The Condor 98:293–299

COMPLETE MIGRATION CYCLE OF GOLDEN EAGLES BREEDING IN NORTHERN QUEBEC[1]

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Abstract. Radio tracking via satellite was initiated to study the year-round movements of Golden Eagles (*Aquila chrysaetos canadensis*) breeding on the east coast of Hudson Bay, Quebec. In June and August 1992, six Golden Eagles (five adults and one juvenile) were marked, three of which completed their year-round movements. The eagles left their breeding area in mid- to late October and migrated to known wintering areas in the eastern United States. They used different routes but each followed the same general path during fall and spring migrations, which lasted between 26 and 40 days, and 25 and 51 days, respectively. Eagles wintered from 93 to 135 days in areas located 1,650 to 3,000 km south of their breeding territory. In spring 1993, satellite telemetry located the eagles in their former breeding territory in late March, mid-April and early May. This study confirms previous suggestions that some breeding Golden Eagles wintering in eastern United States come from northern Quebec and describes the first successful tracking of the complete yearly migration cycle of a bird of prey.

Key words: Raptors; Aquila chrysaetos; *Golden Eagle; migration; telemetry; satellite.*

INTRODUCTION

Raptor migration study has relied mostly on banding data, radar, and migration counts made at sites where migrant raptors concentrate. Although substantial long-term data have been compiled, these techniques provide limited information on the origin, destination, and timing of raptor migration routes (Haugh 1984, Kerlinger 1989, Alerstam 1990). Conventional radiotelemetry has yielded insights into raptor migration behavior but involves considerable logistical and administrative difficulties and is limited by hazardous weather, daylight, and security considerations. Only Harmata (1984) and McClelland et al. (1994) were able to follow Bald Eagles from their autumn migration to their winter range or back to their nest.

Satellite telemetry minimizes many of these difficulties (Fancy et al. 1988, Harris et al. 1990). It has proven useful to describe movements of pelagic birds (Jouventin and Weimerskirch 1990), and parts of migrants' annual flights (Strikwerda et al. 1986, Berthold et al. 1992, Howey 1992, Meyburg and Lobkov 1994, Grubb et al. 1994, Meyburg et al. 1995a, 1995b, Fuller et al., in press). Meyburg et al. (1995b, in press) have recently tracked a complete 12-month cycle of a Lesser Spotted Eagle (*Aquila pomarina*), and a back and forth migration of a Wahlberg's Eagle (*Aquila wahlbergi*).

Golden Eagles can migrate over long distances (DeSmet 1987). The recovery in southern Quebec and Pennsylvania of leg bands of three juvenile Golden Eagles banded in northern Quebec (Spofford 1971, Millsap and Vana 1984), as well as migration counts made at different lookouts around the Great Lakes and along the Appala-

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TABLE 1. Number of locations via satellite according to quality indices (LC) 0 and ≥1.

Eagle (sex)	Period of transmission (1992–1993)	During entire period		During migrations			
				Fall (1992)		Spring (1993)	
		LC0	LC ≥ 1	LC0	LC ≥ 1	LC0	LC ≥ 1
1 (f)	06/25–06/01	449	92	37	14	35	1
2 (?)[a]	06/23–06/05	562	123	51	9	121	28
3 (f)	06/29–02/03	248	44	23	3	—	—
4 (f)	06/22–06/09	411	58	28	3	30	4

[a] Sex classification rejected (P_i value = 0.5); see Edwards and Kochert (1986).

chians (Heintzelman 1986, DeSmet 1987, Titus and Fuller 1990) have revealed that Golden Eagles migrate south from eastern Canada. Here we present the results of satellite radio tracking of four Golden Eagles marked near Hudson Bay in northern Quebec (Morneau et al. 1994).

METHODS

The Golden Eagles were captured along the eastern shore of Hudson Bay, in nesting areas located between the Great Whale River (55°17′N, 77°47′W) and the Nastapoka River (56°55′N, 76°33′W). The climate of the nesting area is subpolar. Average April temperature at Kuujjuarapik-Whapmagoostui is −7.3°C (Canada, Service de l'Environnement Atmosphérique Can 1982). Snow cover and ice on lakes extend from October to mid-May. Birds were captured in boreal forest and forest tundra vegetation zones (Payette 1983).

Based on estimates from the 1990 reproductive season, egglaying in the study area occurred between early April and early May and fledging from late July to late August (Morneau et al. 1994). In June 1992, a member of each of five breeding pairs (four females and one of undetermined sex) were captured using a netgun fired from an helicopter (O'Gara and Getz 1986, S. Brodeur, unpubl.). The body weight function developed by Edwards and Kochert (1986) was used as a predictor of sex. One eagle per nesting territory was captured in order to limit nest disturbance. The average distance between the nests of eagles captured was 34.7 km (24.7–49.9 km). A sixth transmitter was attached to an eaglet in a nest on 8 August.

