densest aggregation between Brownsville and Highway 100, west of Port Isabel (Brownsville Prairie). Some pairs

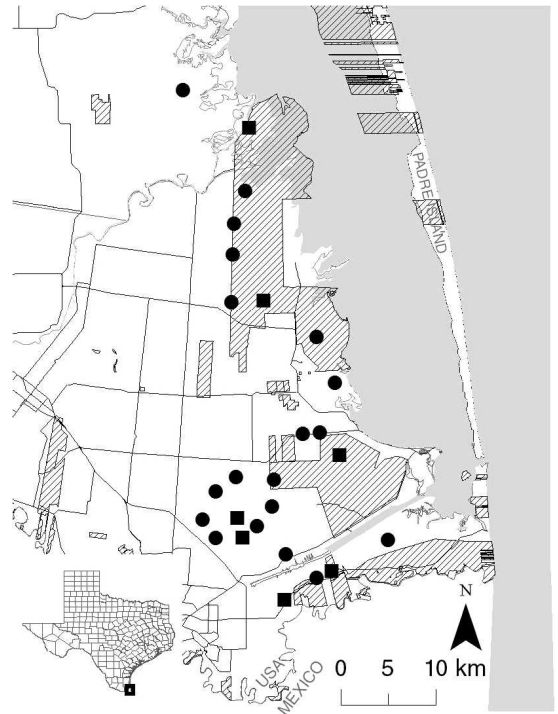


Figure 6. Distribution of the Brownsville subpopulation of Aplomado Falcon breeding territories. Circles depict sites recently occupied, and squares show sites of intermittent occupancy. Hatched areas show National Wildlife Refuge lands.

nest on the refuge, some on municipal property (Port of Brownsville), and some on private ranches. Breeding aplomados occupy the larger expanses of salt prairie, seasonally inundated, and vegetated by gulf cordgrass (*Spartina spartinae*), sea oxeye daisy (*Borrchia frutescens*), saltflat grass (*Monanthochloe littoralis*), and glasswort (*Salicornia* sp.). Woody vegetation on salt prairie is sparse except where disturbed by vehicle rights-of-way and other soil alterations that encourage honey mesquite (*Prosopis glandulosa*) and huisache (*Acacia farnesiana*). Woody plants occur more frequently at slightly higher elevations, and occasional small hills (lomas) may support dense aggregations of brush unless controlled by periodic fire.

During the establishment of the Brownsville population, the role of tree-yuccas (*Y. treculeana*) in protecting wild nestlings from attack by ground predators became apparent (Fig. 7). Other nest-supporting woody plants, such as mesquite, were less effective in deterring climbing raccoons (*Procyon*



Figure 7. Aplomado Falcon nesting in a Spanish dagger (*Yucca treculeana*) just north of Brownsville, Texas. The stiff, pointed, outward-facing leaf-blades deter mammalian predators from accessing the nest.

litor) and other mammals that destroyed aplomado eggs and young (Jenny et al. 2004). Twenty-four nesting attempts by aplomados at 11 yucca nests in the Brownsville study area produced an average of 1.56 fledglings per attempt, whereas 33 nesting attempts at 17 sites in other woody species yielded 0.70 fledglings per attempt. The latter included 22 attempts in honey mesquite, four in spiny hackberry (*Celtis ehrenbergiana*), and seven in other species. These observations suggest that nests in yuccas were over twice as productive of young aplomados as were nests in other woody species ($t = 2.244$, $P < 0.05$).

Reproductive rates of the Brownsville population in 2012 and 2013, the first estimates since 2006, were 1.60 and 1.93 fledglings per nesting attempt. We found fewer pairs in 2012 and 2013 than in all previous years of survey (Table 1), and overall, during the past 7 yr there has been an increased proportion of single adult females on territory, as well as females paired with juvenile males, suggesting a deficit in male recruits.

Rockport population. The number of pairs on Matagorda Island has remained more or less constant for almost a decade (Table 1). Matagorda Island is part of the Aransas NWR, with a small area on the northern end administered by the Texas Parks and

Wildlife Department. The island is dominated by gulf cordgrass, marsh hay cordgrass (*S. patens*), gulf dune paspalum (*Paspalum monostachyum*), and gulf bluestem (*Schizachyrium maritimum*). Periodic burning maintains the open character of the grassland, although brush and trees occur on the northernmost end of the island. Potential avian predators of aplomados over most of the island include resident White-tailed Hawks (*Buteo albicaudatus*) and Crested Caracaras (*Caracara cheriway*), as well as migrating and wintering Peregrine Falcons (*F. peregrinus*).

