INVESTIGATING AND MITIGATING RAPTOR ELECTROCUTION IN AN URBAN ENVIRONMENT

By

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James F. Dwyer

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ABSTRACT

Electrocution of raptors in the United States has been a cause of concern since the early 1970s when it was first identified as a significant source of mortality. Since then, biologists and industry personnel have developed an understanding of how and why raptors are killed more often on some pole types, and have developed techniques to identify those poles and to modify them to prevent a raptor from simultaneously contacting multiple, differentially energized conductors. Doing so has enabled the electric industry to focus limited resources on the most lethal poles. This work has been conducted primarily in rural areas, but raptors are found in urban areas also. Since previous research indicated that Harris' hawks living in urban Tucson, Arizona were affected by electrocution, I investigated: 1) whether poles close to nests were more likely to electrocute a hawk than poles of the same configuration farther away; and 2) whether pole modifications intended to prevent the electrocution of raptors were effective. I was also able to asses the extent of raptor electrocution in Tucson.

Over 18 months of study, I found 133 electrocuted raptors, 9 electrocuted corvids, 15 raptors suffering from electric shock injuries, and evidence to suggest that I failed to detect 1 out of every 3 electrocutions, even in the areas I searched most intensively. All electrocutions on monitored poles around Harris' hawk nests occurred within 300 m of nests, suggesting that poles close to nests are more likely to electrocute a raptor. In early 2003, prior to any nest-specific retrofitting, I detected 1.4 electrocutions per monitored nest. In 2004, after roughly half of poles within 300 m of nests were retrofitted, I detected 0.2 electrocutions per nest. Retrofitting utility poles does reduce electrocutions.

PREVENTING ELECTROCUTION OF RAPTORS IN AN URBAN ENVIRONMENT

INTRODUCTION

Electrocution on overhead power lines and poles was identified as a potentially significant source of mortality for birds of prey (raptors) in the United States in the early 1970s (e.g., Olendorff 1972, Boeker and Nickerson 1975, Lehman 2001). This "take" is illegal under the Migratory Bird Treaty Act (1918). Efforts to reduce incidents of raptor electrocution have led to the development of techniques for modifying poles with potentially lethal electrical configurations (Miller et al. 1975, Olendorff et al. 1981, APLIC 1996). Application of these techniques (retrofitting) likely has reduced the number of raptor electrocutions in the United States, but electrocution continues to be identified as a common cause of raptor mortality (e.g., Harness 1997, Harmata et al. 2001, Manosa 2001, Weech 2003, Ress 2004). However, the scope and significance of the electrocution of raptors remains largely unknown (Bevanger 1998, Lehman 2001).

Efforts to modify potentially lethal poles have been undertaken in some areas used by raptors, with an initial focus on identifying and retrofitting the most likely lethal poles (Pearson et al. 1999, Harness and Wilson 2001). Retrofitting these poles first enables electric utilities to use limited budgets to the greatest effect. In rural environments, poles in high places overlooking large, open areas (e.g., along ridgelines or agricultural fields) have been found to be the most lethal to raptors because birds prefer these perches from which to hunt and advertise territory (Harness and Wilson 2001, Schomburg 2003). In addition to the position of the pole in the environment, the potential for a pole to electrocute a raptor depends on the pole-top configuration (e.g., Janss and Ferrer 2001), and the species and behavior of raptors present (e.g., Dawson and Mannan 1994, Janss 2000). In urban and suburban areas, the pole-top configurations and raptor species present may be similar to rural areas, but power poles often are situated in low areas for aesthetic reasons, and large, open areas may be uncommon. Thus, the criteria used to identify the most likely poles to be lethal to a raptor in exurban areas may be sub-optimal for identifying the most likely poles to be lethal to a raptor in towns and cities.

Several species of raptors nest in urban environments in the United States (Adams 1994). For example Harris' hawks *(Parabuteo unicinctus)*, red-tailed hawks *(Buteo jamaicensis)*, and great-horned owls *(Bubo virginianus)* are common year-round residents in Tucson, Arizona (Mannan et al. 2000), and are large enough to be susceptible to electrocution on power poles. The history of electrocution of raptors in southern Arizona, and particularly in Tucson, mirrors the national scenario. Electrocution of Harris' hawks was first noted in the 1980s (Whaley 1986), then again in the 1990s, when electrocution was suspected to be a significant source of mortality among breeding groups (Dawson and Mannan 1994). By 1998, Tucson Electric Power Company (TEP) had instituted a program designed to reduce the number of raptors being electrocuted on its overhead distribution system. Their program focused on installing insulating hardware on the "high-side" bushings and jumpers of all new transformers, and on existing transformers where a raptor was electrocuted (TEP, personal communication). In July 2003, Bill Mannan and I suggested to TEP that retrofitting poles around the nest sites of Harris' hawks might be a logical prioritization of management efforts, and TEP then added this proactive element to their program. A prior study had suggested that rates of electrocution might be highest in these areas (Dawson and Mannan 1994). I began monitoring the effectiveness of TEP's program in February 2003. My objectives were to assess: 1) whether poles within some definable distance of Harris' hawk nests were more likely to electrocute a Harris' hawk than were poles of the same configuration beyond that distance; and 2) whether modification of potentially lethal poles within 300 m of Harris' hawk nests reduced the number of electrocutions occurring in those treated areas. Since no study prior to this one had attempted to document electrocutions on retrofitted poles, the effectiveness of these modifications was unknown. In an effort to identify other avian species susceptible to electrocution, I investigated all reported incidents of avian electrocution throughout TEP's service area.

STUDY AREA

My study area was broadly defined by those portions of metropolitan Tucson serviced by TEP (approximately 1,000 km^2, and 111,000 utility poles. The Tucson metro area includes a population of about 900,000 people (Pima association of governments 2004), is located in the Sonoran Desert and supports Lower and Upper Sonoran vegetation types (Brown et al. 1979). Although remnants of these vegetative communities persist in Tucson, much of the natural vegetation has been removed or replaced with exotic plants. Rivers and drainage courses are common in the area, but are dry most of the year. Tucson also supports a diverse assemblage of raptors during both the breeding season and through the winter (Mannan et al. 2000, Sibley 2000).

METHODS

I searched for nests of Harris' hawks from March through September, 2003 and from February through August, 2004. To find nests, I investigated areas where electrocutions had occurred previously, and where nests and sightings of Harris' hawks were recorded in a database maintained by the Arizona Game and Fish Department. I visited potential territories weekly throughout the nesting season and traveled by vehicle in expanding circles up to about 2 km from the reported sighting. I visited all potential nest sites (e.g., large trees) within this area and examined them for evidence of nesting (e.g., molted feathers, prey remains, suitable stick nests). When a Harris' hawk was found, I followed it for up to 2 hours to observe behavior (e.g., carrying sticks or food) that would assist me in locating nest sites. I also examined potential nest sites noticed while moving between known and suspected territories.

Because I found more nests than I could study effectively, I selected nests for study only if the young from that nest had not yet fledged, and if there was at least one potentially lethal pole within 100 m. I defined a pole as "potentially lethal" if it had two or more exposed, differentially energized conductors closer together than about 61 cm. Conductors were in service and energized during this study, most with an inter-phase electric potential of about 14 kV AC and phase to ground electric potential of about 8 kV AC (TEP, personal communication). Thus, distances between conductors could not be measured safely and were estimated from the ground. The cross arms on most of TEP's system are 244 cm (8 ft) long, and provided an effective scale to assess inter-conductor spacing.

In 2003, once a nest was selected for study, I identified and monitored a sample of poles within 300 m. I chose a 300 m radius because an area of this size encompasses the average natal area for a breeding group of Harris' hawks in Tucson, Arizona (Dawson and Mannan 1994). All potentially lethal poles within 100 m of nests were monitored. Each potentially lethal pole within 100 m of each nest was matched to a pole with a similar configuration between 101 and 300 m from the nest. I selected matching poles by generating a random compass bearing for each pole within 100 m and walking away from the nest along that bearing until I saw a matching pole. Occasionally, there were no poles between 101-300 m that matched the configuration of poles ≤100 m from a nest. In these cases, a matching pole was located and monitored at another nest already selected for study. Because I generally found matching poles within 250 m of nests, my sample of poles between 250 and 300 m was small in 2003. To correct this sampling problem in 2004, I matched all potentially lethal poles found ≤100 m from nests to poles found in each 100 increment from 101 to 500 m. In 2003, I detected electrocutions up to 300 m from nests, and in response I expanded my sampling area to a 500 m radius in 2004 in an attempt to detect a biologically relevant cutoff for retrofitting. I chose 500 m because Dawson and Mannan (1994) found this to be the size of a territory defended by Harris' hawks in Tucson against conspecifics.

I monitored poles by visiting them once each week to examine the pole-top with 8x40 binoculars and to search an area of 7.6 m radius (Harness 1999) around the base of each pole for evidence of electrocuted hawks. Evidence consisted of at least some portion of an electrocuted carcass or injured hawk suspended from the pole or found at its base. All carcasses were collected to prevent recounting, and were categorized when possible as juvenile (hatch year) or adult (second year or after second year), and male or female. Electric injuries were diagnosed as described in Hass (1993), Dawson and Mannan (1994), and Koumboulis (2002), and selected diagnostic injuries were photographed (Appendix A). Poles in nest areas were monitored from the time I confirmed a nest to be active until 8 weeks after the young had fledged. Poles from all nests were pooled by distance from the nest into 50 m increments for analyses.

From April through June 2003, I monitored potentially lethal poles around nests prior to TEP proactively modifying them. Some breeding groups of Harris' hawks produce more than one brood per year (Whaley 1986, Bednarz 1987, Dawson 1991). Based on evidence of electrocutions collected through June 2003, I advised TEP to add a proactive element to their avian protection program. I suggested that all potentially lethal poles within 300 m of each nest be retrofitted prior to the fledging of the young from that nest. TEP then modified potentially lethal poles around the nests of breeding groups producing a second brood. Due to ethical implications, an experimental design assessing the effectiveness of proactive modification of poles could not be conducted. To do so would have required me to randomly select nest areas to be protected and, conversely, to leave unprotected. Use of this approach potentially would have condemned hawks in unprotected areas to relatively high rates of electrocution. Instead, I reported all second nesting attempts of Harris' hawks to TEP in 2003 and all nesting attempts in 2004. Throughout my study, I reported all raptor electrocutions to TEP within 12 hours, of my encountering in the incident. TEP then attempted to modify all potentially lethal poles within 300 m of active nests prior to fledging, and all poles where incidents occurred. In 2004 I monitored retrofitted poles around nests as described above. I compare herein the rate of electrocution for potentially lethal poles around a sample of nests without modification (early 2003) to the rate of incidents after modification (late 2003, 2004).

