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ANNUAL MIGRATIONS OF BALD EAGLES TO AND FROM CALIFORNIA

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ABSTRACT.—We fitted four nestling Bald Eagles (*Haliaeetus leucocephalus*) with Doppler-based satellite Platform Transmitter Terminals (PTTs) in northern California in 1997–1999. We also fitted immature and adult Bald Eagles with apparent origins in Canada with PTTs on their wintering grounds in central and southern California in 1997–2002. Post-fledging California eagles moved northward in their first summer, three to coastal and near-coastal central British Columbia and one to Great Slave Lake in Canada's Northwest Territories (ca. 1200–1400 and 2200 km by straight line, respectively). Three eagles with still-functioning PTTs returned to California between October and April. In subsequent years, the California-fledged eagles returned to or near their original northern summer areas in British Columbia or Northwest Territories annually for as many as 2 yr. Migrations of one young California eagle to and from Great Slave Lake were geographically similar to those of adult and immature Bald Eagles we studied concurrently that spent the breeding season in Canada and wintered in California, but timing of movements differed. In migrations subsequent to their first year, California eagles departed California later (late May to late July) than wintering migrants of all ages (mid-February to mid-March), and returned as early as September, while the winter migrants did not arrive in California until December–January.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *California*; *Canada*; *migration*; *satellite telemetry*.

MIGRACIONES ANUALES DE ÁGUILAS *HALIAEETUS LEUCOCEPHALUS* HACIA Y DESDE CALIFORNIA

RESUMEN.—Les acoplamos terminales de transmisión satelital basadas en Doppler a cuatro pichones de *Haliaeetus leucocephalus* en el norte de California entre 1997 y 1999. También pusimos transmisores en individuos inmaduros y en adultos aparentemente originarios de Canadá en sus áreas de invernada en el centro y sur de California entre 1997 y 2002. Después del emplumamiento, los individuos de California se movieron hacia el norte en su primer verano: tres hacia regiones costeras o cercanas a la costa en British Columbia y uno hacia el lago Great Slave, en Northwest Territories, Canadá (ca. 1200–1400 y 2200 km en línea recta, respectivamente). Tres águilas con transmisores aún funcionales regresaron a California entre octubre y abril. En años subsiguientes, las águilas nacidas en California regresaron anualmente a la misma área de verano original o a lugares cercanos en British Columbia o Northwest Territories hasta por dos años. Las migraciones de un individuo joven de California hacia y desde el lago Great Slave fueron geográficamente similares a las de aves adultas e inmaduras estudiadas al mismo tiempo que pasaron la época reproductiva en Canadá y el invierno en California, pero los movimientos tuvieron lugar en momentos diferentes. En las migraciones posteriores a su primer año, las aves de California abandonaron California más tarde (desde finales de mayo hasta finales de julio) que los migrantes de invierno de todas las edades (desde mediados de febrero hasta mediados de marzo), y comenzaron a regresar en septiembre, mientras que los migrantes de invierno no llegaron a California sino hasta diciembre-enero.

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Using band encounters and VHF radiotelemetry, researchers have shown that recently-fledged Bald Eagles (*Haliaeetus leucocephalus*) in southern portions of the species' range tend to migrate northward; e.g., birds hatched in Florida (Broley 1947 and Millsap et al. 2004), Arizona (Hunt et al. 1992a), Texas (Mabie et al. 1994), Oklahoma (G.M. Sutton Avian Research Center unpubl. data), and California (Hunt et al. 1992b). Using VHF telemetry transmitters, Hunt et al. (1992b) tracked four northern California juvenile Bald Eagles from Shasta County by airplane northward into British Columbia, but were unable to determine the eventual terminus of the eagles' movements. A later study in the same region found radio-tagged eagles hatched in northern California returning to natal regions following their post-fledging dispersal, and suggested the possibility of subsequent vernal or summer northward migrations because non-adult eagles were relatively scarce in the study area from June to late summer and fall (Jenkins et al. 1999).

We used satellite telemetry to track four young eagles hatched in northern California for as many as 26 mo post-fledging. Using satellite telemetry, we also compared movements and timing of migrations of California-hatched eagles to those of northern Bald Eagles of various ages that wintered in California.

