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QUANTIFYING SOURCES OF MORTALITY AND WINTERING RANGES OF GOLDEN EAGLES FROM INTERIOR ALASKA USING BANDING AND SATELLITE TRACKING

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Abstract.—Documenting the year-round movements and factors affecting the survival of wide-ranging birds is essential for developing effective conservation strategies. This is especially true for long-distance migratory species that spend much of their lives away from their breeding areas. Encounters of banded birds have provided information on the movements and survival of many bird species. More recently, telemetry studies provided new information on movements and survival of migratory birds. Golden Eagles (*Aquila chrysaetos*) raised in the higher latitudes of northwestern North America are usually migratory, but little is known about their year-round movements or survival. From 1988 to 2009, I banded 307 Golden Eagle nestlings in and near Denali National Park and Preserve in interior Alaska. From 1997 to 1999, I also deployed 90-g satellite transmitters on 48 of these eagles just before they fledged. Ten of the 307 banded eagles (3%) were encountered after the banding event, including five within 1 yr of banding. All encounters with banded eagles were >800 km from the banding location outside Alaska during winter or the migration season. All banded eagles were encountered <2 km from a road or human settlement and the primary sources of mortality were electrocution and shooting. In contrast, all recoveries of dead radio-tagged eagles (14) were >5 km from a road, and post-mortem necropsy indicated that all but one of these eagles died from starvation. Locations of banded eagles encountered in winter ranged from southern Alberta to north-central Mexico. Relocations of radio-tagged eagles in winter ranged from central Alberta to southeastern New Mexico. These results, despite small sample sizes, demonstrate how different marking and tracking tools can produce different results regarding the sources of mortality and the wintering range of Golden Eagles from the same study area.

Key Words: *Golden Eagle*; Aquila chrysaetos; *banding*; *mortality*; *satellite telemetry*; *winter range.*

CUANTIFICACIÓN DE LAS FUENTES DE MORTALIDAD Y DE LOS RANGOS DE INVERNADA DEL ÁGUILA *AQUILA CHRYSAETOS* EN ALASKA UTILIZANDO ANILLAS Y RASTREO SATELITAL

Resumen.—La documentación de los movimientos durante todo el año y de los factores que afectan la supervivencia de las aves con grandes rangos de distribución es esencial para el desarrollo de estrategias efectivas de conservación. Esto es especialmente cierto para las especies que migran grandes distancias y que pasan gran parte de sus vidas lejos de sus áreas de cría. Los encuentros de aves anilladas han proporcionado información sobre los movimientos y la supervivencia de muchas especies de aves. Más recientemente, los estudios de telemetría han proporcionado nueva información sobre los movimientos y la supervivencia de las aves migratorias. Las águilas *Aquila chrysaetos* que se criaron en las latitudes más altas del noroeste de América del Norte son generalmente migratorias, pero se sabe poco acerca de sus movimientos durante todo el año o sobre su supervivencia. De 1988 a 2009, anillé 307 polluelos del águila *A. chrysaetos* cerca del Parque Nacional y Reserva Denali en el interior de Alaska. De 1997 a 1999, también usé transmisores satelitales de 90 g en 48 de estas águilas, justo antes de que emplumaran. Diez de las 307 águilas anilladas (3%) se encontraron después del evento de anillamiento, entre ellas cinco dentro del año de anillamiento. Todos los encuentros con las águilas anilladas fueron a >800 km de la ubicación de anillamiento y se encontraron fuera de Alaska durante el invierno o la temporada de migración. Todas las águilas anilladas se encontraron a <2 km de una carretera o de asentamientos humanos y las fuentes principales de mortalidad fueron la electrocución y disparos. Por el contrario, todas las recuperaciones de los individuos muertos equipados con radiotransmisores (16) estuvieron a >5 km de una carretera, y el análisis post-mortem indicó que todas

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estas águilas, menos una, murieron de hambre. La ubicación de las águilas anilladas encontradas en invierno fue desde el sur de Alberta al centro-norte de México. La ubicación de las aves con transmisores durante el invierno fue desde el centro de Alberta al sudeste de Nuevo México. A pesar de los tamaños de muestra pequeños, estos resultados demuestran cómo diferentes herramientas de marcado y de seguimiento pueden producir resultados diferentes en cuanto a las fuentes de mortalidad y del rango de invernada de *A. chrysaetos* de la misma área de estudio.