In an effort to verify that the poles I monitored accurately represented the poles in the system that were the most likely to be lethal to raptors, I also responded to all reported incidents in TEP's service area involving the death or injury of a raptor. I did this 1 February 2003 through 31 October, 2004, and did so regardless of whether the reporting party suspected that the animal had been electrocuted. I recorded for every electrocution, the species and pole-top configuration involved, and the distance from the incident to the nearest known nest within 1 km. I compared the proportions of various pole types that electrocuted birds to the proportions of these pole types in TEP's system (Appendix B).

Because I thought it unlikely that I would consistently be the first to encounter injured or dead hawks, especially in residential neighborhoods, I explained my project to all local agencies and individuals who might be expected to encounter a dead or injured raptor, and I requested that they notify me of suspected incidents. I then tested the efficacy of this reporting network (Appendix C). I also discussed the work at a public Tucson Audubon Society meeting, held training sessions for electric company personnel, and collaborated with TEP on a bill insert requesting information from customers regarding suspected raptor nesting and electrocution sites. People living within 300 m of the nests I studied were notified by letter of my project, and asked to contact me immediately if they encountered a dead or injured raptor. Residents sometimes reported that they had found an electrocuted hawk and thrown it away. Diagnosing the cause of death from a carcass can sometimes be problematic, therefore, if I could not view a carcass first hand, I did not record it, and do not report it here.

I captured as many Harris' hawks as I could from each breeding group with a bal-chatri trap (Bloom 1987), and banded them with uniquely numbered plastic or aluminum leg bands (Appendix D) prior to releasing them. Banded hawks assisted me in associating breeding groups with nests, and allowed me to assess whether group members may have suffered electric injuries and survived (Appendix E).

RESULTS

MONITORED NESTS

I found 115 Harris hawk nests, most of which were in an area of about 100 km^2, mainly within 5 km of the Rillito, Santa Cruz, and Cañada del Oro River beds. Twenty-four nests (21%) were discarded because there was no potentially lethal pole within 100 m. I monitored 58 of the remaining 91 nests. The other 33 never became active, failed prior to fledging, were not found until after young had fledged, or were second nesting attempts in 2004 that did not fledge prior to the close of my monitoring period.

I monitored 104 unmodified poles around 26 nests in early 2003, and 22 unmodified poles around 6 nests in late 2003 (2003 total = 126 poles). In 2004, I monitored 91 unmodified, and 86 retrofitted poles within 300 meters of 26 nests, and 77 unmodified and 31 retrofitted poles between 301 and 500 meters of these same nests (2004 total = 284 poles). Thirteen of the nests monitored in 2004 had been monitored in 2003, and 4 additional nests monitored in 2004 were within 100 m of nests monitored in 2003. No electrocutions were detected on monitored poles >300 meters from nests. In early 2003, prior to poles having been modified, I found 1.4 incidents of confirmed electrocution per nest. This rate was reduced to 0.83 incidents per nest in late 2003 after poles were modified. In 2004, retrofitting techniques were applied more thoroughly and the number of detected electrocutions declined to 0.2 per monitored nest.

In 2003, 23 electrocutions were detected within 300 meters of nests. The proportion of poles in 50 m increments that electrocuted a hatch year Harris' hawk remained relatively constant out to 300 meters (X^2 = 2.04, $P \le 0.8433$, d.f. = 5) (Figure 1). However, poles from 201 to 300 m from nests were more likely to electrocute second year or after second year hawks than were poles ≤200 meters from nests (X^2 = 28.0, $P <$ 0.001, d.f. = 5) (Figure 2). In 2004, only 6 electrocutions were detected, and there was no relationship between the proportion of poles causing electrocution and distance from nest within 300 m, for either hatch year (X^2 = 3.38, $P \le 0.6417$, d.f. = 5) or adult birds (X^2 = 3.17, $P \le 0.6736$, d.f. = 5) (Figure 3). No electrocutions were detected in 2004 beyond 300 meters, and when combined with 2003 data, poles beyond 300 meters are less likely to electrocute birds in either age class. (X^2= 11.8, $P < 0.001$, d.f. = 1) (Figure 4).

In both years, I monitored all unmodified poles within 100 meters of all detected Harris' hawk nests. In 2003, 66 potentially lethal poles electrocuted 12 birds. In 2004, 29 potentially lethal poles electrocuted 2 birds. A 56% decrease in the number of potentially lethal poles within 100 m of Harris' hawk nests resulted in an 83% decrease in the number of electrocutions in this same radius. Thus, unmodified poles within 100 meters of nests were more likely to electrocute a bird in 2003 than in 2004 (X^2= 6.2, P<0.025, d.f. = 1). I also monitored a sample of potentially lethal poles from 101-300 meters. In 2003, 64 poles electrocuted 11 birds, whereas in 2004, 62 poles electrocuted 4 birds; a decrease in potentially lethal poles of 3%, and a decrease in electrocutions of 64%.

Overall, I found a 74% decrease in the number of Harris' hawks electrocuted within 300 meters of nests. I monitored 2.2 times as many poles in 2004, and detected 0.27 times as many electrocuted Harris' hawks. None of the Harris' hawk electrocutions that occurred around monitored nests caused outages.

ALL MORTALITIES

I found 75 electrocuted Harris' hawks during my study (including the 29 within 300 m of monitored nests). Of these, 52% were female (where sex could be determined, *n*=61), and 61% were juveniles (*n*=46) (Figure 5). Of 46 electrocuted juveniles, the fledge date was known for 27. Of these, 63% (*n*=17) were killed within 3 weeks of fledging. I also observed 17 Harris' hawks suffering from either confirmed or suspected electric shock injuries, (i.e., electric current had passed through those animals resulting in diagnostic electric injuries, but not in immediate death). Two of these were hatch year birds which were never captured; each was missing a leg. The other 15 were captured and are discussed in Appendix E.

Away from monitored nests, I found a total of 156 dead raptors, including Harris' hawks, great-horned owls, red-tailed hawks, and 6 dead common ravens *(Corvus corax)* (Figure 6). Many of these carcasses were brought to my attention by area residents in response to TEP's bill insert. Of the mortalities I detected, 85% were either confirmed or suspected electrocution incidents (Figure 7). When nests for each species could be found, most electrocutions (79%) were found within 300 meters of nests (*n*=56) (Figure

8). Some mortalities, including 74 confirmed electrocutions, were detected either during the breeding season (March through August) but their nests could not be found (*n*=59), or from September through February when breeding activity was minimal (*n*=52). Although many animals were found during non-breeding months, the number of electric contact incidents peaked each year with the peak of fledging (Figure 9). I also found a 190% increase in the overall number of electrocuted raptors detected away from monitored nests in 2004 despite a 2-month shorter monitoring period (Table 1).

DISCUSSION

I searched for Harris' hawk carcasses around nests which were close to at least one potentially lethal power pole. Thus I may have overestimated the importance of electrocution relative agents as a mortality factor. However, Harris' hawk nests with a potentially lethal pole nearby represent 79% of the nests I found. Furthermore, I probably failed to detect all electrocutions at those nests because: 1) some carcasses are likely to have disappeared from monitored poles between my weekly visits; 2) I did not monitor every pole in the territory, and; 3) I did not include potentially credible incidents which were described to me by residents, but for which I could not view a carcass firsthand. Finally, electrocution was a significant agent of mortality for many species found independent of monitored nests where my emphasis on electrocution was probably less influential. Therefore, I suggest that the number of incidents of electrocution reported herein specifically for Harris' hawks and generally for raptors in Tucson be interpreted as conservative.

Fledgling raptors and adult female raptors have tended to be reported as the most common electrocution fatalities (Dawson and Mannan 1994, Harmata et al. 2001, Rubinolini et al. 2001). I found similar trends, and though this pattern may reflect population structure rather than individual susceptibility, the mortality of adult females is particularly troublesome because the growth or contraction rates of a population tend to be closely tied to the rates of survival of breeding females (Caswell 2001). That numbers of Harris' hawk breeding females are so impacted by electrocution lends ecological weight to the legal assertion that the electrocution of raptors must be mitigated. My data indicate that this mitigation can be accomplished, in part, by retrofitting potentially lethal poles around nest sites. Hatch year birds tended to be electrocuted within 200 meters of monitored nests, whereas second year and after second year birds tended to be killed beyond that radius. I speculate that these patterns reflect behavioral differences. Young birds tend to stay in familiar areas close to the nest, whereas adults advertise their territory farther away from the nest or may be prevented from approaching the nest by dominant group mates (Dawson and Mannan 1991).

I do not know why there was a disproportionately large decrease in the number of electrocutions of both adult and juvenile Harris' hawks around monitored nests after retrofitting only about half of the potentially lethal poles. It appears that personnel from TEP insulated many of the most potentially lethal poles near nests while inadvertently overlooking less potentially lethal poles with similar pole-top configurations. Poles missed during retrofitting operations tended to be those that were at least partially hidden behind buildings or large trees. Such obstacles could reduce the awareness (juveniles) or utility (adults) of poles to hawks, and thus these poles would be disproportionately underused and less likely to be lethal. However, if all poles in the natal area had been retrofitted, the number of electrocutions likely would have decreased even further.

It is possible that there were environmental differences between 2003 and 2004 that changed the patterns of movements of hawks around monitored nests, and thus reduced their likelihood of being electrocuted. However, because the detection of electrocutions increased throughout the rest of the study area in 2004 this explanation seems unlikely. I suspect that the increase in the number of electrocutions reported in 2004 is largely due to an increased awareness of my study by citizens throughout Tucson. I also can speculate that increases in brood size or changes in defended territory may have made predatory birds more susceptible to electrocution in 2004, though I have no evidence to support those ideas. Despite uncertainty about the underlying cause of the increased reports in 2004, at a minimum these reports suggest that the electrocution of raptors did not decline outside of monitored nests. I conclude therefore, that retrofitting poles did reduce the number of Harris' hawks electrocuted near nests in 2004.

MANAGEMENT IMPLICATIONS

Overhead electric systems will probably always be a hazard to raptors, especially when inclement weather is involved. However, the number of electrocutions can be greatly reduced with only minor modifications to specific portions of the overhead system. The nest is the focal point of activity for most species throughout the breeding season, and the probability that an incident will occur in an area is likely to increase with the amount the time spent there. For all raptors in Tucson, electrocutions decreased significantly beyond 300 meters from nests, and I recommend a program of retrofitting all potentially lethal poles within this distance. However, working only around nests will fail to protect raptors over much of their territories, and will leave non-territorial migrating raptors especially vulnerable. In exurban areas, poles in open habitats tend to be the most lethal to raptors (Harness 2001, Schomburg 2003). My data from an urban area support that pattern even within the natal territory. To more fully protect raptors from the danger posed by overhead power systems, my recommendations should be implemented in concert with broader habitat-based risk assessment models like those developed by Schomburg (2003), Harness (1999), and APLIC (1996). Even in urban areas, potentially lethal poles in relatively open areas, and relatively high places can be proactively identified and retrofitted.