The reproductive rate of the Rockport population averaged 1.85 and 2.00 fledglings per nesting attempt in 2012 and 2013. When aplomados began nesting on Matagorda Island, predation on broods in natural nests was too frequent for sustainability. During 1999–2006, 15 nesting attempts in natural nests were in McCartney rose (*Rosa bracteata*), a shrub; 12 were in yaupon (*Ilex vomitoria*), 7 in honey mesquite, one in huisache, and three on grass (gulf cordgrass and gulf bluestem). Falcon reproductive rates at these natural nests averaged only 0.57 young in 38 nesting attempts at nine sites, but when we erected barred boxes in those breeding territories,

Table 1. Nesting territory occupancy by Aplomado Falcons in coastal Texas, 2008–2012.

LOCATION	YEAR	ADULT PAIR	AD F JUV M	JUV F AD M	JUV F JUV M	UNAGED PAIR	LONE F	LONE M	LONE UNAGED	TOTAL PAIRS
Brownsville	2008	14	4	0	0	0	2	1	0	18
	2009	17	0	0	0	0	6	0	0	17
	2010	16	2	0	0	0	7	0	0	18
	2011	14	4	0	0	2	1	1	0	20
	2012	12	3	0	0	0	6	0	0	15
	2013	13	1	0	0	0	2	0	0	14
Rockport	2008	14	0	0	0	0	1	0	0	14
	2009	13	1	1	0	0	2	0	0	15
	2010	14	0	0	0	0	1	0	0	14
	2011	12	0	0	1	1	3	1	1	14
	2012	13	0	0	0	0	2	0	0	13
	2013	12	1	1	0	0	0	0	0	14

they became more productive. The boxes yielded an average of 1.87 young in 20 nesting attempts at nine sites during 2004–2006, and continued at this level in 2012 and 2013. Competition with caracaras for barred boxes led us to narrow the bar spacing to the precise point of excluding them. In one instance, after caracaras had usurped a box, aplomados

accepted another within 1 hr of its placement. Note that the somewhat regular distribution of aplomado nest sites apparent in Fig. 8 is natural, as we placed the boxes as near as possible to existing natural nests. Spacing between the nests of territorial pairs in 2011 averaged 3.9 km (range 2.3–5.6 km), a distance comparable to that among pairs in the