The adults and the eaglet were fitted with 95 g platform transmitter terminals (PTTs) (Microwave Telemetry, Inc., Columbia, Maryland). PTTs were attached as a "backpack" with Teflon ribbon (Snyder et al. 1989). Biodegradable cotton thread was used to tie the ribbons. Each transmitter (less than 3% of the bird's mass) was programmed to transmit data on a 8 hr on/40 hr off duty cycle to allow tracking of a complete migration cycle. Locations of PTTs were obtained from the Argos satellite tracking system (Fancy et al. 1988). Two TIROS satellites received signals sent by transmitters (401.65 Mhz, 60 sec transmission interval). Four classes of location accuracy (LC) were provided by the Argos system. According to Service Argos (1988), 68% of class 3 locations are accurate within 150 m, 68% of class 2 within 350 m and 68% of class 1 within 1 km. The accuracy of class 0 locations is undetermined. We tested the accuracy of class 0 locations with ≥4 messages on known targets and found the mean (±SD) distance from the target to be 9.2 ± 6.4 km (n = 15) (G.R.E.B.E. 1993).

Migration route maps were established using satellite location classes 1–3. Class 0 locations with ≥4 messages were used to confirm departure dates and to fill large gaps between better quality fixes along the routes followed around the Great Lakes. Weather variables were registered in the breeding range (Kuujjuarapik weather station) prior to the eagles' departure in 1992.

RESULTS

The radio-marked eagles remained in the Hudson Bay area for approximately four months before starting their fall migration in October. One adult died of unknown causes during the nesting season and the four remaining adults migrated south to different wintering locations in the eastern United States. The fate of the eaglet remains unknown.

After three to four months, three eagles returned to their former breeding range. For unknown reasons, satellites ceased receiving signals from the fourth bird during winter. A total of 1,987 locations was obtained from satellite tracking during the study. Of these, 168 locations were obtained during the fall migration and 219 during the spring migration. The remaining were during summer and winter (Table 1).

Three eagles left their breeding territories during 14–16 October and the fourth bird started to migrate on 30 October (Table 2). In October, the average daily temperature was 1.3°C (−6.6 to 11.7°C), average daily rain and snow precipitations were 8.8 mm and 1.1 cm (maximum daily precipitation 11.6 mm and 6.6 cm) and average daily snow accumulation was 1.4 cm (max 10 cm) (Luc Mercier, pers. comm.; Table 3). A northerly wind was generally associated with the eagles' departure.

The eagles used different routes to their wintering range (Fig. 1). Three birds flew a southernly course through central Quebec, then around Lake Ontario and along the Appalachian Mountains to their wintering area in the eastern United States. Eagle one reached Pennsylvania in early December and wintered there. Eagle 3 flew through Pennsylvania during the first week of November and wintered in West Virginia. Eagle 4 crossed the former state during the second week of November. It was observed in Fulton County, southern Pennsylvania on 13 November by K. Striedieck (pers. comm.) and wintered near the junction of the Alabama, Tennessee, and Georgia borders. Eagle 2 chose an entirely different route. It migrated along Hudson Bay, then moved through Ontario to cross the Great Lakes by the Strait of Mackinac between Lake Huron and Lake Michigan, finally wintering in Michigan. The birds took between 26 and 40 days to reach their respective wintering areas separated by 150 to 1,000 km (Table 2) and spent three to four months on their wintering grounds.

After 3 February, we lost track of eagle 3 in West Virginia; this bird was not seen again. The other three eagles left their wintering areas in March. Two eagles started to migrate in early March and used almost the same route as during fall along the Appalachians and through central Quebec (Fig. 1). One was located in Mont Tremblant Park, a provincial park in southern Quebec (46°30′N, 74°30′W). The other eagle crossed the strait of Mackinac at the end of March, wandered west of James Bay, then turned back, crossed the southern tip of James Bay and followed its former route along Hudson Bay. This eagle remained for about a month on the west shore of James Bay, along the coast and on the large Akimiski island (53°00′N, 81°30′W) before returning to its breeding territory. Satellites located the

TABLE 2. Migratory patterns of four adult Golden Eagles radio tracked via satellite.

	Migration chronology						
Eagle	Departure from breeding territory	Arrival at wintering ground	Distance rate (km/day)	Departure from wintering ground	Arrival at breeding territory	Distance rate (km/day)	Wintering area (Dist. from nest, km)
1	10/30/92	12/07–09/92	49	03/07–09/93	03/29–31/93	80	Pennsylvania (2,000)
2	10/14–16/92	11/13–15/92	50	03/27/93	05/14–16/93	32	Michigan (1,650)
3	10/14–16/92	11/03–09/92	80	?[a]	?	—	Western Virginia (2,150)
4	10/14–16/92	11/17–19/92	81	03/09–13/93	04/08–10/93	91	Alabama (3,000)

[a] No message received after February 3.

