Migration and Summer Ranges of Golden Eagles Tracked by Tail-Mounted Satellite Transmitters

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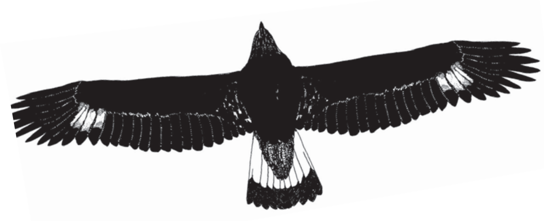
ABSTRACT

Six Golden Eagles (Aquila chrysaetos) *captured in Montana in late winter and early spring were tagged with satellite-tracked, Platform Transmitter Terminals (PTT) mounted on central tail feathers to evaluate tail-mounted systems as alternatives to backpack mounts, which may have negative effects on survival and behavior. Eagles were tracked to summer ranges in Montana, Alberta, British Columbia, and Alaska. Vernal migrations of Golden Eagles averaged 2,497 km, consuming an average 20 days to reach summer ranges. Eagles were tracked on summer range an average of 109 days. Mean 95% Kernel Density Estimate (KDE) summer range area for five eagles wearing Doppler shift PTTs was 2,151 km^2 (SD = 3,254), much smaller than one eagle that wore a GPS PTT (91,959 km^2). Summer range area was related to number of days tracked in the range (r_s < 0.77, P = 0.07). Two eagles were tracked on autumn migration a maximum of 4,167 km. End-of-movement of PTTs based on activity sensors showed juvenile/immature eagles tended to wear PTTs longer (= 216 da) than subadult/adult eagles (= 134 da). Two tail-mounted PTTs were molted and recovered while reason for end-of-movement for four others was unknown.*



INTRODUCTION

Knowledge of seasonal movements and ranges of Golden Eagles (*Aquila chrysaetos*) in western North America has increased exponentially since ca. 2005, mostly from use of satellite telemetry systems, either Platform Transmitter Terminals (PTT) or Global System for Mobile Communications units attached almost exclusively by backpack harnesses (Katzner et al. 2020). Despite recent evidence to the contrary (Garcia et al. 2021), some studies indicate backpack harnesses alter eagle behavior, survival, or reproduction (Gregory et al. 2003, Moss et al. 2014, Stahlecker et al. 2015). Tail-mounted PTTs have been shown to be effective in recording survival of resident Golden Eagles and are less likely to negatively affect individual Golden Eagles than backpack harnesses (Harmata et al. 2018). However, tail-mounted PTTs have not been deployed to record long-range movements of Golden Eagles that must undergo rigors of two 1500 to 4000 km seasonal migrations. The objectives of this study were to evaluate the utility of using tail-mount PTTs for recording long-range seasonal migrations and summer ranges of golden eagles captured in Montana as an alternative to backpack harness

METHODS

Free-flying Golden Eagles were captured with Coda net launchers (Coda Enterprises, Mesa, Arizona) or padded leg-hold traps (Miner 1975) baited with ungulate, lagomorph, or ground squirrel carcasses between 46^{o} 29’ and 45^{o} 25’ N latitude and 110^{o} 25’ and 112^{o} 15’ W longitude in Montana from Feb-Apr (2012-2015). Golden Eagles were sexed by size (Harmata and Montopoli 2013) and aged by plumage (Humphrey and Parkes 1959; Table 1 in Bloom and Clark 2001, Ellis 2004). Juvenile and immature (Basic I and II) age classes were combined as After Hatch Year (AHY) age class and subadult (Basic III) and adult age classes combined as After Third Year (ATY) age class to create larger group sizes for more meaningful comparisons.

Golden Eagles were tagged with one of two PTT configurations attached to center two rectrices. One was a 32 g, 63.5×22×18 mm Argos satellite transmitter powered by batteries (NorthStar Science and Technology, LLC, King George, VA), attached ventrally, which calculated eagle locations by Doppler shift. The other was a 22 g, 63×20×17 mm, photo-voltaic (PV) powered, Global Positioning System (GPS) capable satellite PTT (Model 22GPS, Northstar Science and Technology, LLC, King George, VA.) attached dorsally to expose the PV module to direct sunlight. Antennae on both units were 195 mm long and were sutured ventrally adjacent to one rachis (see Harmata 2016 for details). Duty cycles were 6 hr on, 2 da off for both PTT configurations. Both units provided up to seven eagle locations between 0800 and 2200 Mountain Standard Time. Eagles were banded with United States Geological Survey (USGS) size 8A or 9 pop-rivet leg bands under authority of USGS Federal Bird Banding Permit #20357.