In response to the specific demands placed upon the electric system at a given point, utility poles are assembled in an almost infinite variety of configurations. I documented electrocutions on almost every type, but none occurred as a fault through or across a piece of raptor protective equipment, and only a few occurred on poles where protective equipment was improperly or incompletely installed. In some cases, raptor protective equipment was correctly installed according to the manufacturer, but it did not fit TEP components, and it fell off. It is important that new materials be monitored to verify that they are retained by the system. Those instances where birds were killed on poles or in territories which were only partially retrofitted indicate that when even a single point on a potentially lethal pole, or even a single potentially lethal pole in a territory remains unprotected, it is likely that a raptor will encounter that site eventually and be electrocuted there. Very few (<10%) (TEP personal communication) of the incidents I documented were associated with outages, and outages appear to be an ineffective method of assessing the number of raptor electrocutions occurring on an overhead electric system.

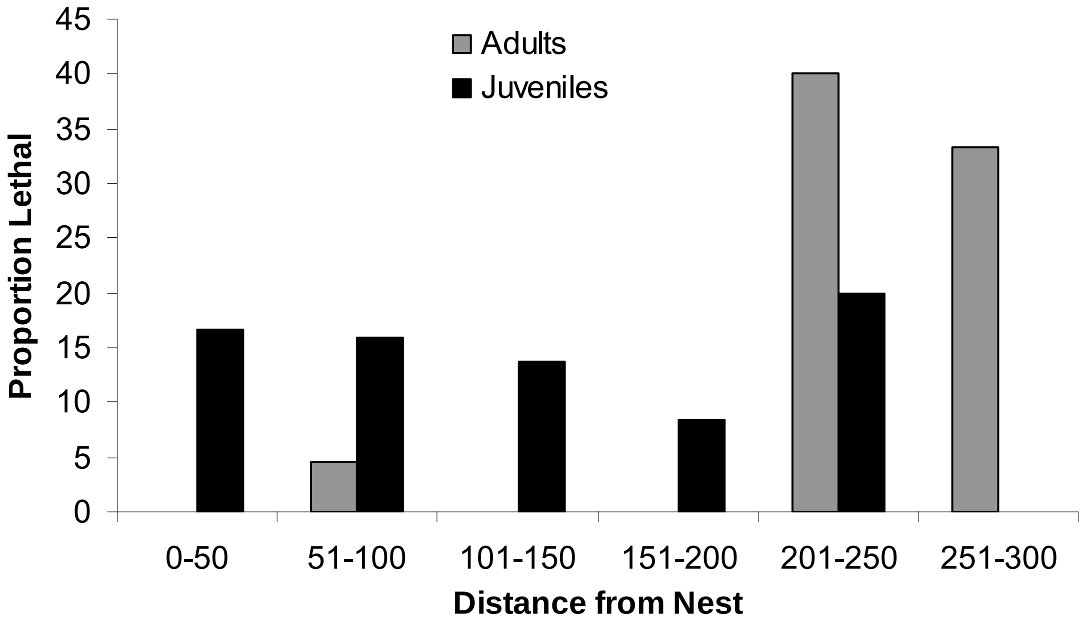

Figure 1. Proportion of potentially lethal poles monitored within 300 m of Harris' hawk nests that electrocuted at least one adult or juvenile Harris' hawk in Tucson, Arizona, USA, between 1 February 2003, and 30 September 2003. Sample sizes of monitored poles in each increment were: 18 from 0-50 m, 44 from 51-100 m, 29 from 101-150 m, 24 from 151-200 m, 5 from 201-250 m, and 6 from 251-300 m.

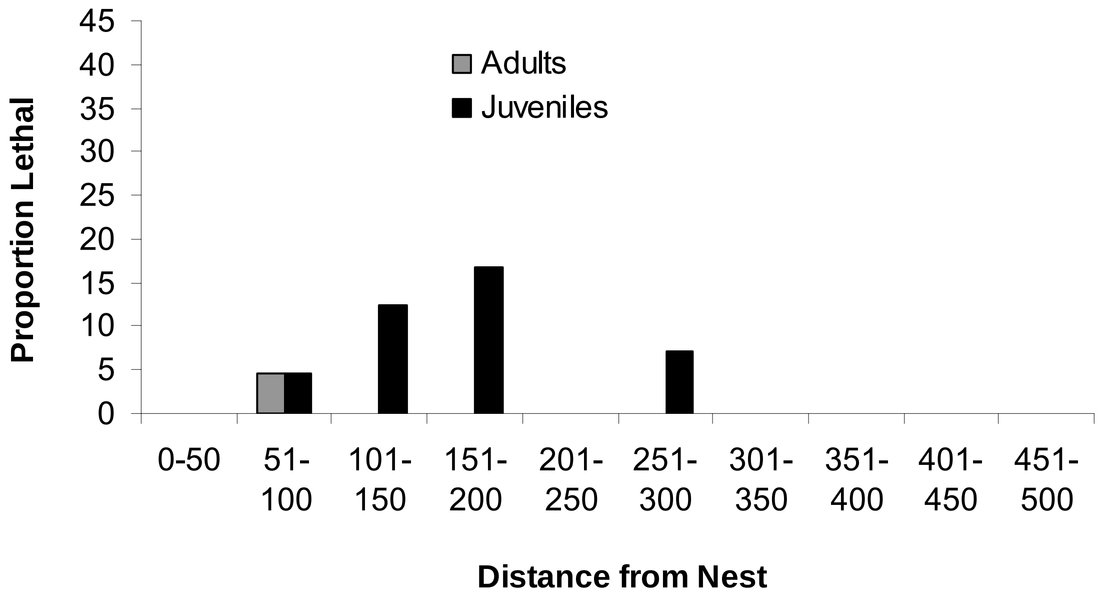

Figure 2. Proportion of potentially lethal poles monitored within 500 m of Harris' hawk nests that electrocuted at least one juvenile or adult Harris' hawk in Tucson, Arizona, USA, between 1 February 2004, and 31 August 2004. Sample sizes of monitored poles in each increment were: 7 from 0-50 m, 22 from 51-100 m, 16 from 101-150 m, 12 from 151-200 m, 20 from 201-250 m, 14 from 251-300 m, 17 from 301-350 m, 26 from 351-400 m, 19 from 401-450 m, and 15 from 451-500 m.

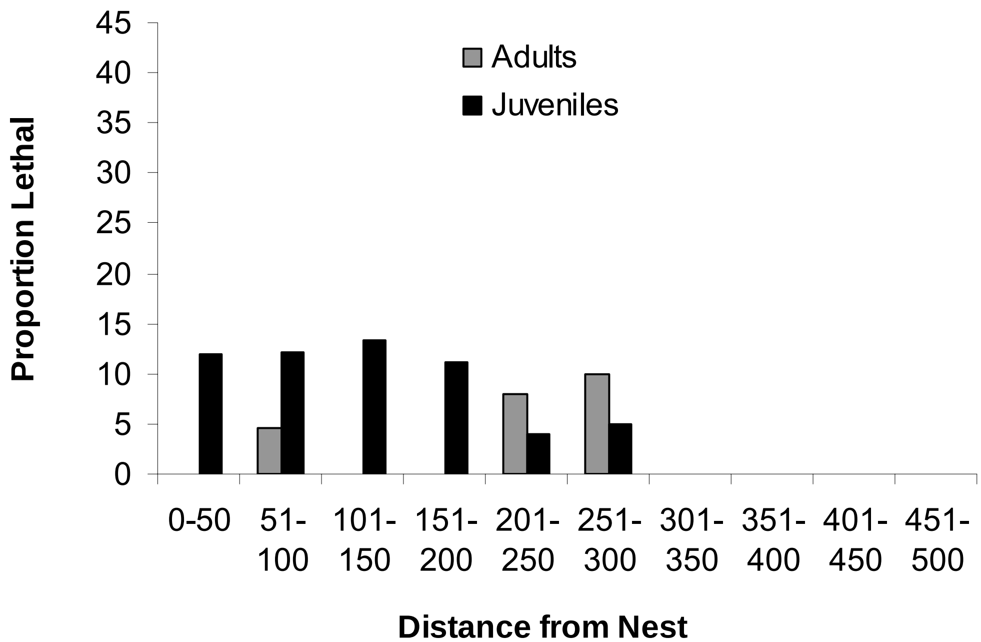

Figure 3. Proportion of potentially lethal poles monitored within 500 m of Harris' hawk nests that electrocuted at least one Harris' hawk in Tucson, Arizona, USA, between 1 February 2003, and 30 September 2004. Sample sizes of monitored poles in each increment were: 25 from 0-50 m, 66 from 51-100 m, 45 from 101-150 m, 36 from 151-200 m, 25 from 201-250 m, 20 from 251-300 m, 17 from 301-350 m, 26 from 351-400 m, 19 from 401-450 m, and 15 from 451-500 m.

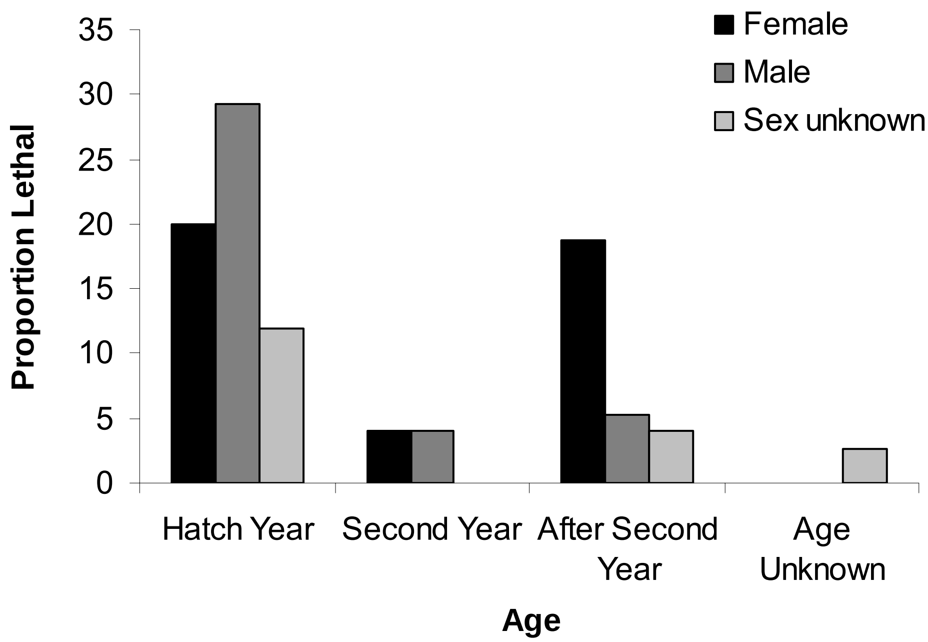

Figure 4. All confirmed Harris' hawk electrocutions in Tucson, Arizona, USA, from 1 February 2003 through 31 August 2004 (n = 75), by sex and age.