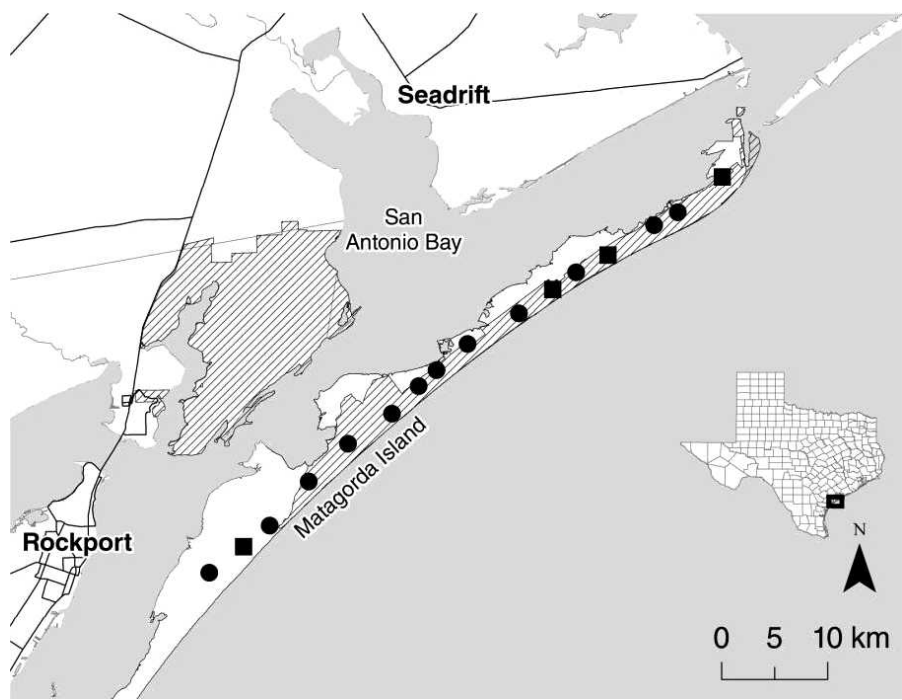


Figure 8. Aplomado Falcon nesting territories on Matagorda Island near Rockport, Texas. Circles depict sites regularly occupied by adult pairs, and squares indicate sites of intermittent occupancy. Hatching shows Aransas National Wildlife Refuge boundaries.

Brownsville population, though less apparent there because of habitat heterogeneity (Fig. 6).

Intervening ranchland. The coastal region between the Rockport and Brownsville populations appears largely, if not entirely, devoid of nesting aplomados, although our surveys have been incomplete. There were occasional reports of single birds from the Padre Island National Seashore, but almost none from the vast mainland ranches occurring south of Corpus Christi. Regular birding tours on the King Ranch where, or near to which, TPF released 72 aplomados from four hack sites (Fig. 2) have rarely, if ever, encountered the species, and no aplomados have taken residence in the barred boxes we erected near the release sites. Our searches of the King and Kenedy ranches revealed Great Horned Owls in association with even the smallest aggregation of live oaks.

Interestingly, two female aplomados released on the Kenedy Ranch were not seen for 5 yr and 6 yr, and then appeared as breeders on San Jose Island (138 km) and near the Port of Brownsville (105 km), respectively. An individual released in 1996 on Matagorda Island later bred near Brownsville, a dispersal distance of 302 km.

Chihuahuan Desert. *West Texas.* The first two pairs appeared in West Texas in 2007, 5 yr after releases began, and by 2009, there were 8–10 pairs, all near the town of Valentine, producing in the aggregate three wild young that year. We detected only two pairs the following year (2010) despite searching; the female of one was taken by a predator during the nesting season, and the male thereafter disappeared. We found only one pair in 2011, and none in 2012. Reasons for the abrupt loss of pairs during fall 2009 and winter 2009–2010 could not be determined conclusively. The area was beset with severe drought by mid-2009 (Fig. 9), resulting from the virtual absence of late-summer and fall thunderstorms and winter rain, a condition that necessarily reduced seed and insect abundance essential to prey bird populations (see Macías-Duarte et al. 2004). It was unknown whether the falcons starved, died from other causes, or survived by relocating to wetter areas, but we found no concurrent reports of aplomados anywhere else in West Texas.

New Mexico. Despite the release of 337 captive-bred fledglings from eight hack sites in New Mexico during the 7-yr period from 2006 to 2012 (Fig. 5), the project resulted in only two known nesting pairs. Both were successful, and both were on the Armandaris Ranch where managers enhanced prey bird

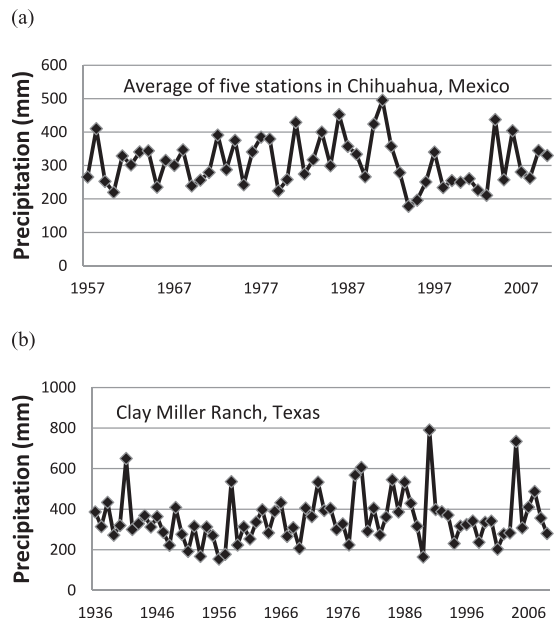


Figure 9. Annual rainfall averaged at five meteorological stations in Chihuahua (A. Macías-Duarte) and at the Clay Miller Ranch near Valentine, Texas (lower chart, courtesy of Clay Miller).

populations year-round with grain stations and water. One of the pairs consisted of two yearlings from the 2006 release that remained and produced two young the following year near the release site (Armandaris #1, Fig. 5). This pair had been routinely provisioned with dead Japanese Quail from the time of release until its disappearance a year later. The second pair, which contained a yearling male, was discovered in the same area in 2011 and produced three young. Only the male was present the following year. Twenty-eight additional sightings, compiled by the BLM during 2006–2011, included a few ephemeral pairings, none of which appeared to be nesting (R. Lister, BLM, pers. comm.).