STUDY AREAS AND METHODS

Shasta Lake is a reservoir along the Sacramento River at 325 m elevation, 125 km south of Oregon and 16 km north of Redding, California, in Shasta County (46°N, 122°W). Millerton Lake is a reservoir along the San Joaquin River at 171 m elevation, 35 km northeast of Fresno, California, in Fresno County (37°N, 119°W). Silverwood Lake is a storage reservoir for California's Central Valley Irrigation Project at 1020 m elevation in the San Gabriel Mountains in southern California located 20 km north of San Bernardino, California, in San Bernardino County (33°N, 117°W).

We fitted 7–8-wk-old nestlings (two males and two females) with combination satellite Platform Transmitter Terminals (PTTs) and VHF radiotransmitters at four separate nests near Shasta Lake in 1997–1999. Eagles were sexed using standard measurements described in Bortolotti (1984a, 1984b) and aged by plumage characteristics according to McCollough (1989).

Using a combination of techniques described in Jackman et al. (1993, 1994), we captured six adult and 10 immature [5 hatch-year, 2 second-year, 2 third-year, 1 fourth-year (hereafter, HY, SY, TY, and FY, respectively] Bald Eagles wintering at Millerton and Silverwood lakes and fitted them with PTT and VHF transmitters. We attached transmitters backpack-style using Teflon-coated nylon straps joined together over the sternum with three stitches of cotton embroidery thread. Eagles are distinguished here by tagging location, (i.e., SH = Shasta Lake, SI = Silverwood Lake, and MI = Millerton Lake), followed by age and sex.

The Doppler-based PTTs were from Microwave Telemetry, Inc., Columbia, MD U.S.A., and North Star Science and Technology, LLC, Baltimore, MD U.S.A., and weighed 45 and 32 g, respectively. We glued a 16 g VHF transmitter (Advanced Telemetry Systems, Inc., Isanti, MN U.S.A.) to the side of the PTTs for local tracking. Satellite data were processed through NOAA and Service Argos, Inc. and distributed to us via the Automatic Distribution Service e-mail system. Data were transformed into spreadsheet format with a custom-designed ActivePerl script (ActiveState Software Inc., Vancouver, BC Canada), and plotted using ArcView GIS 3.2 and ArcMap 8.2 software (Environmental Systems Research Institute, Redlands, CA U.S.A.). PTTs were programmed for daily transmission in initial weeks post-deployment or during expected migration periods. Regular duty cycles were programmed to maximize battery life, and varied between 10–12 hr on and 7–10 d off.

We used the resulting data to track broad-scale movement only (i.e., ≥5 km; Britten et al. 1999) so distances reported here are approximate. We considered some signals of low accuracy rating by Service Argos (i.e., A, B, and 0 location class) to be useful on a continental scale if they occurred in temporal and spatial clusters. We determined how far and when the eagles traveled, and whether they repeated the journeys in subsequent years.

PTTs contained sensors for battery strength, temperature, and activity, the latter increasing incrementally with physical movement of the eagle. Ambient temperature was mediated by the warmth and insulation of the eagle, so wide temperature fluctuations coupled with no activity sensor change suggested the eagle was dead or the transmitter detached. For reasons possibly related to satellite coverage, low battery voltage, and/or topography, signals from some PTTs used early in the study were intermittent, lapsing beyond off cycles for months in a few cases; in our analyses, we include only data