[Traducción del equipo editorial]

Documenting the year-round movements of wide-ranging birds is essential for identifying factors that influence their survival and for developing robust conservation strategies for their populations (Steenhof et al. 1984, Higuchi et al. 2004, Steenhof et al. 2005). This is especially true for migratory species from northern latitudes that spend much of their lives away from their breeding areas. Golden Eagles raised in the northern latitudes of northwestern North America (interior and northern Alaska, Yukon, and Northwest Territories) are usually migratory, but little is known about their movements or survival (Kochert et al. 2002, McIntyre et al. 2006, 2008, Watson 2010).

Banding has been used for many decades to identify individual birds. Encounters of banded birds can provide information regarding survival, sources of mortality, and locations of migration routes and both breeding and wintering areas. Banding studies have made important contributions to the understanding of movements and survival of Golden Eagles in parts of their range (Harmata 2002). Newer active-tracking tools, including satellite-based tracking and global positioning system tracking (GPS), also are being used to study the movements and sources of mortality of Golden Eagles (McIntyre et al. 2006, 2008) and many other birds. These active-tracking tools are revealing new and exciting results about bird migration.

Results from both banding and telemetry studies have helped protect raptors and their habitats around the world (Bildstein 2006), but few studies have compared results of encounters with birds banded and radio-marked in the same study area to determine whether the results generated by two different methods differ (Thorup et al. 2003).

Here I use data from banding and satellite telemetry studies to compare the sources of mortality and wintering ranges of Golden Eagles from Denali National Park, Alaska (Denali). Banding is a passive tool and required someone to encounter a band and report it. Telemetry is an active-tracking tool that did not require someone to encounter the marked bird.

Methods

Golden Eagle nestlings were banded and radio-marked at nests in the northern foothills of the Alaska Range in and near the northeastern portion of Denali (63°35.8′N, 149°38.2′W; McIntyre et al. 2008). I entered occupied nests from late June through late July 1987 to 2009 using standard rock-climbing techniques and banded nestlings with U.S. Geological Survey (USGS) size nine rivet leg bands. All eagles were banded under the authority of the USGS Bird Banding Laboratory (BBL) and the state of Alaska. I submitted banding records to the BBL at the end of each calendar year. The BBL sent me a band encounter report when they received information about an encounter with a banded Golden Eagle, and I then contacted the person who found the banded eagle to obtain additional information, including source of mortality and the specific location of the encounter. Here, I consider a band encounter as any event where the band number was documented, regardless of the condition of the eagle (i.e., dead, injured, or captured) following Harmata (2002) and the Bird Banding Lab (www.pwrc.usgs.gov/bbl/manual/glossary.cfm).

From 1997 to 1999, I radio-marked 48 nearly-fledged Golden Eagles (21 in 1997, 5 in 1998, and 22 in 1999) with 95-g satellite transmitters (PTTs; Microwave Telemetry, Columbia, Maryland, U.S.A.) and used the ARGOS satellite tracking system to monitor their movements. I also banded the eagles with U.S. Geological Survey (USGS) size nine rivet leg bands. The mass of the entire radio-package, including harness, was within the conventional guidelines for telemetric studies of birds (Caccamise and Hedin 1985). Methods used to recover and necropsy dead radio-marked eagles are summarized in McIntyre et al. (2006).

Results

Ten of 307 banded eagles (3%) were encountered after banding, including five birds encountered within 1 yr of banding (50% of all encounters; Table 1). All encounters of banded eagles were >800 km from the banding location, outside of Alaska, and all but one occurred during winter or the migration season (Ta-

Table 1. Summary of encounters of Golden Eagles banded as nestlings in and near Denali National Park and Preserve, Alaska, 1987 to 2009.