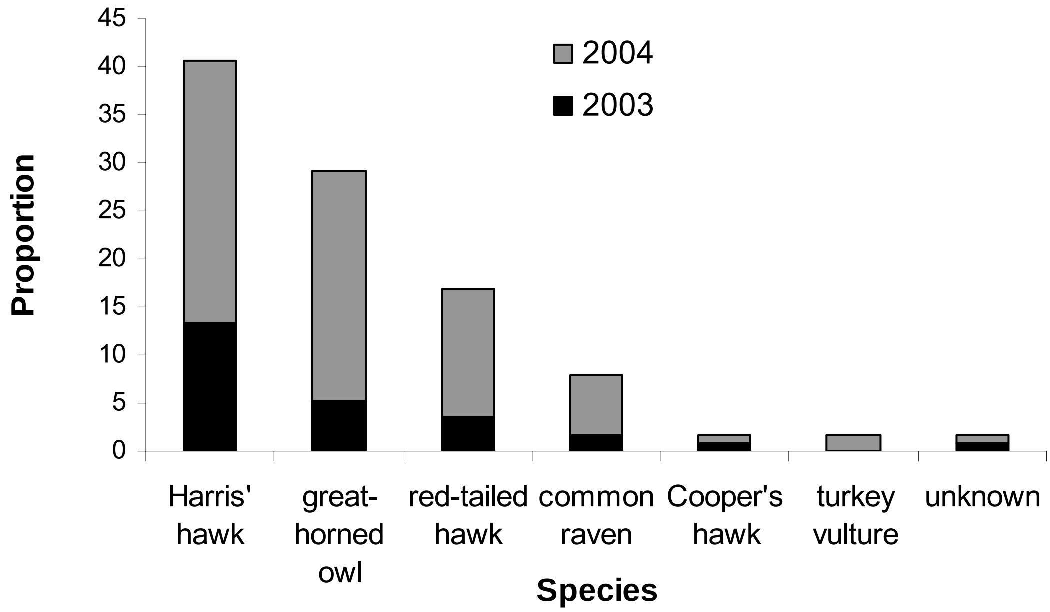

Figure 5. Proportion of raptor and corvid species found electrocuted in Tucson, Arizona, USA, between 1 February 2003, and 30 September, 2004 (n=160). All I found of the animals in the "unknown" category was a burned foot clamped to an energized wire, approximately 10 cm from the grounded case of a transformer served by that wire.

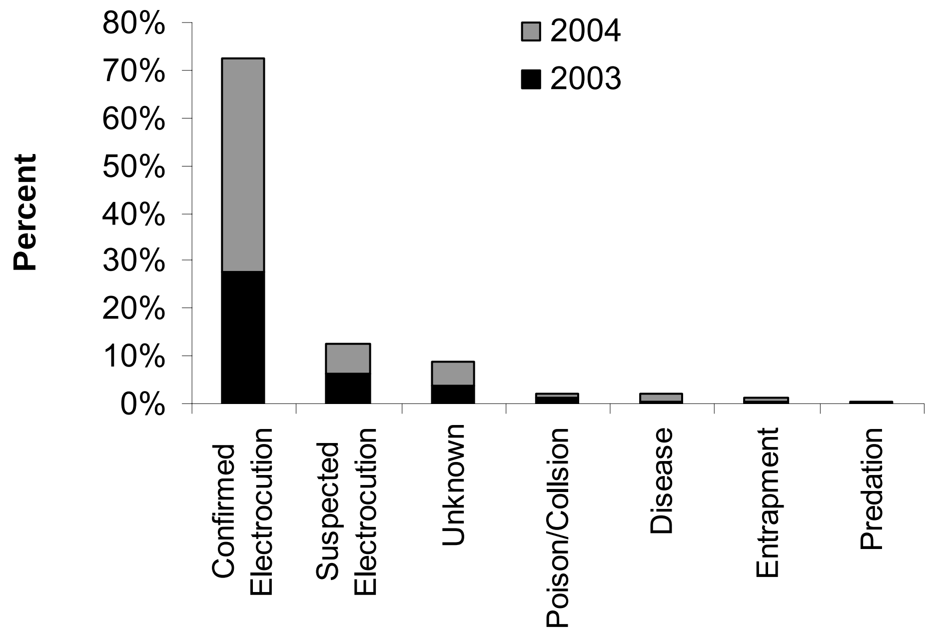

Figure 6. Cause of death for raptor mortalities detected away from monitored nests in Tucson, Arizona, USA, between 1 February 2003, and 30 September, 2004 (n=160).

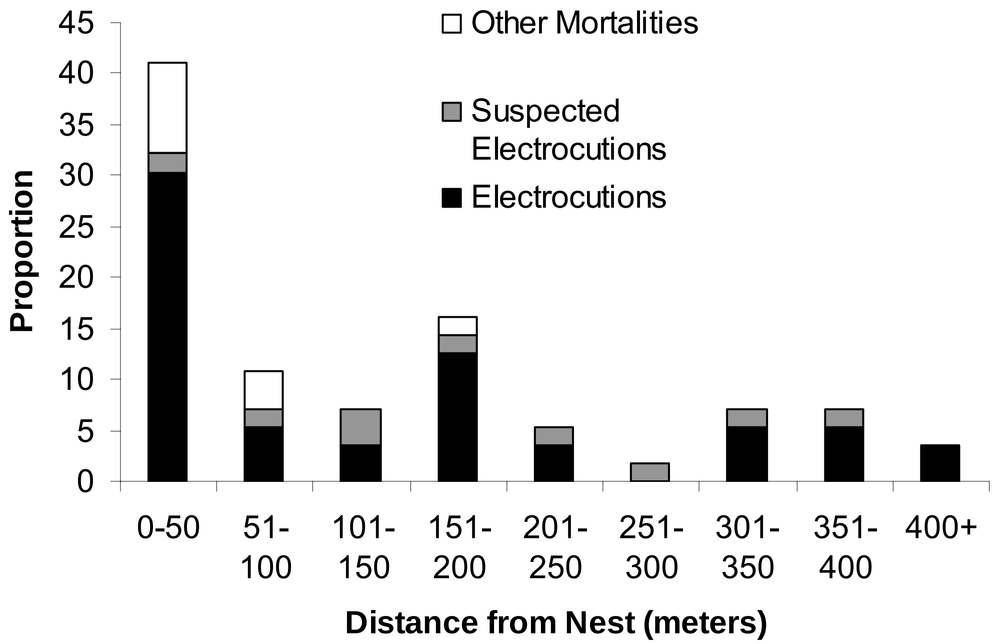

Figure 7. Distance between nest and mortality sites for raptors found dead away from monitored nests in Tucson, Arizona, USA, between 1 February, 2003, and 30 September, 2004, when nest sites could be found (n = 56).

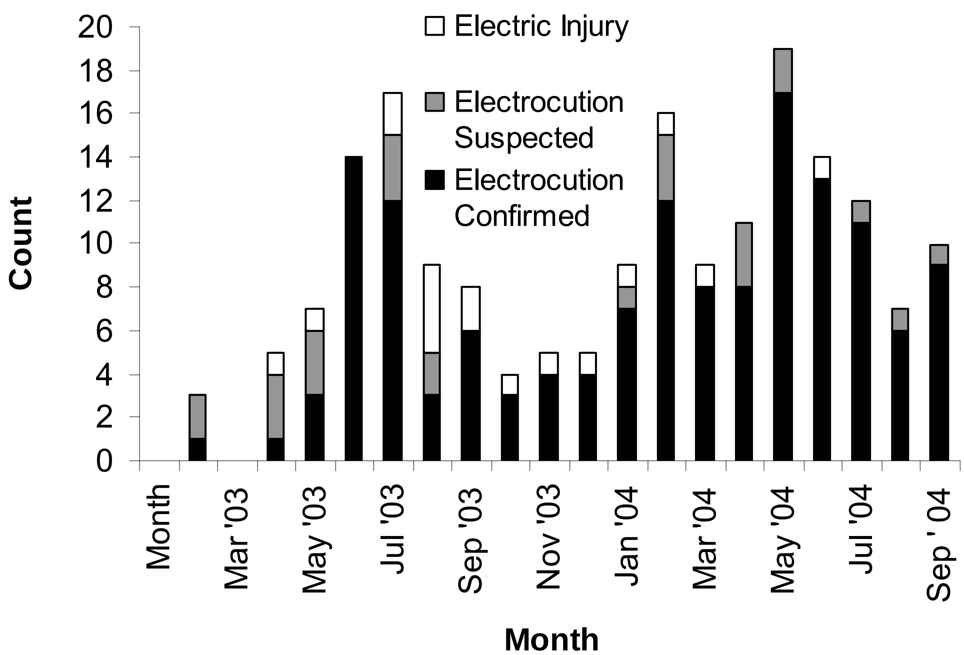

Figure 8. Month of incident for all detected avian electrocutions and suspected electrocutions in Tucson, Arizona, USA, between 1 February, 2003, and 30 September, 2004 (n=183).

Table 1. Confirmed avian electrocutions detected (n=142) away from monitored nests in Tucson, Pima County, Arizona from 1 February 2003, through 31 August 2004. The two electrocution victims for which the species could not be determined consisted only of a charred foot found clamped around an energized transformer jumper.

Species	Detected Electrocutions 2003	Detected Electrocutions 2004	Total	Percent Increase in 2004
Harris' hawk	15	31	46	107
great-horned owl	6	27	33	350
red-tailed hawk	4	15	19	275
common raven	2	7	9	250
Cooper's hawk	1	1	2	0
turkey vulture	0	2	2	N/A
unknown	1	1	2	0
Total	29	84	113	190

APPENDIX A:

PHOTOGRAPHIC HANDBOOK OF ELECTRIC INJURIES TO RAPTORS

A wide variety of injuries can be sustained when a raptor serves as a conduit for electric current. Research on injuries resulting from electric contact in birds is scarce, but in cases of human electrocution, where more extensive research has been conducted, it has been shown that there is no "typical" electrocution (DeBono 1999). Differences in voltage, contact points, duration of contact, and the resistance of the victim's body vary considerably from case to case and the resulting trauma varies accordingly. Death by electrocution most often results from the flow of electric current through the internal tissues, especially the nervous system, and from cardiac and respiratory arrest (Lederer et al. 1999). Death does not typically result from thermal trauma, and in some cases, external burns may not be detectable at all.