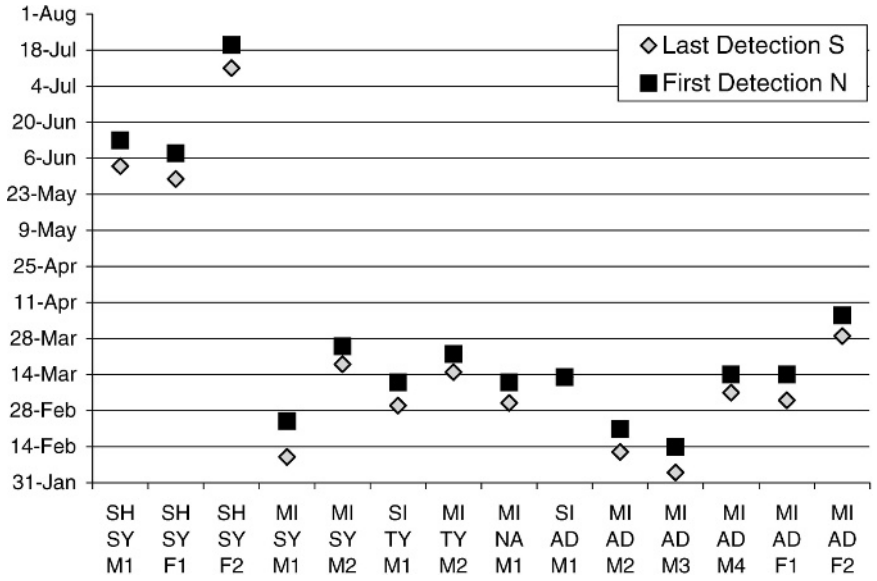

Figure 1. Approximate departure dates from CA of native Bald Eagles (SH) in their second yr (SY), and wintering (MI and SI) Bald Eagles of all represented ages (SY; TY = third yr; NA = near adult; AD = adult). Actual departure dates were usually unknown due to scheduled non-transmission periods and lie on or between the dates presented. Last detection S is the last day an eagle was known to be at its wintering location; first detection N is the subsequent transmission period confirming that the eagle had departed northward. SI-AD-M1 departed Silverwood Lake on 13 March and traveled into Nevada that day.

that were not affected by such lapses. Because of scheduled off-portions of the duty cycle, we considered a bird's departure dates to be the last signal of the season in an area, provided that confirming signals during the next scheduled transmission period indicated that the eagle had departed northward. Thus, the actual departure date was on or between the two dates, usually separated by 7–10 d.

RESULTS

The PTTs on four California juveniles, five wintering immatures, and six wintering adults provided consistent data and were used in the following analyses. For all analyses, we assumed that eagles that spent the breeding season in Canada likely originated there, although this was not confirmed. All eagles, including those of presumed Canadian origin and those fledged in California, spent time during summers in Canada and winters in California. The California eagles departed the state later, and returned to it generally earlier, than Canadian eagles of all ages and sexes (Fig. 1). California eagles returned to their northern summering areas for as many as two additional years before PTTs ceased to function.

California Eagles. Eaglets (SH-HY-M1, SH-HY-M2, SH-HY-F1, SH-HY-F2) fledged at Shasta Lake at approximately 12 wk of age and departed their natal areas in July or August, 3–5 wk post-fledging. SH-HY-M1, SH-HY-M2, and SH-HY-F1 traveled to coastal or near-coastal fjord regions of British Columbia (BC) between 50.5 and 52.7°N, SH-HY-F2 to Canada's Great Slave Lake in the Northwest Territories at 60.8°N. They appeared to remain in localized areas once they terminated migration in the north, but the early model transmitters on SH-HY-M1, SH-HY-M2, and SH-HY-F1 were not accurate or prolific enough to quantify this (e.g., for one eagle, 69% of signals were A, B, or 0 quality). Return journeys to California from British Columbia began as early as October and as late as December. The eagle SH-HY-F2 that traveled to Great Slave Lake began southward migrations in September.

The PTTs on SH-HY-M1 and SH-HY-F2 functioned into the California eagles' second year, and SH-HY-M1 into the third year. After spending 4–7 mo during October–July in California, the three California eagles departed in June or July, and returned to the same northern summer areas used previously in British Columbia and Northwest Ter-