Survival of released falcons. Estimates of annual survival of released falcons, like those reported for coastal Texas by Brown et al. (2006), are unavailable for West Texas and New Mexico because of the extreme paucity of resightings. 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. This is a markedly different result from that obtained in coastal Texas where two populations quickly formed and persisted, albeit with the provisioning of barred boxes

Table 2. Aplomado Falcons dead or missing within 21 d of release from hack sites in West Texas (2002–2011). Note that attrition in 2011 (84%) was 2.5 times the average in prior years (34%).

YEAR	HACK		DEAD OR MISSING		PERCENT
	SITES	RELEASED	WITHIN 21 d	LOSS	
2002	2	36	10		27.8%
2003	3	48	12		25.0%
2004	5	81	22		27.2%
2005	6	138	19		13.8%
2006	8	115	58		50.4%
2007	6	85	24		28.2%
2008	4	79	38		48.1%
2009	3	45	23		51.1%
2010	2	50	17		34.0%
2011	2	19	16		84.2%

where tree-yuccas were lacking. Visual monitoring at the Chihuahuan Desert hack sites prior to 2011 suggested that mortality during the hacking process was comparable to that observed in coastal Texas where 248 (34%) of 738 falcons died or disappeared within the first 21 d following release (see also Perez et al. 1996). We therefore sought information on the causes of the presumed excessive mortality among falcons dispersing from the Chihuahuan Desert hack sites by radio-tagging 66 fledglings in 2011 and nine in 2012.

Hack site monitoring in 2011 indicated that mortality of hacked falcons in the Chihuahuan Desert during the first 21 d after release was at least twice the average of all other years. In West Texas in 2011, 84% were dead or missing within 21 d, compared with an average of 34% during 2002–2010 (range = 25–51%; Table 2). In New Mexico, the highest rate of early attrition (50%) also occurred in 2011 compared with 23% in the previous 5 yr (range = 0–31%; Table 3) and 32% the following year (2012).

The overall results of radio-tracking in 2011, together with visual observation, showed avian predators as the principal agents of mortality (Table 4). At least 49 individuals (74%) either died or were missing within 21 d (and therefore presumed dead) among the 66 radio-tagged falcons, and not one was known to have survived longer than 146 d after release. Raptor predation accounted for 79% of the 33 diagnosed fatalities. Radio signals of all 18 birds that may have survived (Table 4) were eventually lost ($n = 12$) or became stationary ($n = 1$). It was unknown whether the loss of signals resulted from

Table 3. Aplomado Falcons dead or missing within 21 d of release from hack sites in New Mexico (2006–2011). Attrition in 2011 was twice the average of other years.

YEAR	HACK		DEAD OR MISSING		PERCENT
	SITES	RELEASED	WITHIN 21 d	LOSS	
2006	1	11	0		0.0%
2007	2	39	12		30.8%
2008	3	70	21		30.0%
2009	4	70	21		30.0%
2010	5	67	16		23.9%
2011	4	46	23		50.0%
2012	3	32	10		32.1%

transmitter failure or from mortality (or transmitter detachment) events that inverted the solar panels; 11 of those falcons were last observed at their release sites, two were within 10 km of the site, and four travelled more extensively prior to signal loss. In all, only seven falcons were last detected at distances of >10 km from their release sites: two were recovered fatalities: one died of predation and the other struck a barbed wire fence.

Fates among the radio-tagged falcons released in New Mexico in 2011 varied among sites. Those surviving best were at the Armendaris Ranch where grain and water stations artificially enhanced prey bird numbers (Table 4). In all, at least 31 birds (66%) perished within among 47 radio-tagged individuals released at the four sites in New Mexico, including 24 discovered carcasses and seven birds that disappeared within 21 d of release.