TABLE 3. Meteorological variables registered at Kuujjuarapik weather station (Environment Canada) on the presumed days of departure of Golden Eagles from their breeding range.

Date	Temperature Max. (°C)	Temperature Min. (°C)	Temperature Ave. (°C)	Precipitation Rain (mm)	Precipitation Snow (cm)	Snow accumulation (cm)	Wind Velocity Min. (km)	Wind Velocity Max. (km)	Wind Origin
10/14/92[1]	3.9	−0.3	1.8	11.6	Tr	0	14	29.6	West and north-west
10/15/92[1]	0.9	−0.7	0.1	0	Tr	0	5.55	22.2	West and north-west
10/16/92[1]	0.7	−2.2	−0.8	0	0	Tr	0	22.2	North-east and east
10/30/92[2]	−0.3	−3.4	−1.9	Tr	1.6	8	18.5	48.1	South-west, west and north-west

[1] Eagles nos. 2, 3 and 4 left their breeding range between 14 and 16 October.
[2] Eagle no. 1 left its breeding range on 30 October.

eagles in their nesting territories in March, April and May 1993 (Table 2). The location data also revealed that the birds remained in their respective nesting areas until transmitter battery depletion during the first and second week of June 1993.

The four eagles migrated according to a regular schedule, never staying in one location for more than two days except for the eagle that stopped along the James Bay coast during its spring migration. The eagles migrated mean (±SE) distance of 65 ± 18 km/day (range 49–81 km/day), during the fall migration and 68 ± 31 km/day (range 32–91 km/day) as they returned to their nesting area (Fig. 1, Table 2). Eagle 2 covered the 1,650 km to its nesting range at an average rate of 79 km/day, not considering the time spent on Akimiski Island and along James Bay shoreline. These migration rates are based on distances between location samples. Thus the birds probably flew a greater distance since it is unlikely that all flights were straight, point-to-point.

DISCUSSION

Radio tracking Golden Eagles via low orbiting satellites provided the first complete migration of individuals to and from their wintering grounds as well as new insights into adult Golden Eagle ecology in eastern North America. Results revealed that individuals from the same breeding area migrated and wintered in different areas of latitude separated by up to 1,000 km. Two of the three birds tracked on spring migration flew a route similar to that for their fall migration. Studies on the Lesser Spotted Eagle in Europe and on the Wahlberg's Eagle in Africa have shown similar results (Meyburg et al. 1995b, in press).

Movements of the marked eagles showed that topographical features were associated with the eagles' paths in United States but not in central Quebec and Ontario where they migrated over a largely flat or featureless terrain with only sparsely distributed mountains. Eagles 1 and 3 followed the Appalachian Mountains for a few hundred kilometers and eagle 4 migrated along the Appalachians for more than 1,150 km in fall and spring migrations.

Many raptors are counted along the Appalachians during migration in eastern North America (Haugh 1984, Heintzelman 1986). These mountains are oriented northeast to southwest (250°–260° Kittatinny Ridge, Pennsylvania) and facilitate migration with orographic lift (Kerlinger 1989:96–99). A study of eagle passages at Hawk Mountain Sanctuary, a well-known observation point in Pennsylvania, showed that adult Golden Eagle flights peak in early to mid-November (Brett 1991:54). Two of our radio marked eagles passed through this region from 3 to 13 November, the third wintered in Pennsylvania after arriving in early December.

Our results indicate that Golden Eagles may compensate for potential flight path displacement caused by winds. Eagles deviated little from a direct line (160°) when migrating through Quebec and Ontario. Moreover, eagle 2 followed a 200° heading when crossing Ontario during its autumn migration, mostly against prevailing winds.

Our results also suggest that the shorelines of large bodies of water can act as diversion lines or barriers, especially for broad-winged raptors like eagles that are dependent on updrafts (Kerlinger 1989:263–266). The fall and spring movements of our eagles support this idea; they flew around the Great Lakes past well known migrant hawk concentration areas (Haugh 1984, Titus