PTT-generated location data (termed "fixes") were used to depict migration routes and summer ranges. Latitude-longitude coordinates from Doppler quality 3 and 2 category fixes (accuracy ±250, 500 m, respective) or GPS fixes (accuracy ±20-100 m) were tabulated sequentially in PTT Tracker (GeoTrack 2011). Sequential data were exported as Microsoft Excel files and displayed in 3D Maps module. Microsoft Excel files were converted to .csv format and imported into Google Earth. Distances (km) between sequential fixes were measured in Google Earth ruler module and were considered representative of direct movements.

Eagles that ranged widely (ranges > 55 km^2, e.g., Collopy and Edwards (1989)) and exited Montana after 15 April were considered migrants. Migrational movement was characterized by directional, sequential fixes >32 km in distance (Broduer et al. 1996). Migration distance was calculated along sequential fixes from capture site to center of summer range. Seasonal movements ≥ 1000 km were considered here as long-range migrations. Arrival in a summer range was inferred when movement was <140 km during two duty cycles (≥ 4 days) after long-range movements. Stop-over periods after departing Montana were defined here as fixes occurring within 10 km of each other over > 3 da. The lack of movement of a tail-mount PTT unit during one entire duty cycle as determined by PTT activity sensor indicated either a dead or debilitated eagle or a shed (i.e., molted or forcibly removed by eagle) PTT and was considered end-of-movement.

Kernel Density Estimates (KDE, Getz et al. 2007) of fixes were constructed using "PLUGIN" bandwidth estimator within the Geospatial Modeling Environment (Beyer 2014). Graphic contours (isopleths similar to geographic elevational lines) represented the smallest area where probability of relocating an individual was equal to 95%. KDE of 95% represented an individual's summer range. KDE was constructed from the time an eagle arrived on its summer range until end-of-movement or obvious initiation of autumn migration.

Due to small sample sizes statistical group comparison tests were avoided, but when deemed instructive, measures of central tendency are presented as mean ($\bar{x}$) and median ($\bar{x}$) and occasionally tested. Group differences were tested using nonparametric procedures (Mann-Whitney Z statistic, Spearman Rho (r_s)) in STATISTICAL version 13.3 (TIBCO 2017). When statistical tests were performed, P-values ≤ 0.15 were accepted to minimize Type II error and illustrate potential trend differences.

RESULTS

Six Golden Eagles were captured between early February and early April 2012-2015 and marked with tail-mount PTTs (Table 1). Five Golden Eagles were tagged with Argos Doppler shift PTTs and one with a GPS capable PTT. Mean duration of PTT tracking for all migrant eagles from capture to end-of-movement was 176 days ($\tilde{x}$ = 150, range 111–312 days, n = 6). Up to Feb 2022, no migrant eagles tagged with tail-mount PTTs were found dead or otherwise encountered

Vernal Migration

Vernal migrations of six Golden Eagles captured in Montana averaged 2497 km ($\tilde{x}$ = 2751 km, range 484 km-3975 km), consumed an average of 20 days ($\tilde{x}$ = 18, range 5–48 days), and covered a mean of 126 km/days ($\tilde{x}$ = 118, range 83 – 175 km/days)(Table 1). The number of days spent migrating was correlated with distance to summer range (r_s = 0.80, P = 0.055). Two Golden Eagles terminated vernal migration in British Columbia, and three travelled to summer ranges in Alaska > 3000 km north of their capture site (Fig. 1). An immature male Golden Eagle moved the shortest distance between capture site and summer range, travelling < 500 km to southern Alberta/British Columbia.