Documented mortality was higher in West Texas than New Mexico. Thirteen carcasses were recovered of the 19 falcons released, and an additional four were missing within 21 d and presumed dead. One survived about 100 d, travelling to the Aplomado Falcon study area in Chihuahua, Mexico, where its satellite-reporting transmitter became stationary by early November and remained so. In all, only two (10%) of the 19 falcons released in West Texas may have survived.

In 2012, in contrast, only one (11%) among the nine radio-tagged falcons released in New Mexico in 2012 died within 21 d of release. However, six were dead or presumed dead by December. Of the remaining two, one falcon's transmitter became inoperable, and one falcon frequented the vicinity of Nuevo Casas Grandes, Mexico, approximately 225 km south of Deming, New Mexico. Its signal became stationary after 26 December 2012.

Table 4. Fates of 66 captive-bred Aplomado Falcons radio-tagged and released at four hacks sites in New Mexico (Armendaris, White Sands, Delk, and Cole) and two in West Texas (Baeza and Moon) in summer 2011 (see Fig. 6, 7 for hack site locations). Falcons missing within 21 d of release were presumed dead.

FALCON FATES AND MORTALITY AGENTS	HACK SITES (NUMBER OF FALCONS RELEASED)						TOTALS (n = 66)
	ARMENDARIS (n = 10)	WHITE SANDS (n = 12)	DELK (n = 18)	COLE (n = 7)	BAEZA (n = 9)	MOON (n = 10)	
Swainson's Hawk			5				5
Great Horned Owl		2		1		3	6
Red-tailed Hawk					1		1
Large falcon					1		1
Unidentified raptor	2		6			5	13
Bobcat				1			1
Unknown mammal				1	1		2
Wire strike				1			1
Lightning strike		2					2
Starvation					1		1
Unknown agent		2	1		1		4
Missing within 21 d	2	2	3		3	1	11
Missing at 22-42 d	2	1		1	1		5
Known surviving >42 d	4	3	3	2		1	13

DISCUSSION

Coastal Texas. The incompatibility of aplomados with brush in southern Texas was poorly understood when TPF began releasing them. We began in habitat deemed suitable on the basis of previous observations of wild pairs in Veracruz, Mexico, where trees were well tolerated, at least on the margins of breeding territories (see Keddy-Hector 2000). The fates of the captive-bred falcons, however, and the emerging distribution of breeding pairs, quickly revealed that habitat structure typical of aplomado territories in Veracruz was not necessarily predictive of where aplomados could survive and reproduce along the Texas coast. Trees and brush there supported the Great Horned Owl, now known to be a primary predator of aplomados, accounting for the majority of recorded deaths among both newly released falcons and free-ranging birds; 91% of 141 predation fatalities at hack sites on the Texas coast were listed as known or suspected predation by Great Horned Owls (Jenny et al. 2004). Aplomado distribution on Matagorda Island is a mirror image of that of Great Horned Owls; the latter are virtually absent on the island, except on its northern end which supports stands of mesquite and tickle-tongue (*Zanthoxylum hirsutum*). Aplomado pairs are absent or ephemeral on this portion of the island. San Jose Island, also wooded on its northern end, shows a similar pattern of falcon and owl distribution. White-tailed Hawks and Crested Caracaras,

both potential predators of aplomados, occur throughout both islands, suggesting that these species are lesser threats. The most likely reason why aplomados in coastal Mexico tolerate more woody vegetation than they do in Texas is that Great Horned Owls apparently do not extend into Veracruz or southward along the coast of eastern Mexico (Houston et al. 1998).