Encounter Date	General Encounter Location	Encounter Age	Encounter Condition	Cause of Death
February 1999	San Luis Potosi, Mexico	<1 yr	Alive	NA
April 1994	Paradise, Kansas, U.S.A.	<1 yr	Dead	Shot
November 1999	Pincher Creek, Alberta, Canada	<1 yr	Dead	Electrocuted
December 1988	Lamar, Colorado, U.S.A.	<1 yr	Dead	Electrocution
December 2003	Muzquiz, Coahuila, Mexico	<1 yr	Dead	Unknown
June 1997	Destruction Bay, Yukon, Canada	<1–2 yr[a]	Dead[a]	Unknown
March 1993	Brighton, Colorado, U.S.A.	4 yr	Dead	Electrocution
July 1994	Laguna Del Rey, Coahuila, Mexico	4 yr	Alive[b]	NA
March 1995	Ringling, Montana, U.S.A.	6 yr	Alive[c]	NA
March 2001	Ringling, Montana, U.S.A.	10 yr	Alive[c]	NA

[a] Eagle found as decomposed carcass and date of mortality could not be established.
[b] Eagle found alive but injured; final fate was unknown.
[c] Captured and released by A. Harmata during spring migration research project.

bles 1). Six banded eagles were dead when encountered (Table 1). Causes of death included electrocution, shooting, and unknown (Table 1, 2). Four banded eagles were encountered alive, including two eagles captured during spring migration in Montana and two eagles found alive, one injured and one captured in a turkey pen, in Mexico (Table 1). In contrast, all recoveries of dead radio-tagged eagles (16) were >5 km from a road and postmortem necropsy of 13 of these eagles indicated that all but one died from starvation (Table 2; McIntyre et al. 2006).

The extent of the winter range based on band encounters and telemetry relocations was different and barely overlapped. Winter encounters of banded eagles ($n = 4$) occurred from latitude 23° to 40°N ($\bar{x} = 32.2$°N, SD = 8.1°). In contrast, winter deaths of radio-tagged eagles ($n = 9$) occurred from latitude 45° to 60°N ($\bar{x} = 53.4$°N, SD 4.2°): relocations of radio-tagged eagles that survived their entire first winter ($n = 14$) ranged from 32° to 54°N ($\bar{x} = 46.1$°N, SD = 5.3°); and relocations of radio-tagged eagles that survived three winters ($n = 3$) ranged from 43° to 48°N).

Discussion

The percentage of banded Golden Eagles encountered during this study (3.2%) was lower than that in most other studies reporting encounter rates for this species (see Harmata 2002). The low encounter rate was not surprising because Golden Eagles from Denali migrate across vast expanses of relatively undeveloped areas in western North America (McIntyre et al. 2008) where the density of people is very low; hence, the probability of someone encountering a banded Golden Eagle in these areas is presumably very low. The highest encounter rate (50%) occurred within 1 yr after banding. In the Rocky Mountains, the highest encounter rate (12.2%) occurred 3 yr after banding (Harmata 2002).

Most cases of mortality of Golden Eagles are attributed to direct or indirect human causes (Franson et al. 1995, Watson 2010). Reports of death as a result of natural causes in free-flying Golden Eagles are rare and mostly anecdotal (Watson 2010). Encounters with Golden Eagles banded in Denali supported these conclusions, but results from the Denali satellite telemetry study provided a striking contrast. All banded-bird mortality was directly linked to human causes, whereas starvation was the most common proximate cause of mortality in radio-marked eagles. Evidence for starvation as a cause of death of Golden Eagles is difficult to find (Watson 2010); it was accomplished in this study by retrieving and performing necropsies on a sample of the eagles that died. I do not know if starvation was caused indirectly by human-related factors, but I could not rule out the possibility that some of the starvation deaths were caused by the added mass of the transmitter or a negative effect caused by the harness (see below).

Three radio-tagged Golden Eagles (23%) had elevated levels of lead (Pb), but levels were not in the range normally considered consistent with the diagnosis of lead toxicity (McIntyre et al. 2006). I could not exclude the possibility that Pb exposure influenced survival and indirectly led to starvation, and Pb exposure may have impaired the ability of birds

Table 2. Cause of death of Golden Eagles banded and radio-marked as nestlings in Denali National Park and Preserve, Alaska, 1987 to 2009.

Cause of Death	Banded	Radio-marked
Electrocution	3	1
Gunshot	1	0
Starvation	0	9
Poached	0	1[a]
Unknown	2	3
Total	**6**	**14**

[a] Based on the encounter (the PTT was cut off the eagle and found in a dumpster), we assumed that the eagle had been poached (McIntyre et al. 2006).

to hunt, obtain food, and digest food (Wayland et al. 2003, McIntyre et al. 2006). Further, negative effects of the 90-g PTT and backpack-style harness may have confounded the effects of Pb exposure.