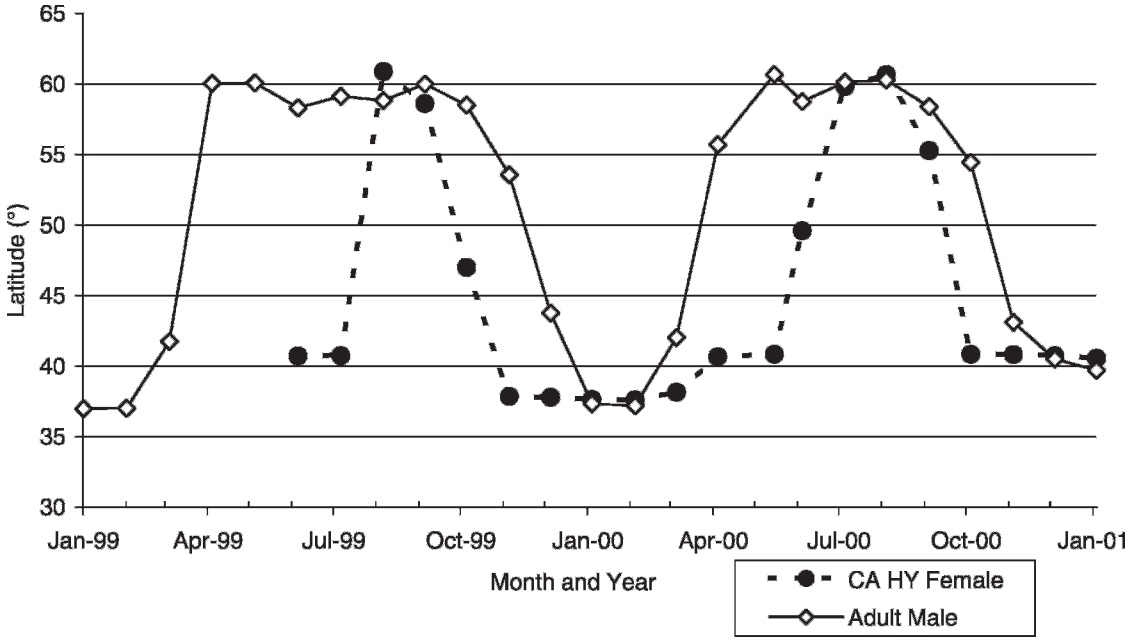

Figure 2. Latitude comparison of first monthly detections of Bald Eagle HY-SY-F2 tagged as a nestling in California and Canadian Bald Eagle MI-AD-M3 tagged as an adult in California. Both summered at or near Great Slave Lake, Northwest Territories. The adult wintered at Millerton Lake in central California; the younger eagle in central and northern California, including Shasta Lake.

ritories. The PTT on the fourth eagle SH-HY-M2 failed during the first year. Female SH-HY-F2 occupied the same <1 km^2 area on the south shore of Great Slave Lake in consecutive summers.

Subsequent dates of northward migration were generally earlier than the eagles' initial, post-fledging migrations (which were constrained by the eagles' fledging dates; Fig. 2).

While SH-HY-M1 and SH-HY-F1 were in California their PTT signal quality was poor ($<1\%$ of 156 signals of >0 location class), but the large majority of signals were in northern California and southern Oregon, including the Klamath Basin. A third PTT provided more precise locations and showed that SH-HY-F2 was at Lake McClure and New Don Pedro Reservoir in the Sierra Nevada foothills, Eagle Lake at the edge of the Great Basin, and at or near Shasta Lake between 29 April and 20 May 2000 before departing northward. She was at Shasta Lake again in October to December, when her transmitter failed.

Eagle SH-HY-F2 traveled for two seasons in a loop migration (Lincoln et al. 1998) up the Cascade Range to the Canadian Rocky Mountains in British Columbia on northward trips to Great Slave Lake, then followed the eastern Rocky Mountains at least as far south as Montana during returns to California. Interestingly, her first signals in California in fall of 1999 were near Millerton Lake, one of the wintering areas also used by Canadian eagles that shared her summer range. This eagle might have been led there by the same topography that brought the Canadian migrants, also exhibiting loop migrations, to that part of California. She returned to the same shoreline area she frequented her first summer at Canada's Great Slave Lake by 19 July 2000, where she remained through 29 August 2000. On her second southward trip she revisited Lesser Slave Lake in Alberta on 8 September 2000, where she had been on 29 June of the same year while moving north, and on 29 September 2000 the same area of the Clark's Fork in Montana where she had been September–October 1999 while moving southward. By 8 October 2000, she was back in California near Shasta Lake, where she remained through her PTT's last received transmission in January 2001.