Predation may also contribute to the apparent shortage of breeding males in the Brownsville population. A possible explanation concerns sex-differences in size and parental roles. As in most raptors, the male aplomado is the primary hunter during most of the breeding cycle, while the female tends to remain near the nest to incubate, brood the young, and defend them against predators. The foraging male, like the female, is often crepuscular (Keddy-Hector 1998) and weighs less than the female by an average of 35%. These factors necessarily expose males to greater risk during their more frequent travels to find prey; in the process, they may encounter brush patches harboring Great Horned Owls, Harris's Hawks (*Parabuteo unicinctus*), and Cooper's Hawks, the latter having increased in recent decades (J. Arvin, Gulf Coast Bird Observatory, pers. comm.; Sauer et al. 2011). Whereas Great Horned Owls are also present in open savanna, they are more exposed there to chronic harassment by aplomado pairs and other diurnal raptors defending territories. Such attacks are likely more effective

where perches and roost sites offering protection to owls are widely spaced, and when the owls are visible within them. This may explain why live oak savannas in South Texas remain unoccupied by aplomados: even small live oaks, in retaining their dense foliage year-round, can effectively protect owls from view and consequent harassment and displacement.

Another limiting factor is predation by mammals climbing into natural nests other than those in tree-yuccas, the latter apparently offering a substantial degree of protection to eggs and young. We deduce from this, and from evidence of predation by brush-associated avian predators, that the historical population of aplomados on the Texas coastal plain lived in extensive open prairie with scattered tree-yuccas. This assertion is supported by the success of breeding aplomados on the virtually unbroken grassland of Matagorda Island where barred boxes substitute for tree-yuccas in deterring ground predators.

Tree-yuccas are often absent in otherwise suitable grasslands, and many tree-yuccas are unserviceable because they lack nests. A paucity of yucca nests has been additionally problematic near Brownsville in recent years because of an apparent severe decline of Chihuahuan Ravens in the region, most likely due to West Nile virus (J. Arvin, Gulf Coast Bird Observatory, pers. comm.). Raven nests on power-pole cross-arms supported several pairs of aplomados in past years, and the smaller number of raven nests on poles have reduced aplomado breeding opportunities. Other nest-building species are still present, however, including White-tailed Hawks, Crested Caracaras, and White-tailed Kites (*Elanus leucurus*). Barred boxes, as well as occasional artificial nests we supplied on power poles and other elevated structures, are also available.

Chihuahuan Desert. Reports of aplomado sightings were extremely rare in the grasslands of western Texas, New Mexico, and Arizona throughout most of the 20th century, even though habitat conditions appeared similar to those where the species bred in adjacent Mexico. Immigration of falcons from Chihuahua into New Mexico after 1990 was documented by Meyer and Williams (2005; see also Young et al. 2004, Young and Young 2010) who reported scattered sightings, including a pair that produced young in 2002 and whose territory remained occupied for 3 yr. Several other territorial pairs of wild aplomados have been documented in New Mexico since 2000 (R. Lister unpubl. data), along with additional sightings of unbanded birds. The occurrence of pairs and individuals was almost

always brief, however, suggesting that conditions were unsuited to sustained occupancy.

Eleven years of experimental releases (2002–2012) totaling 940 falcons in West Texas and southern New Mexico did not produce a breeding population aside from the eight or ten ephemeral pairs that inhabited West Texas in 2009 following several years of above-average rainfall (Fig. 9). All but two of these pairs abruptly disappeared in spring 2010 after summer, fall, and winter rains failed, and the remaining pairs have since vanished. Food-stressed falcons may have been more susceptible to pathogens, or forced to forage closer to brush-inhabiting predators, or may, with the drying of surface water, have been tempted to drink or bathe, and thereby drown, in the many steep-sided stock tanks in the region. Not a single pair could be found in West Texas or New Mexico in 2012, and it seems clear that the Chihuahuan Desert program cannot succeed under current environmental conditions. This conclusion is supported by predictions of continued drought influence (Intergovernmental Panel on Climate Change 2007, see Peterson et al. 2002) upon an already unstable food supply characteristic of an ecosystem where grassland birds have long been in decline (Knopf 1994, Sauer et al. 2011).

The high 21-d attrition of falcons released in the Chihuahuan Desert in 2011 (Tables 2 and 3) may have resulted from the influence of drought on predator activity. Survival in West Texas corresponded with the amount of precipitation in the previous year as recorded on the nearby Clay Miller Ranch (Fig. 9): survival was highest in 2005 following an unusually wet year (twice the 74-yr average precipitation), and lowest in 2011 following an extraordinarily dry one (<50% of average). Severe drought also pervaded southern New Mexico in 2011 and 2012, but the association with predation mortality at hack sites was less clear, partly because local precipitation data were unavailable. It is conceivable that our use of transmitters influenced survival in 2011, but that possibility appears doubtful in that most fatalities occurred near the hack sites where such evidence would have been detectable. Moreover, eight of nine identically tagged falcons in 2012 survived >21 d. The higher 21-d survival in 2012 may have related to the use of new hack sites with fewer resident raptors and their lack of prior exposure to hacked falcons as a source of food.