Raptors tend to be electrocuted on higher voltage portions of electric systems than humans and thus often exhibit the external, but sometimes cryptic, thermal damage illustrated herein. The simplest cases to diagnose are those in which greater than 10% of the surface area of the animal exhibits singeing to the skin or feathers. These cases are relatively rare, tending to occur at transmission voltage (Figure A1), or in cases where an animal has fallen across distribution conductors following an initial shock (Figure A2).

Cases in which less than 10% of the surface area of the animal is burned can be more difficult to diagnose. Electric damage may occur at any point on an animal, but damage to the head and limbs is most common. Singeing around the face is typical of contact made while perched on a pole and scanning the adjacent area (Figure A3), or while consuming prey that has been carried to the pole and contacts an energized conductor (Figure A4). Burns to the back of the head also occur (Figure A5). Isolated burns can occur on single feathers (Figure A6), or groups of feathers (Figure A7) whereas adjacent feathers remain undamaged (Figure A8). Even when one burn is apparent, special care must be taken to examine each feather on an electrocution victim to try to determine a second point of contact, and thus to deduce where on the pole the animal was when it made simultaneous contact with two conductors. Doing so allows investigators to identify the exact potentially lethal point on the pole where the animal was when it was electrocuted.

Burns to the wings, especially the carpals of electrocuted raptors are relatively common. These injuries may present as “pinholes” in the carpals (Figure A9), singeing of a small group of feathers (Figure A10), or more extensive damage (Figure A11), including explosive separation of the limb (Figure A12). The most common electric damage found in raptors involves the feet and legs, with trauma ranging from an isolated burn or pinhole on the sole of the foot (Figures A13-A15), to a melted talon (Figure A16), to extensive damage of the entire foot and lower leg with or without apparent singeing (Figure A17), to explosive separation of the limb (Figure A18). Any of the damage described above may also be found on live birds suffering from electric shock injuries (Figures A19-A22).

Figure A1) Adult great-horned owl electrocuted by a 46 kV phase to ground fault.

Figure A2) Electrocuted adult red-tailed hawk which fell across two differently phased 8 kV conductors. The animal was eviscerated, decapitated, and lost a wing. Each of the separated portions of the animal were charred, none were scavenged, and all were within 7 m of the base of the pole.

Figure A3) Electrocuted great-horned owl with singeing restricted to the rictal bristles.

Figure A4) Electrocuted fledgling Harris' hawk with singeing to the beak, rictal bristles, and aricular feathers.

Figure A5) On this electrocuted Harris' hawk neither the contour feathers covering the wound, nor any other part of the animal indicated thermal trauma. This burn was found by lifting each feather individually to examine the skin beneath.

Figure A6) A line of singeing on this feather is indicative of electric shock. In this case, there was no carcass at the base of the pole. An injured Harris' hawk, was found alive but immobile 15 m away after the discovery of this feather led to a search of the area.

Figure A7) Typical charring of feather calamus (from an electrocuted Harris' hawk in this case).

Figure A8) A single primary is partially burned on this electrocuted great-horned owl. The feathers adjacent to this primary were not burned.

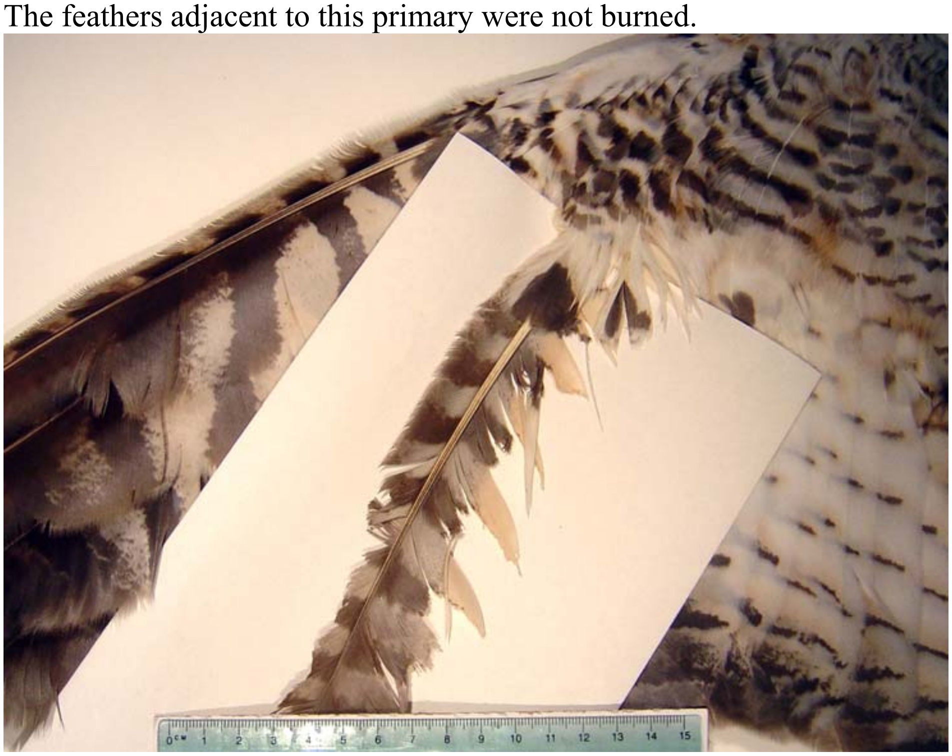

Figure A9) A pinhole burn to the dorsal side of the ulna and greater primary coverts of an electrocuted red-tailed hawk.

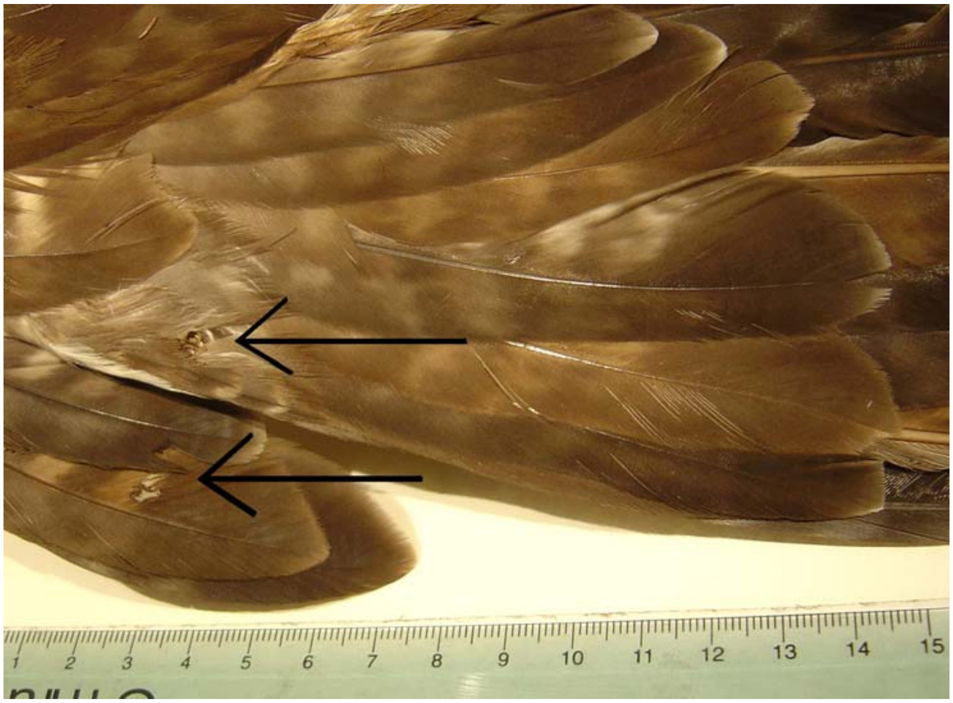

Figure A10) Minimal singeing to the contour feathers on the ventral carpals of a Harris' hawk.

Figure A11) Extensive burning of the dorsal side of a Harris' hawk's wing.

Figure A12) The wing of a great-horned owl explosively separated from the body with burns extending to the primary and secondary flight feathers and coverts.

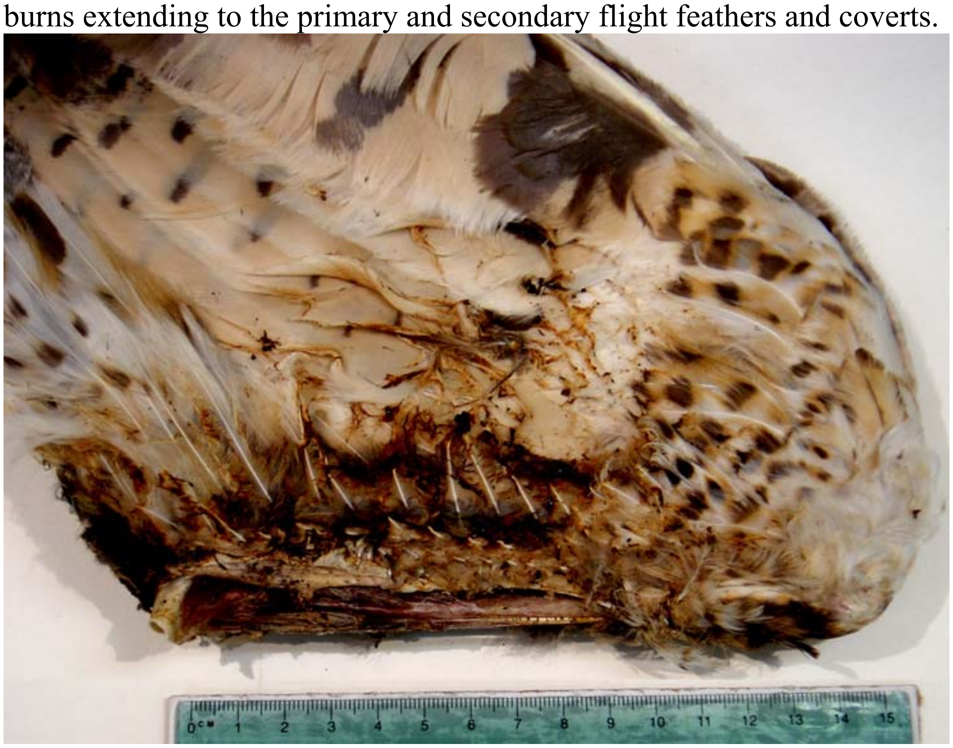

Figure A13) The leg of this red-tailed hawk presents burns on the sole of the foot, and an red track (petechial haemorrhage) (Karger et al. 2002) indicating the path of the current from the sole to the top of the foot and up the leg.

Figure A14) The foot of an electrocuted common raven. Note that on black skin, burns appear whitish or brownish. This is in contrast to most of the other photographs in this appendix where burns on lighter colored skin or feathers appear black.

Figure A15) Charring of a single toe of an electrocuted great-horned owl.

Figure A16) The melted talon on this red-tailed hawk specimen is occasionally the only burn evident.