One juvenile female Golden Eagle spent a month and a half migrating and completed the longest migration of any eagle tracked to a single summer range (Table 1). The longest two-day movements (PTT duty cycle 2 da off) for eagles on vernal migration averaged 468 km ($\tilde{x}$ = 526, range 108 – 912 km, n = 6). The longest single day movement was > 456 km by a juvenile female. Only three stop-over periods were detected for long-range vernal migrants, two for a juvenile female (14 - 17 Apr, 29 Apr - 3 May) and one for another juvenile female (25 Apr - 3 May). A male subadult Golden Eagle travelled the quickest ($\bar{x}$ =175 km/d) of any migrant eagle, terminating migration in south-central Alaska.

Summer Range

Six Golden Eagles captured in Montana were tracked on summer ranges over an average of 109 da ($\tilde{x}$ = 104, range 74 - 169 da). During summer range tracking, PTTs produced an average of 220 Doppler fixes per eagle ($\tilde{x}$ = 252, range 76 - 357, n = 6) with a mean of 5.3 fixes/transmission day (range 2.3 - 8.9 fixes/da) (Table 1). Summer range area was related to number of days tracked in the range (r_s < 0.77, P = 0.07). Two eagles, one from a far northern Alaska and one from southern Alberta (Fig. 1, Table 1), were tracked from arrival to departure from summer ranges.

A juvenile female tracked to south central Alaska wearing a GPS PTT occupied two distinct summer ranges widely separated by > 600 km. The first straddled the western Alaska Range ~175 km west-northwest of Anchorage until late Jun when she moved east over 15 da (27 Jun - 11 Jul), then north to center activity ~90 km from the Chukchi Sea coast until late Aug (Fig. 1). Fixes between the two ranges were generally directional, sequential, and commonly >100 km apart signaling an inter- rather than intra-range movement of over 1500 km.

One immature male eagle summered in a range that straddled the Montana - Alberta - British Columbia border < 500 km north of his capture site (Fig. 1, bottom inset). This eagle appeared to have two distinct ranges ~100 km apart. One range was centered north of the US - Canada border, and the other encompassed parts of Glacier National Park and Blackfeet Nation Tribal Lands in the USA. Transmissions from PTTs on three eagles that confined their movements to one distinct range for the duration of summer tracking (Denali National Park and Preserve, northern British Columbia, central British Columbia) ended no later than 18 Jul and subsequent wide-spread inter-range movements may have been missed.

Autumnal Migration

Autumn migrants moved considerably slower than vernal migrants (54.4 km/da vs 126 km/da). No stop-over periods were detected for either long-range autumnal migrant. A juvenile female Golden Eagle was tracked on a complete autumn migration, revealing a maximum distance between last summer fix on the North Slope of Alaska and final moving fix in eastern Yellowstone National Park (YNP) of 4167 km on 4 Feb (Fig. 1). The following Aug, her transmitting PTT attached to molted tail feathers was recovered in west-central Montana 195 da after and 287 km northwest of the last Feb fix. A molted Black-billed Magpie (*Pica pica*) feather was found nearby. Notorious for their curiosity, a magpie may have rolled the molted PTT over and exposed PV panels to permit resumption of normal transmissions that aided in recovery. An immature male also was tracked on his autumn migration south to eastern Idaho (Fig. 1, bottom inset). His PTT also was recovered also attached to molted rectrices, and movement history suggested he continued migration to the southwest.

Because final fixes from the four other tail-mounted PTTs were in remote areas of Alaska and Canada, and impractical to access, causes of end-of-movement were unknown. PTTs on AHY eagles tended to move longer (/ = 221/214 da, SD = 87) than on ATY eagles (/ = 131/120 da, SD = 28) (Z = 1.53, P = 0.15). PTTs on older Golden Eagles all stopped moving within 8 da of each other (10

Jul, 15 Jul, 18 Jul) while younger eagles end-of-movement dates spanned at least 167 da (Table 1). No differences were detected in duration of movement by sex (P = 0.35).

DISCUSSION

Garcia et al. (2021) indicated "null" effects of backpack harnesses (Garcelon 1985, Hunt et al. 1992) or transmitters on physical condition of 17 encountered Golden Eagles clinically evaluated. These in-hand evaluations showed no marks, injuries or abrasions on feathers or skin caused by backpack mounted PTTs, and Garcia et al. (2021) concluded "no effects of attaching this Garcelon-type backpack system on the physical status of the birds". Change in mass or body condition was not investigated nor could negative behavioral impacts (i.e., aversion to foraging movement due to discomfort) be determined. Additionally, they said "an adult Golden Eagle was hanging from a tree branch held by one of the harness straps"; hardly a null effect. Also, 94% (n = 15) of Golden Eagles with backpack harnesses evaluated were found dead or admitted to a rehabilitation center, but the reasons were not presented.