Canadian Migrants. We successfully monitored 11 Bald Eagles (six adults, five immatures), of presumed Canadian origin, that migrated between Canada and California. Most arrived in California in December and January and left in late February

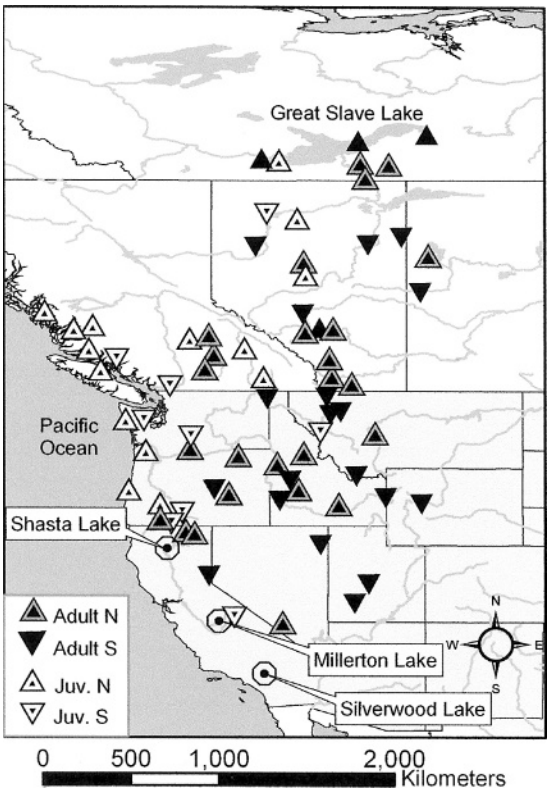

Figure 3. Representative northward and southward detections of Californian and Canadian Bald Eagles during migration, showing a general tendency for northward movements to be west of the southward routes.

and March. They arrived in the north in March and April. Canadian eagles performed mild loop migrations, with northward movements west of southward routes (Fig. 3). Small sample sizes precluded statistical testing between subgroups of these eagles, but there were no apparent differences in migration timing by age classes, sex, or breeding status (Fig. 1). All traveled to, and resided in, an area encompassing NE Alberta, NW Saskatchewan, and especially the Great Slave Lake region of southern Northwest Territories. An exception was a TY male captured at Millerton Lake in California. He spent May through August at Great Slave Lake and the Mackenzie River nearby, and in September moved 900 km NE, passing Great Bear Lake and coming within 100 km of the Beaufort Sea at 68.2°N before returning to Great Slave Lake in October and California in January. Estimated distance traveled was 35 000 km.

Based on localized signals (i.e., very tight clusters of signals <1 km apart), three adults (SI-AD-M1, MI-AD-F1, and MI-AD-M2) appeared to hold territories: SI-AD-M1 on Big Island in the western arm of Great Slave Lake, MI-AD-F1 on an island in the eastern arm, and MI-AD-M2 near Churchill Lake, Saskatchewan. This last eagle remained at a lower latitude (55.7°N) than the other adults, and left California earlier (late February) than most other Canadian eagles. The two remaining adult males ranged widely, one just southeast of Great Slave Lake, the other near Lake Athabasca in Alberta and Saskatchewan and points north. Their departure dates from California did not differ from those of two males that were apparently territorial. Canadian eagles repeated their journeys and returned to the wintering areas at which they had been tagged. MI-AD-F2's transmitter failed as she neared Great Slave Lake during migration and thus her breeding status was unknown.

DISCUSSION

The tendency to revisit natal regions has been shown in many juvenile Bald Eagles returning from migration (Gerrard et al. 1978, Jenkins et al. 1999). All California juveniles in our study with functioning transmitters showed some fidelity to their natal region when in California, but in most cases fidelity was not quantified due to poor signal quality.