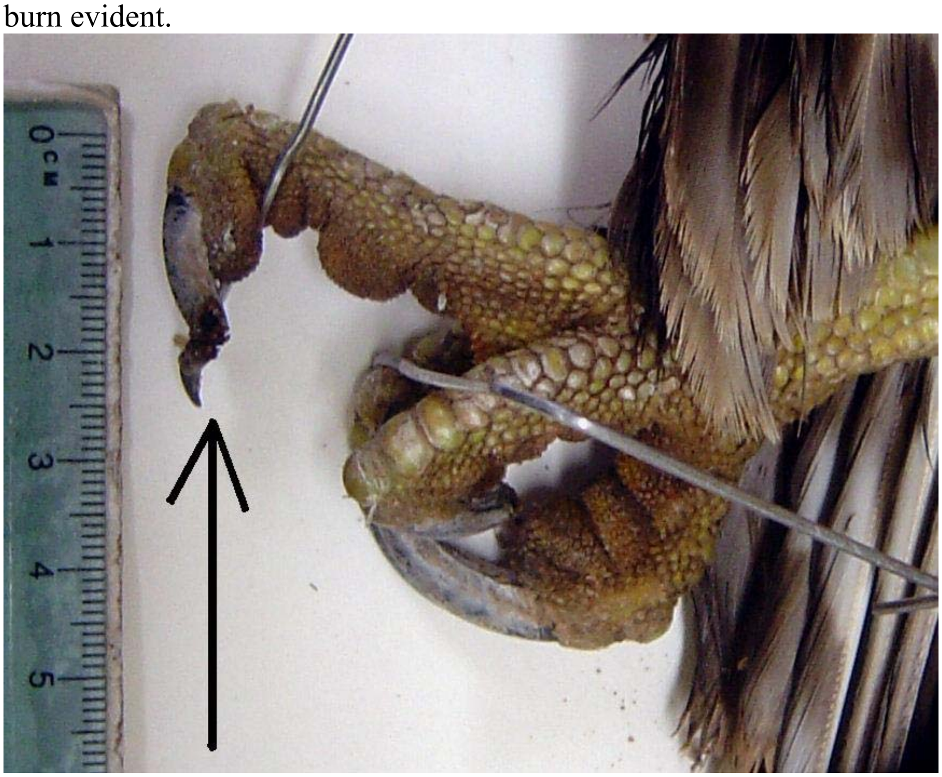

Figure A17) A rupture in the center of the tarsometatarsus of this Harris' hawk is diagnostic of an electric contact incident. Ruptures like this occur when cells explode as a result of the heat generated by the body's resistance to the flow of electric current.

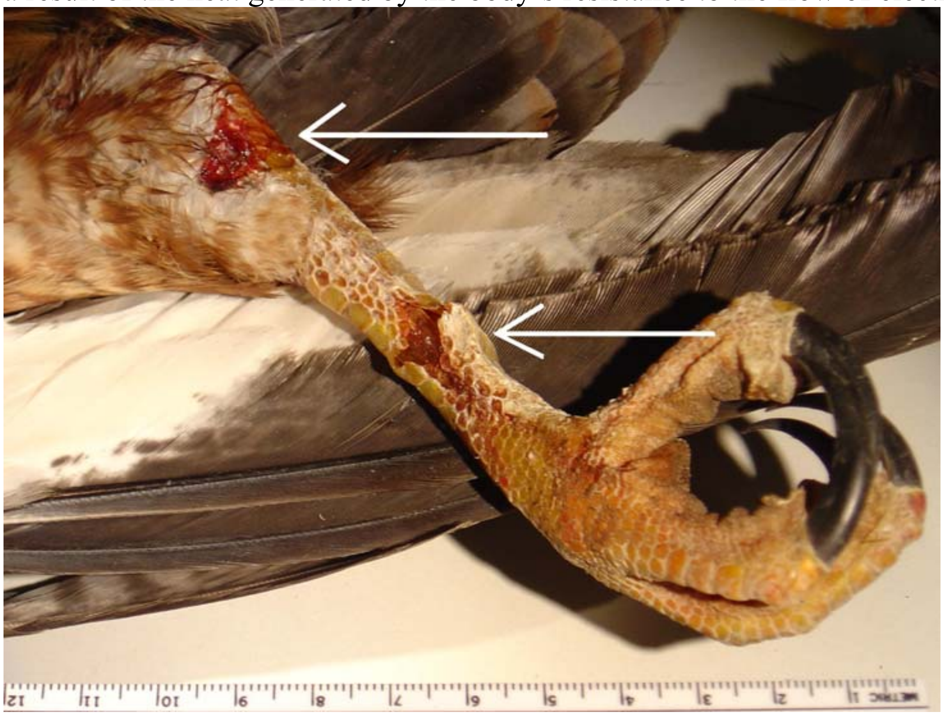

Figure A18) A foot blown off a Harris' hawk as a result of the passage of electric current. All pieces of a carcass should be collected when possible and used to reconstruct the lethal situation.

Figure A19) This Harris' hawk was collected alive. It was unable to fly but appeared unharmed. While under observation it shed the primary flight feathers of the right wing as a result of necrosis of the wing following an electric shock incident.

Figure A20) A closer view of the feathers shed by the Harris' hawk in Figure A19. The feathers on the left were lost as a result of necrosis following an electric shock injury and have been shed with dead tissue attached. Feathers on the right were molted normally and are shown for comparison.

Figure A21) A fledgling Harris' hawk which has lost its right foot and tarsometatarsus but survived. Note the scar at the proximal end of the fibula which indicates that current passed through the leg only, and not into the body of the bird.

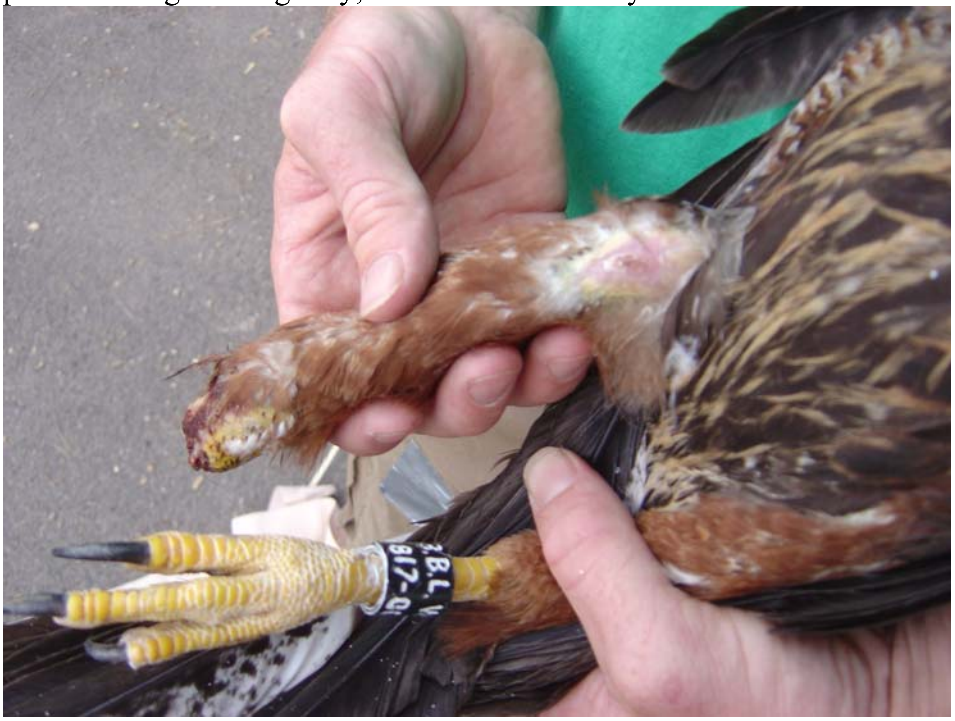

Figure A22) The injury to the Harris' hawk pictured in Figure A21 are not readily apparent to a human observer on the ground.

APPENDIX B:

LETHAL CONFIGURATIONS

All poles in an overhead electric system are not equally likely to be lethal to raptors (APLIC 1996, Lehman 2001, Schomburg 2003). I wanted to know which pole types in Tucson were the most likely to be lethal because TEP could use that information to proactively retrofit those poles types. To asses this, I collected information on the pole top configuration of all poles known to be involved in avian electrocutions occurring in Tucson, Arizona from 1 February 2003 through 30 September 2004. All calculations in this appendix compare the configurations involved in the electrocutions I documented to proportions of the total system (provided by TEP, personal communication). I include all confirmed electrocutions of all species gathered both around and away from monitored nests where the configuration of the pole involved was identified (*n*=122).

RESULTS

I detected electrocutions on both distribution (1, 2, and 3 phase) and transmission structures. There is no significant difference between the construction of the system at this level and the proportion of electrocutions (X^2 = 4.2, P = 0.24, DF = 3) (Figure D1). However, when only the voltage of distribution structures is considered, the 8 kV portions, which account for 75% of the system and 98% of electrocutions are found to be more lethal to raptors than the 4 kV portions, which account for 25% of the system and 2% of incidents (X^2 = 35.5, $p \leq 0.001$, DF = 1).

There are about 100,000 distribution poles in the study area, and 25% of these support at least one transformer. Transformers were present on 66% of the poles that electrocuted raptors. Poles supporting transformers are significantly more likely to electrocute a raptor than poles which do not support transformers ($X^2 = 149.8$, $P \leq 0.001$, DF = 1), but transformers are not the only potentially lethal point on those poles. Eighty six incidents were detected on poles supporting transformers, but of those, only 10% were found to have definitively occurred on the transformer (as indicated by "flash marks"), whereas 11% did not. For the remainder, no evidence could be identified to discern whether the transformer was involved or not. An additional 4% of incidents occurred on poles which supported hardware typically associated with transformers (fused cutouts, lightning arrestors, etc.), but no transformer. Thus, while poles supporting transformers are more likely to be lethal, the danger is not restricted to the transformer.

Of 122 confirmed electrocutions, 9% occurred on retrofitted poles. Of these 11 incidents, 64% occurred on poles where only a transformer and the energized jumper connecting it to the rest of the system had been insulated, but no other portions of the pole had been modified. Another 18% occurred on partially modified poles where the transformer and additional equipment was modified, but a potentially lethal point remained, and 18% occurred when a bushing cover slipped away from a bushing and exposed the energized conductor within. Tracking problems can be exacerbated by inclement weather, and while rain was almost certainly a factor in 4% of incidents, and may have been a factor in another 4%, none of these incidents involved retrofitted poles, and no incidents occurred as a result of current arcing through or over raptor protective equipment.