Lower annual precipitation may render parts of southern New Mexico less suitable for this species

than the area of West Texas where pairs established themselves. Annual precipitation measured at Deming, New Mexico, during 1957–2009 averaged 246 mm, and 273 mm at the Jornada Experimental Range north of Las Cruces. The Miller Ranch near Valentine, Texas, averaged 365 mm during that period, and five meteorological stations in Chihuahua, Mexico, averaged 309 mm (Fig. 9).

The aplomado population in adjacent Chihuahua, Mexico, has drastically declined. The 35 pairs present in Montoya's study area when he began his investigations in the early 1990s had dwindled to 25 by 2002 (Macías-Duarte et al. 2004), and only six could be found in 2011 (A. Macías-Duarte unpubl. data). Obvious factors associated with the loss were continuing drought and the sudden conversion of 15–17 territories to irrigated croplands beginning in the mid-2000s (Macías-Duarte et al. 2007, A. Macías-Duarte unpubl. data).

Macías-Duarte et al. (2004, 2009) found large seasonal and yearly variation in grassland bird abundance in the two Chihuahua study areas, Tinaja Verde and Sueco. The most abundant wintering species were Chestnut-collared Longspur (*Calcarius ornatus*), Lark Bunting (*Calamospiza melanocorys*), Brewer's Sparrow (*Spizella breweri*), and Horned Lark (*Eremophila alpestris*). The variation in bird numbers was related to annual differences in precipitation, and aplomado reproduction was sensitive to this variation, with productivity ranging from 1.6 fledglings per occupied territory in wet years to 0.7 during drought (Macías-Duarte et al. 2004). Drought has been prevalent in both Chihuahua, New Mexico, and West Texas since the mid-1990s, but with occasional spikes of precipitation (Fig. 9). The distance from one of our release sites near Valentine, Texas (Miller Ranch), to the nearest aplomado nesting pair in Mexico was only about 105 km. It therefore remains puzzling that, despite the proximity and similarity of habitat, aplomado reports were extremely rare in West Texas during most of the 20th century. Even during the fairly wet period of the 1970s and 1980s, when productivity in Chihuahua may have yielded excess recruits, aplomados were virtually unreported in West Texas.

Overall, carrying capacity for aplomados has decreased markedly on both sides of the Rio Grande since the late 1800s. Not only has the extent of open savanna diminished as a result of livestock grazing and agriculture, but so has the abundance of wintering grassland prey birds, which are of demonstrated importance to nest success among aplomados in this

region (Macías-Duarte et al. 2004, 2011). Populations of grassland birds are thought to have declined more steeply than any other avian guild in North America (Knopf 1994). Some 80% of migratory grassland birds nesting in the western Great Plains of North America overwinter in the Chihuahuan Desert (Macías-Duarte et al. 2011). A primary source of those migrants is the northern prairie grassland, extending northward and westward from South Dakota to Saskatchewan and eastern Alberta, a region that has undergone extensive agricultural development and other transformations, with consequent reductions in grassland bird numbers. The implication is that there are fewer migrants, a factor that may have reduced aplomado foraging habitat quality and therefore falcon productivity even in areas where habitat conditions were otherwise suitable (Macías-Duarte et al. 2011). The Lark Bunting, for example, a wintering species of importance to aplomados in the Chihuahuan Desert because of its mass (36–40 g) and relative abundance (Macías-Duarte et al. 2009), is reported to have declined at an annual rate of 3.2% during 1966–2010 (Knopf 1994, Sauer et al. 2011).

CONSERVATION AND MANAGEMENT

Coastal Texas. The rarity of aplomado sightings in all but two places along the Texas coast suggests that virtually all habitat for breeding aplomados in that region is occupied. The absence of pairs in brushy areas, the disappearance of pairs where brush has encroached, and the failure of aplomados to establish in savannas supporting even widely scattered live oak motts all suggest that predation by brush-associated raptors is the proximate factor limiting aplomado distribution in coastal Texas. Evidence of predation at multiple hack sites (Jenny et al. 2004), as well as predation on free-ranging falcons, suggest that a primary predator is the Great Horned Owl, a generalist species that thrives in honey mesquite, huisache, oaks, and other woody vegetation.