The results presented here illustrate a safe and effective way to collect short-term (< 2.5 yr) data similar to that obtained from backpack PTTs. No eagles so marked have been encountered as of Feb 2022. Long-range vernal migration routes recorded were consistent with high use spring migration corridors from Montana to southeastern Alaska as those for Golden Eagles wearing backpack PTTs in other studies (McIntyre et al. 2006, Bedrosian et al. 2018). Only one eagle (a juvenile female) deviated east of this corridor. McIntyre et al. (2008) found only 2 of 12 vernal migrants to Alaska wearing backpack harnesses followed a similar path. Travel time was longer (24 da - 54 da) for eagles wearing backpack harnesses than eagles wearing tail-mounts in this study (5 da - 48 da). Adults were typically first to reach summer ranges in eastern North America (Katzner et al. 2020) like the one adult in this study. Tail-mounted PTTs were retained long enough to delineate complete autumnal migration for one eagle and part for a second. Mean maximum and daily long-range migration distances (> 1000 km) of five Montana eagles (= 2899 km) was nearly 2.7 times farther than maximum long-range movements of five non-adult Golden Eagles tracked from southern California wearing backpack harnesses transmitters (1075 km; calculated from Table 3, Poessel et al. 2016). The rate of travel of eagles on vernal migration in this study (=126 km/day) was similar to those in the eastern North America (129-134 km/days, Rus et al. 2017), but two moved considerably faster (166 and 175 km/da) than any noted in that study. Capture dates of most tagged eagles were during mid-vernal migration periods so whether they had wintered in Montana or farther south was unknown. One subadult female moved to central Wyoming prior to initiating extended northward migration that ended in northern British Columbia. Whether her movement represents leapfrog migration (Swarth 1920) or chain migration (Nilsson 1858, as cited in Chabot et al. 2018) is equivocal.

Close end-of-movement dates of PTTs on ATY Golden Eagles mid-summer strongly suggest rectrices supporting unrecovered PTTs were molted rather than on expired eagles. The mode of molt chronology of older Golden Eagles occurs during early to mid-summer (Jollie 1947, Ellis and Kery 2004) and the timing of Basic III molts (ATY) tends to be more concentrated (Ellis et al. 2006). Longer retention of tail-mount PTTs on AHY Golden Eagles suggests molt occurred consistent with Basic I and II molts noted for younger (AHY) Golden Eagles, which often extend into autumn (Bloom and Clark 2001).

Tail-mounted satellite transmitters also permitted recording of summer movements of Golden Eagles. One eagle that wore a GPS PTT had a much larger summer range (91,951 km^2) than the five other eagles wearing Doppler PTTs (= 1052, = 2150 km^2, range 31 - 7851) but likely was not a factor of PTT technology precision. Increased accuracy and data return from GPS units would likely be preferred for any future project. The rectrices of one juvenile female supported a PTT 10 g lighter in mass than those on other eagles in this study, and the PTT was retained at least 3½ mo longer than all others, indicating PTTs < 20 g also would be preferable. Retention would be maximized if they were deployed on newer, hard-penned rectrices (< 1 yr old) at appropriate times (Sep - Apr), at least on younger age classes that retain feathers longer. Central rectrices have been retained up to two years on adult eagles and more lateral rectrices even longer (Ellis and Kery 2004, J.M. Lockhart pers. comm. 2 Jun 1975, AH pers. obs.). Possibly, Golden Eagles, even males could commonly retain smaller, lighter GPS devices ≥ one or two yr. Evolving technology likely will provide new generations of lightweight (promoting normal feather retention), PV powered PTTs for tail mounts more tolerable to an eagle with technical capabilities commensurable to current backpack harness-mounted systems. Negative effects on survival and behavior of eagles tagged with backpack harness-mounted systems also will be avoided by use of tail-mounted transmitter packages.