DISCUSSION AND CONCLUSIONS

When a nest site is identified, all poles within 300 m should be evaluated regarding their potential lethality to raptors, regardless of the number of phase wires a pole supports or whether poles are part of transmission or distribution systems. When two or more nests are found and must be prioritized, the relatively large number of electrocutions occurring on 8 kV portions of the distribution system indicates that nests in these areas should be addressed first. Poles which support transformers should be also be high priority, but it must be recognized that the transformer itself may not be the only potentially lethal point on the pole.

Poles were modified with a variety of devices, but I was not notified of where, when, or how many devices were installed, thus I could not track them quantitatively. However, I do have a qualitative sense of the effectiveness of these devices: bushing covers which wrapped around transformer bushings were used successfully to insulate, not just transformers, but the energized portions of lightning arrestors and fused cutouts as well. Line hose was used in association with bushing covers to insulate energized jumpers, when retrofitting existing equipment, and insulated wire was used to prevent avian electrocutions on new installations. Insulating covers intended for center phases were unreliable until a model was identified which adhered to the specific gauge and type of phase wire used in the TEP system. Insulated links effectively prevented phase to ground faults through ground wires. TEP experimented with supplemental perches, but I found that hawks did not reliably select these perches over other, potentially lethal, portions of a structure. Thus these perches did not effectively prevent electrocutions by themselves, but they did function effectively as part of a complete retrofit.

Some of the equipment experimented with during this study failed to meet required standards of durability, longevity, and effect, but I would not know this if I had not monitored retrofitted poles. When new brands or models of equipment are installed to prevent the electrocution of raptors on an overhead system, that new equipment should be evaluated regularly to verify that it functions as intended.

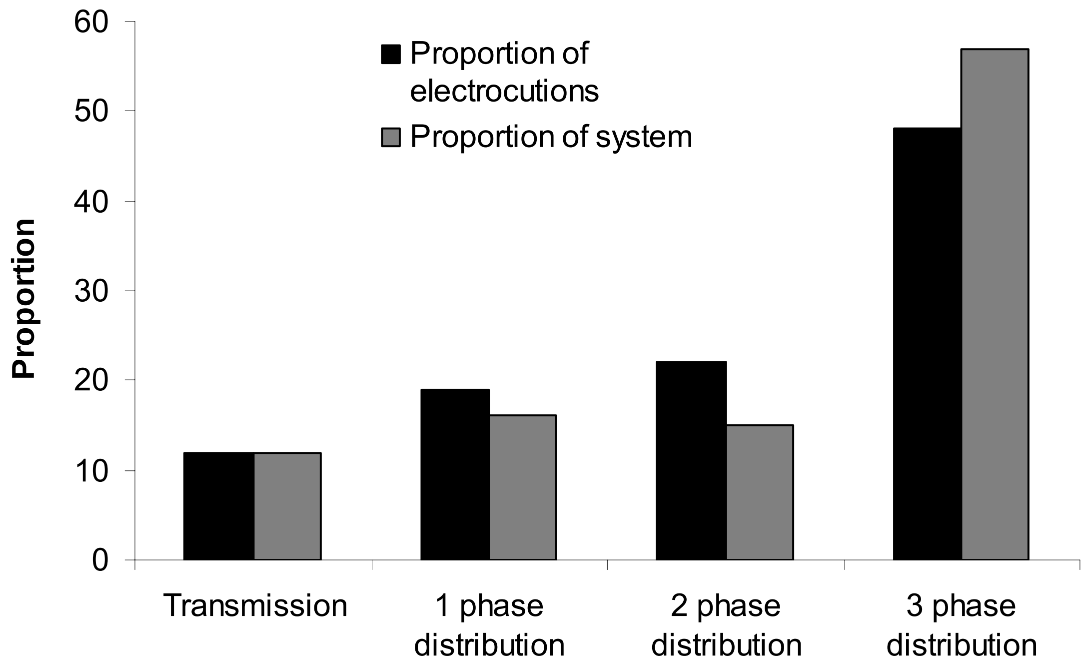

Figure B1) Proportion of electrocutions vs. proportion of the electric power system in Tucson, Arizona, USA, from 1 February 2003, through 31 August 2004 (n=122 electrocutions, and an estimated 111,300 poles).

APPENDIX C:

DISAPPEARANCE RATES OF RAPTOR CARCASSES IN AN URBAN ENVIRONMENT

Mortality is one of the most important aspects underlying population dynamics (Rickleffs 2000), and causes of mortality often differ markedly in different environments (DeVault et al. 2003), largely as a function of community structure (Houston 1995). Understanding mortality often hinges on the ability to find carcasses and diagnose the cause of death. When carcasses go unnoticed or unreported, estimates of mortality may be skewed or underestimated. Scavenging by terrestrial vertebrates has been implicated as a major reason carcasses disappear (Devault et al. 2004, Kostecke et al. 2001). The purpose of this study was to evaluate the persistence of carcasses of birds of prey (raptors) in an urban landscape, and to asses how carcasses disappear.

STUDY AREA AND METHODS

Tucson supports a diverse assembly of potential terrestrial mammalian scavengers, including coyote *(Canis latrans)*, domestic dog *(Canis familiaris)*, skunk *(Mephitis mephitis* and *Mephitis macroura)*, and bobcat *(Lynx rufus)*, as well as an array of potential avian scavengers including; great-horned owl *(Bubo virginianus)*, red-tailed hawk *(Buteo jamaicensis)*, common raven *(Corvus corax)*, and turkey vulture *(Cathartes aura)*.

Since electrocution may be a significant agent of mortality to raptors in Tucson, and since victims of electrocution often are found at the base of the power pole on which they were killed, I was able to mimic and observe the location of typical mortalities in a way few previous studies have done (DeVault et al. 2003). As part of a larger study investigating electrocution, I monitored urban-nesting Harris' hawks in a metropolitan area. In doing so, I delivered letters to all properties within 300 meters of nests to inform residents that there was a Harris' hawk nest in the area and to request that I be contacted in the event that anyone discovered a dead or injured raptor. Eight weeks after the young from a given nest had fledged, I placed the carcass of a raptor at the base of the nearest "safe" power pole to the nest. Safe poles were defined as poles where all exposed, differentially energized conductors where separated by at least 61 cm. These locations were selected to minimize the possibility that avian scavengers would be electrocuted as a result of our study. Raptor carcasses were donated by wildlife rehabilitators only after efforts to treat these bird's critical injuries had failed.

I visited carcasses daily for one week, and every other day for another week, to determine whether the animal had been moved or removed and to try to decipher what may have moved it. I also responded to calls when residents reported carcasses by explaining this portion of the project to the resident (it was not mentioned in our letter), and collecting the carcass. To minimize human scent at carcasses and any attention I might attract, I observed carcasses through binoculars from >15 m during routine checks, and only approached more closely if the carcass appeared to have been moved or disappeared. On each visit, carcasses were recorded as unmoved, moved but still within 7.6 meters of the base of the pole, or moved beyond 7.6 m (disappeared). I classified carcasses as within or beyond 7.6 m from the base of the pole because avian electrocution fatalities are typically sought within this distance (as in Harness 1999). I searched a radius of 25 m from the pole for missing carcasses to try to determine what may have removed them.

In exurban habitats, Kostecke et al. (2001) found that the size of a carcass had no impact on the rate at which it was scavenged, even for species as different in size and appearance as house sparrows *(Passer domesticus)* and ring-necked pheasants *(Phasianus colchius)*. However, I suspected that in an urban environment, passerines and smaller hawks might not be as likely to be noticed, investigated, or reported by human residents. In an effort to mimic as closely as possible the carcasses of Harris' hawks around whose nests I was working, I limited experimental carcasses to Harris' hawks, red-tailed hawks, Coopers' hawks (female only) *(Accipiter cooperii)*, and great-horned owls.

RESULTS

I placed 23 carcasses near nests at distances ranging from 7 to 220 m (Table E1). Of these, 26% disappeared within 1 day, 35% disappeared within 3.5 days, 39% were gone in 1 week, and 43% were gone in 2 weeks (Figure E1). An additional 22% of carcasses were reported by residents within 1 day, and 30% were reported within 3.5 days.

No reported carcasses showed evidence of having been scavenged by wildlife prior to being collected, and only one carcass was definitively removed by wildlife. The remains of this carcass were found scattered 7-15 m away. Three carcasses were found >7.6 m from the base of the pole where I had left them, and were classed as "removed." Each of these was removed by humans: one was buried, with a makeshift cross placed above the grave, one was placed in a trash can, and one was apparently thrown over a fence and adjacent hedge into a vacant lot. Overall, 43% of carcasses were encountered by residents and either removed or reported prior to being consumed by scavengers, while only 4% of carcasses were encountered by scavengers and consumed prior to being removed by humans. Another 26% of carcasses were never reported, removed, or consumeded, and the fate of the remaining 27% could not be assessed.

DISCUSSION AND CONCLUSIONS

If I searched for carcasses only once each week (as I did around monitored nests), one out of three carcasses would have disappeared before I encountered them. If I searched monthly, I would have failed to detect nearly half. If I assume that the carcasses reported by residents would have been disposed of by those residents if they had not known to call me, I find that 74% of carcasses would have disappeared between visits. Exurban studies of terrestrial scavenging have found non-human terrestrial vertebrates to be the primary scavengers, with about 75% of carcasses disappearing in 22 studies (DeVault 2003, Devault et al. 2004). The proportion of scavenged carcasses are similar in this study, but I found that humans are the primary species to encounter and remove carcasses in my urban study area. Human residents expressed surprise at my interest in carcasses, and many relayed that they had previously encountered raptor carcasses and had disposed of them as garbage. Since I notified residents of my study, the rate of reporting described herein is expected to be high, reflecting a best-case scenario of public input. I suggest that future studies conducted in urban areas avail themselves of this resource.

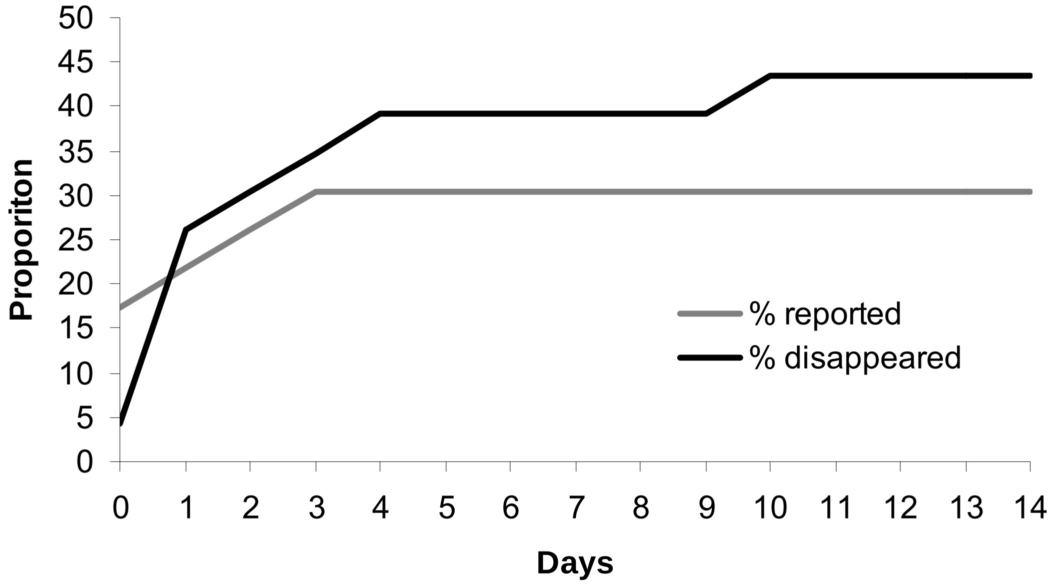

Figure C1. Cumulative percent of carcasses removed and carcasses reported from adjacent to Harris' hawk nests in Tucson, Arizona, USA as a function of time from 2 September, 2003 through 16 August, 2004 (*n*=23).