The widespread occurrence of brushlands, caused by the long-term effects of overgrazing and fire suppression, together with the extensive conversion of prairie to farmland, appears to explain the failure of aplomados to repopulate the coastal region more extensively. Whereas small patches of prairie occur over much of the region, we hypothesize that aplomados are exposed to brush-associated predation along their margins, the implication being that much larger patches are necessary. The Brownsville population is of

particular concern to the current status of aplomados in the United States, not only because it contains the majority of nesting territories, but also because the habitat is fragmented among farms and brushlands. The salt prairie between Brownsville and Port Isabel is a stronghold for the species, both historically and currently, but the pressure of continued human development upon breeding territories is ongoing and contingent upon various modes of land ownership and management. Some of the pairs occur on the Laguna Atascosa NWR, where areas of brushland are managed on behalf of endangered ocelots (*Leopardus pardalis*; USFWS 2010). Other pairs exist on private holdings, and while some of the ranchers have been supportive of aplomado nesting, others appear to be planning development. A ranch containing three active aplomado territories just north of Brownsville was becoming a residential subdivision at the close of 2012. The Port of Brownsville owns a large portion of the remaining Brownsville Prairie, but there is a planned second-access highway to connect South Padre Island with the mainland, as well as urban and industrial projects that may include wind farms and other potential hazards. Overall, the current human population of the lower Rio Grande Valley is 1.2 million (Source: 2010 Census), an approximate 25% increase over population levels in 2000, and with an expected continued growth of about 4% per annum (C. Perez, USFWS, pers. comm.).

Knowledge of how avian predators of aplomados are distributed in the landscape would be valuable in determining the size and structure of prairie habitat patches sufficient to sustain viable subpopulations of aplomados in coastal Texas. Radiotelemetry could be used, for example, to determine (1) the thresholds of vegetation profiles and woody species composition that accommodate nesting and roosting Great Horned Owls, and (2) the extent to which their home ranges penetrate adjacent, more open savanna. Simultaneous use of radio-tags to monitor the movements of wild aplomados could increase knowledge of their ranges relative to raptor habitat and the conditions in which the falcons encounter these predators.

Meanwhile, the presence of nesting aplomados on the Texas coastal plain, made possible by captive breeding and release, is revealing essential facts about what is required to achieve success in reestablishment. We have identified four apparently favorable habitat components, namely, (1) open prairie

virtually devoid of oak and mesquite brush (or their structural equivalents) that harbor the Great Horned Owl and other predators, (2) a wide scattering of tree-yuccas (or barred nest boxes) for nesting, (3) the presence of nest-building species, especially the Chihuahuan Raven, and (4) seed grasses and insects sufficient to support passerines and other avian prey in all seasons. An absence of aplomados in patches exhibiting these features is a likely indication that those patches are too small.

Of the two populations occurring on the Texas coast, the one near Rockport appears secure as presently managed. The habitat near Brownsville, however, is not only threatened by human development, there is an apparent deficiency of adult male aplomados that likely relates to brush-associated predation. Ensuring the continuance of aplomados near Brownsville will require protection and management of the habitat that currently supports the species, and the establishment of additional large areas of open savanna elsewhere in coastal Texas conducive to the buffering dynamics of a metapopulation. Species benefiting from such habitat restoration might also include Attwater's Prairie Chicken, Whooping Crane (*Grus americana*), and pronghorn—all four, and the habitat itself, representative of the ancestral condition.

Chihuahuan Desert. Whereas habitat structure is the primary factor influencing the reestablishment of aplomados on the coastal plain, additional impediments exist in the Chihuahuan Desert. Ten years of releases in the desert grasslands of West Texas and 7 yr in New Mexico have failed to establish a population in either area. Contrary elements include habitat loss, predation, the influence of drought on prey densities, declines among wintering passerines migrating from the northern prairies, and possibly other factors. Given long-term predictions of increasing drought, it is questionable whether aplomados can regain their former distribution in the Chihuahuan Desert.

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