Most published raptor migration studies involving satellite telemetry have been of southward wintering migrations and returns (e.g., Laing et al. 2005). Our study confirms the postulate of repeated northward migrations of California Bald Eagles and reveals their shared use of flyways and habitats with Canadian eagles that winter in California. The eagles that moved between central Canada and California passed through mountain ranges including the Rockies, Sierra Nevadas, and in some cases Cascades, crossing through two of the flyways delineated in Hoffman et al. (2002) for other migrating raptor species in western North America. Another study found that although most post-fledging Bald Eagles from Saskatchewan migrated south into the Plains states and Missouri River drainage, a few crossed over the Rocky Mountains, including at least one to southern California (Gerrard et al. 1978).

Although the purposes of northward migrations of young California Bald Eagles are uncertain, a likely explanation is access to carcasses of anadromous fish and other seasonally abundant food resources in the north (Hunt et al. 1992b). In another study,

most recently-fledged Bald Eagles in southeast Alaska initially moved to nearby salmon runs, but later migrated south as far as Washington, presumably to exploit later-season salmon runs (Hodges et al. 1987). Harmata et al. (1999) found that most juvenile eagles produced in the Greater Yellowstone Ecosystem migrated longitudinally (west), possibly in search of salmon runs along the Pacific coast.

Young Bald Eagles native to more southern latitudes than our study area apparently move northward somewhat earlier than California eagles, (e.g., late May/early June; Broley 1947, Hunt et al. 1992a, Mabie et al. 1994). As in our study, Broley (1947) noted that southern Bald Eagles likely made return migrations earlier in the fall than their northern counterparts, based on data collected at Hawk Mountain Sanctuary in Pennsylvania, where Bald Eagle counts peaked in September, a time when northern birds were still at their breeding territories.

Mild loop migrations, which are characteristic of some eagles and other birds, were evident among both the Canadian eagles and the California eagle that traveled to and from Northwest Territories, Canada. Harmata and Stahlecker (1993) reported traditional use of Colorado wintering grounds by adults presumably breeding in Canada (e.g., Saskatchewan), in one case over six successive winters. All the Canadian eagles in our study showed fidelity to the wintering locations where they were first captured in California over two to three successive winters of transmitter life.

There was a marked difference in timing of movement between the Canadian and California eagles. The specific timing of arrival at particular destinations likely correlates with life-history requisites such as territory (re)establishment following ice melt and the availability and abundance of seasonal food resources (Buehler 2000). Harmata (2002) found that mated Bald Eagles departed wintering grounds in Colorado closer to the spring equinox and later than unmated eagles; all migrants in his study paralleled the movement of the 2°C isotherm. In our study, Canadian breeders and floaters destined for Great Slave Lake left California in March most years, just prior to the equinox, and arrived in April, presumably based on photoperiod. The lone Saskatchewan breeder in our study left earlier and arrived at Churchill Lake (5° latitude south of Great Slave Lake) in March very near the spring equinox in each of 3 yr he was tracked. The California birds departed northward nearer summer solstice. As duration and length of migrations may vary greatly between populations within a species, and northern and southern populations may differ in schedules of migration (Lincoln et al. 1998), it is possible that the northern California population's northward repeat migrations of young eagles is triggered by a photoperiod that coincides with a superabundance of food to the north in the form of anadromous fish runs.

As Great Slave Lake is near the northern extreme of Bald Eagles' range and California its southwestern extent, these Canadian eagles may have been undergoing a leapfrog migration (Lincoln et al. 1998); however, our sample is limited to birds that visited California. Four of five Bald Eagles wintering on the Skagit River in Washington State that summered in the Northwest Territories did not visit California at all, but spent the entire winter in the Pacific Northwest, feeding on spawned out salmon. The fifth regularly traveled between northeastern California and Great Slave Lake (J. Watson pers. comm.). That study found that eagles native to British Columbia and southeast Alaska departed their wintering grounds heading northward toward their natal or breeding areas by early February; however, eagles bound for interior Alaska, Yukon, and the Northwest Territories left in March and April, presumably because conditions were less temperate in the northern interior at that time of year (Watson and Pierce 2001). Both populations of eagles in our study moved northward more quickly than they did southward. Speed of southward migration was likely influenced by local conditions (Harmata 2002), such as weather and food availability. With the exception of the Klamath Basin, there were no staging areas where eagles stayed >7–10 d during northward migration; however, short-duration stops may have occurred.

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