Table C1. Summary of experimentally placed carcass data collected in Tucson, Arizona, USA, from September 2, 2003 through August 16, 2004 (distance reported in meters).

Placement Date	Disappeared on day #	Removed by	Distance from nest	Direction from nest	Carcass Species
6/28/2004	0	undetermined	45	S	RTHA
6/17/2004	0	me - reported	100	NE	RTHA
6/28/2004	0	me - reported	60	N	COHA
7/2/2004	0	me - reported	160	S	GHOW
7/19/2004	0	me - reported	60	SE	COHA
8/4/2004	1	undetermined	45	NW	COHA
8/16/2004	1	undetermined	140	S	COHA
7/2/2004	1	undetermined	100	SE	COHA
9/2/2003	1	human	30	SW	GHOW
1/3/2004	1	human	130	NW	RTHA
7/5/2004	1	me - reported	7	S	GHOW
7/14/2004	2	undetermined	95	N	COHA
7/19/2004	2	me - reported	65	N	RTHA
6/7/2004	3	undetermined	220	N	COHA
7/14/2004	3	me - reported	105	E	RTHA
7/19/2004	4	wildlife	205	S	RTHA
1/4/2004	10	human	85	NW	HRSH
9/4/2003	never	N/A	20	SW	COHA
5/31/2004	never	N/A	40	E	GHOW
6/11/2004	never	N/A	120	W	GHOW
6/11/2004	never	N/A	205	E	COHA
7/12/2004	never	N/A	25	S	GHOW
8/4/2004	never	N/A	35	S	RTHA

APPENDIX D:

DIFFERENTIAL RETURN OF ALUMINUM AND PLASTIC BANDS FROM ELECTROCUTED HARRIS' HAWKS

I wondered if the activities of raptor banders might increase the risk of electrocution to banded birds. In 2001 in North America, 43,249 hawks and owls were marked, mostly with aluminum leg bands (United States Fish and Wildlife Service Bird Banding Laboratory 2004). These bands are conductive, and I wanted to know if wearing one might increase the probability that a raptor would be electrocuted. To address this question, I fitted Harris' Hawks *(Parabuteo unicinctus)* with either standard United States Fish and Wildlife Service (USFWS) aluminum, or uniquely coded plastic leg bands, or both, and compared differences in the circumstances of death for banded individuals and probability of band recovery.

METHODS

From 1 February 2003 through 31 May 2004, I banded Harris' hawks in Tucson, Arizona. Hawks were captured with a bal-chatri trap (Bloom 1987), fitted with bands sizes 7A or 7B, and released. As part of a larger study, females received bands featuring white characters on a black background, and males received bands featuring white characters on a green background. All colored bands were uniquely numbered with characters 0.5 cm tall and could be read with 8x42 binoculars at distances of up to 20 meters. Trapping sessions lasted from 30 minutes before sunrise to 2 hours after sunrise.

To verify that plastic bands would be retained, the first 10 hawks I captured were fitted with both a USFWS lock-on aluminum band on one leg, and a uniquely numbered plastic wrap-around band on the other. All other birds were randomly assigned either an aluminum or a plastic band.

Tucson is a city and suburban assemblage of about 1,000 km^2, which supports a population of about 900,000 people (Pima association of governments 2004). To locate carcasses I notified area residents, birdwatchers, falconers, wildlife rehabilitators, and county, state, and federal personnel of my interest in recovering dead raptors, and encouraged them to contact me if they discovered a carcass. I also searched for electrocuted hawks in areas of 7.6 meter radius (as in Harness 1999) around the bases of a sample of poles within the territories of banded birds. Diagnoses of electrocution were made as described by Hass (1993), Dawson and Mannan (1994), and Koumbourlis (2002).

RESULTS

Of 89 banded Harris' hawks, I recovered 19%. Of 10 birds fitted with both aluminum and plastic leg bands, I recovered 20%. I recovered 12% of the 41 birds wearing only aluminum bands, and 26% of the 38 birds wearing only plastic bands. I banded 44 males and 45 females, and recovered 10% and 29%, respectively. Of my 17 recoveries, 65% were electrocuted, 29% were suspected to have been electrocuted, and 6% (1 bird) was believed to have died while investigating and becoming trapped in an open and set, but unattended medium-sized mammal trap left near its nest. Seven of 11 confirmed electrocuted Harris' hawks were wearing plastic bands only when they were electrocuted. The other four were wearing metal bands only. Nine of 11 electrocuted birds were female. Of these, one had fledged in that calendar year, two had fledged in the previous year, and six were adult females at least 2 years old. None of the bands on the carcasses of either confirmed or suspected electrocuted hawks showed evidence of having served as a conduit for electric current (i.e., no bands or adjacent tissues were melted or burned). Rather, burns on carcasses were found most often on the soles and toes and were the result of standing directly on un-insulated hardware. I found one banded carcass while searching territories. The remaining 16 were reported to me by human residents, either directly or through the Arizona Game and Fish Department. I encountered and collected the electrocuted carcasses of an additional 64 un-banded Harris' hawks in the study while I gathered data on banded birds.

Because birds wearing both metal and plastic bands confounded return data, they are excluded from analyses. More plastic bands were returned, and more birds wearing plastic bands only were electrocuted. However, there is no evidence that either plastic or metal bands are more likely to contribute to the electrocution of a raptor (X^2=1.23, P=0.266, DF=1). More females were also returned, and there is strong evidence that females were more likely to be electrocuted (X^2=4.97, P=0.025, DF=1).

DISCUSSION AND CONCLUSIONS

Electrocution does not affect banded birds only, and leg bands do not appear to be involved in electrocution incidents. Thus I do not suggest that the banding of raptors be reevaluated on these grounds. To the contrary, the increased visual stimulus of brightly colored bands may increase the likelihood that the band will be noted by a member of the public, and reported. The idea that high visibility leads to an increased return rate is supported by the result that more females were returned. In Harris' hawks, females average approximately 50% larger (Dawson 1988), and that size difference may make them more visible as carcasses on the ground. It probably also contributes to their greater likelihood of electrocution (Janss 2000, Lehman 2001). The high proportion of mortalities detected through banding emphasizes the need to further refine retrofitting techniques for utility poles in Tucson, and to implement these refinements thoroughly.

APPENDIX E:

ELECTRIC SHOCK INJURIES IN A HARRIS' HAWK POPULATION

Contact with electricity on utility poles does not always kill raptors. Rather, some individuals may survive with an electric shock injury (ESI). ESIs have not been reported in field studies of raptors, but wildlife rehabilitators treat these injuries regularly in some environments (e.g., Phoenix and Tucson, Arizona; Arizona Game and Fish Department, unpublished data). The effects of ESIs on raptors is unknown, but even minor changes in wing shape, wing loading, or the profile of a flying bird handicaps aerial performance in passerines (e.g., Norberg 1995, Kullberg et al. 1996, Hedenstrom 2002), and raptors may be similarly affected. If electric shock injuries are as prevalent as electrocution mortality data suggest (Ferrer et al. 1991, Harness and Wilson 2001, Real and Manosa 2001, Donazar et al. 2002, Wayland et al. 2003, Garrido and Fernandez-Cruz 2003), then effects of electrocution on some raptor populations may be underestimated. I wanted to know if ESIs might exist in raptors which appear normal from a distance to human observers on the ground.

METHODS

I located Harris' Hawks by driving through and between known territories, and captured birds with a bal-chatri trap (Bloom 1987). Trapping sessions lasted from 30 minutes before sunrise to 2 hours after sunrise, and all captured animals were sexed by weight, aged by plumage, banded, photographed, and released. I examined each individual for evidence of electric shock injuries as described in Dawson and Mannan (1994), and Koumboulis (2002). These injuries consisted of the absence or charring of the tail feathers, toes, feet, legs, wings, or face. If charring was present, I considered the wound a confirmed electric shock injury. If a wound typical of an ESI (e.g., a missing foot or wingtip) no longer exhibited charring, I considered it a suspected electric shock injury. An unexpected blind trial served to support these diagnoses: two individuals exhibiting confirmed injuries at the time of their first capture were recaptured. Both were listed as having suspected electric injuries when recaptured until their banding records were retrieved, and their prior conditions verified.

RESULTS

I captured 89 Harris' hawks; 49% were male, and 51% female. Fifteen showed either confirmed (9%) or suspected (8%) electric shock injuries to the fore limbs, hind limbs, face, tail, or a combination thereof. Of these, one was a second year male, four were hatch year females, four were second year females, and six were after second year females. Females were significantly more likely to be suffering from ESIs than males (X^2=13.2, $P < 0.001$, DF=1); only 2% of males, but 31% of females exhibited either confirmed or suspected ESIs. I found no significant pattern in the presence of electric injuries by age.

DISCUSSION AND CONCLUSIONS

I found a high proportion of female Harris' hawks suffering from ESIs. Because Harris' hawks in Tucson are social and non-migratory, they may be more likely than other species to persist with ESIs (injured birds may be provisioned by group mates, and non-migratory birds may be able to move within territories, but not fly long distances). Injured animals may also be more likely than healthy animals to strike at novel prey, and thus more likely to attack a bal-chatri trap. Therefore, my estimate of the proportion of animals with ESIs may be high. Nevertheless, animals with ESIs appear to persist in the population and these injuries are likely to increase the energetic cost of flight, and reduce the aerodynamic performance of affected individuals. Survival and fecundity may be affected in turn, and it is particularly troublesome from an ecological perspective that breeding females may be forced by these injuries to divert resources into survival and away from reproduction.

If electric shock injuries exist in other raptor populations, as electrocution mortality data suggest, then biologists could be underestimating the total effect of electrocution, especially if analyses of effective population sizes are count based. Personnel working with raptors and other large birds should look for electric shock injuries in the animals they handle, and report injuries they encounter.

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