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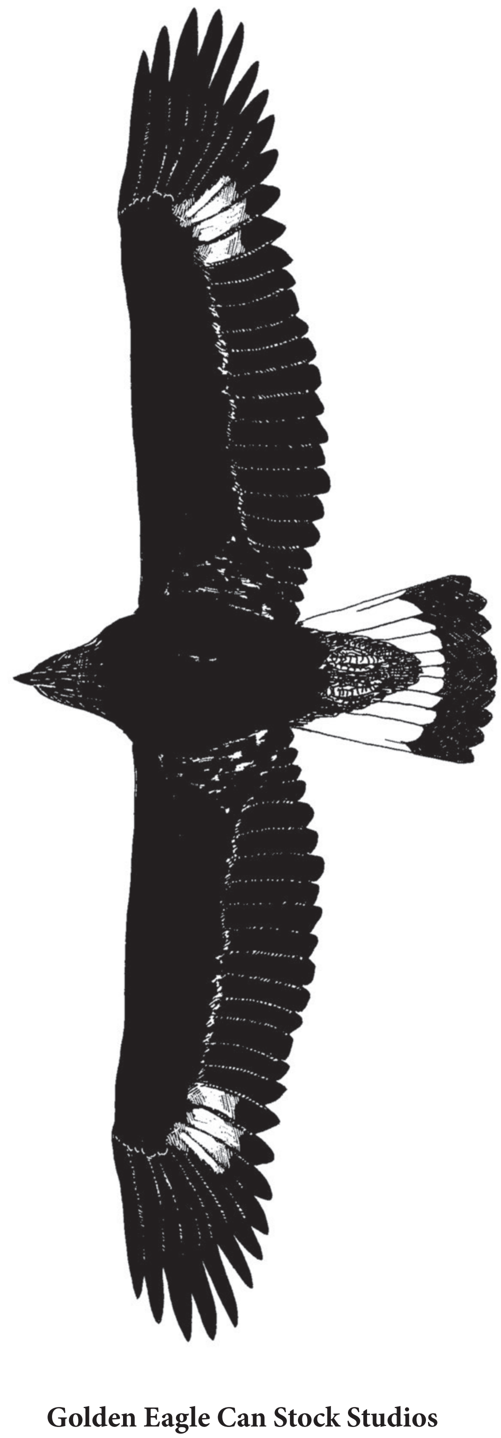

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TABLE 1. Migration parameters and summer range area (95% Kernel Density isopleth) for Golden Eagles captured in Montana, fitted with tail-mounted satellite-tracked telemetry devices, and tracked on vernal (V) and autumnal (A) migration.

		Migration					Summer Range		
Age/Sex	Date captured	Days	Start	End	Destination	Rate (km/d)	Distance (km) *	Track Days	Area (km^2)
Adult F	20 Mar 2015	12 (V)	23 Mar	4 Apr	central BC	93.5	1122	107	31
Subadult F	21 Mar 2015	17 (V)	4 Apr	20 Apr	northern BC	138.5	2354	82	177
Subadult M	1 Feb 2012	19 (V)	18 Mar	5 Apr	southern AK	165.7	3149	100	1052
Immature M	14 Mar 2012	5 (V)	24 Mar	28 Mar	southern AB	96.8	484	176	785
		25 (A)	20 Sep	14 Oct	eastern ID	65.7	788 [a]		
Juvenile F	4 Apr 2012	48 (V)	21 Apr	7 Jun	northern AK	82.6	3975	73	1642
Juvenile F	29 Mar 2012	21 (V)	13 Apr	3 May	northern AK	170.8	3856 [b] - 5543 [c]	118	95139
		54 (A)	29 Aug	27 Jan [d]	northern WY		4167 [a]		

*Calculated from capture site to center of summer range

[a]From center of summer range to last moving fix in autumn.
[b]To first summer range.
[c]To second summer range.
[d]Date of arrival in wintering area. Last transmission on moving eagle, 4 Feb.

Figure 1. Migration routes and summer ranges of six Golden Eagles captured in Montana and tagged with tail-mount satellite Platform Transmitter Terminals (PTT). J♀ = juvenile female, S♂ = subadult male. Top inset shows vernal route of an adult female (A♀) and a subadult female (S♀) that summered in British Columbia, Canada. Bottom inset shows both seasonal routes of an immature male (I♂). See Table 1.