Encounters with banded birds provided new information regarding the extent of the winter range of Denali's Golden Eagles, particularly movements east into the Great Plains and south into Mexico. Relocations of radio-tagged eagles also provided new information regarding the extent of the winter range (McIntyre et al. 2008), but no radio-tagged eagles were relocated in Mexico. This was surprising because three of the 10 banded eagles were encountered in Mexico. Further, the locations of both the radio-tagged eagles that died and those that survived their first winter tended to be further north than encounters of banded eagles, suggesting that the PTTs may have affected the mobility of the radio-tagged eagles. However, the winter ranges of three Golden Eagles that made three round trips from Alaska to their respective wintering ranges were all farther north (range = 43° to 48°N) than any of the encounters of banded birds made during winter (range = 23° to 40°N; C. McIntyre unpubl. data).

Banding did not provide any information about the extent of the summer range and little insight into the migration corridors of Denali's Golden Eagles; no band encounters were made during summer and few were made within migration seasons. In contrast, radiotelemetry provided new and exciting information regarding the summer ranges and migration corridors, as well as the migratory behavior, of nonbreeding Golden Eagles (McIntyre et al. 2008).

Overall, new information on both mortality sources and the wintering ranges of Golden Eagles were gathered by both methods. The low band-encounter rate (3.2%) suggested that banding may not be an effective tool to study survival or movements of long-distance migratory eagles unless researchers make efforts to increase encounter rates.

Researchers need to carefully evaluate and select the tools they use to answer their research questions. The selection of a research tool depends on the questions being asked, the scope of the study, and the geographic location of the study. Banding a larger number of Golden Eagles may result in more encounters, but estimates of survival may not be reliable unless large samples of banded eagles are encountered. Further, banding studies may still result in sources of mortality being biased toward human-related factors and other sources of mortality may go undetected in areas where the probability of encountering a banded eagle is low. Using auxiliary markers, such as patagial markers, may increase encounter rates in areas where encounter rates are expected to be high (Steenhof et al. 1984), but patagial marking is a passive technique that requires someone to observe and report their encounter with the marked bird. It is probably not an efficient tool to use for studying long-distance migratory eagles. These results suggest that radiotelemetry or other types of active tracking may be more efficient tools for studying the survival and movements of long-distance migratory Golden Eagles.

Although these studies were not designed to evaluate the impact of radio-tagging on Golden Eagles, the differences in the sources of mortality and the southern extent of banded and radio-tagged eagles may provide some insights on the potential adverse affects of radio-tagging juvenile Golden Eagles. For example, the low survival rates during the first autumn migration (85%) and winter (84%) and the high proportion of mortalities caused by starvation (McIntyre et al. 2006) might be partly explained by negative effects caused by the radio packages. Unfortunately, no contemporary estimates of survival of juvenile migratory Golden Eagles from other areas are available to test that hypothesis and starvation in Golden Eagles is rarely documented (Watson 2010). Further, the tendency for radio-tagged eagles to winter farther north than banded eagles may also point to a possible negative effect of the PTTs, but the very small sample size of encounters with banded eagles does not allow for a statistically valid comparison.

Several radio-tagging studies that used backpack-style harnesses to attach radio transmitters to free-flying eagles reported no apparent evidence of negative impacts to the eagles (Buehler et al. 1991, Wood 1992, Bowman et al. 1995, Hunt et al. 1996, McIntyre et al. 2006). This, however, does not mean that there was no effect. For example, McIntyre et al. (2006) did not find any physical abrasions caused by the harness on recovered radio-tagged eagles, but this does not mean that the radio package did not have adverse effects on the eagles. Many studies have identified the adverse effects of radio tagging on birds (Barron et al. 2010), including raptors (Steenhof et al. 2006 and references cited within), but no studies have carefully evaluated the cumulative and long-term effects of radio tagging on Golden Eagles (K. Steenhof pers. comm.). Recent concerns about the effects of large-scale wind farms on Golden Eagles in western North America has spurred substantial interest in new radio-tagging studies to evaluate these effects. Many of these studies will use backpack-style harnesses to attach radio-transmitters and other tracking devices on Golden Eagles. A fundamental assumption of survival estimation from radiotelemetry data is that the radio-tagged animals have the same survival probability as animals without radio transmitters (White and Garrott 1990). Researchers must thoroughly evaluate the potential adverse affects of any tracking device or tags on Golden Eagles before implementing their studies. Carefully planned pilot studies are needed to evaluate the potential adverse impacts of radio-tagging Golden Eagles.

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