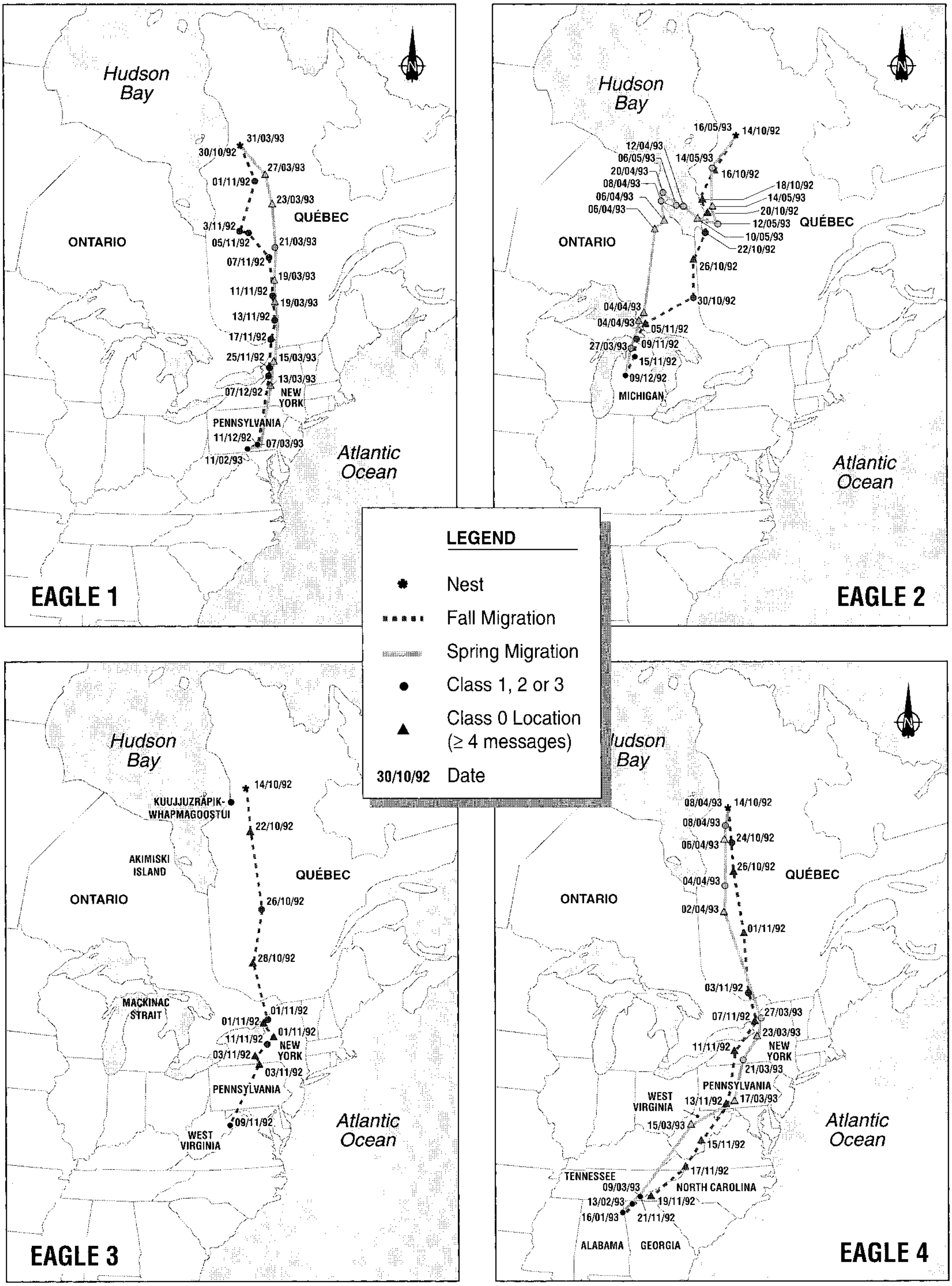

FIGURE 1. Migration patterns of four Golden Eagles via satellite tracking.

and Fuller 1989). Moreover, the eagle that flew over the southern tip of James Bay in spring crossed from Akimiski Island to a smaller island, then to the eastern shore of James Bay. The maximum flight distance covered when crossing sea water from island to island was less than 50 km. This distance is twice the maximum water crossing cited for Golden Eagles by Kerlinger (1989: 338), but the presence of ice on James Bay during the first week of May may facilitate such water crossing, allowing the eagle to land on the ice or at least perceive the ice as potential land.

The average migration distance of these eagles (65 km/day fall, 68 km/day spring) is slightly longer than estimated in studies in western North America. Applegate et al. (1987) estimated the migration distance of a Golden Eagle that was followed for 215 km to be 49 km/day during the fall of 1974 in Wisconsin. An immature Golden Eagle banded in Northwest Territories, Canada, covered approximately 50 km/day (Kuyt 1967). Speeds of two Golden Eagles observed at Hawk Mountain ranged from 45 to 51 km/hr and averaged 48 km/hr (Broun and Goodwin 1943).

Golden Eagles have wintered in Pennsylvania, West Virginia, Alabama and Michigan in the past, but none of the counties visited by these birds are known as regular wintering sites (Millsap and Vana 1984). The topography of mountainous areas or large remote tracts of land together with restricted access and secretiveness of Golden Eagles may explain this discrepancy.

Movements of raptors are closely related to seasonal changes in prey. In general, the adults seem to stay in the breeding areas as long as food permits, thus gaining the maximum time for breeding (Newton 1979:183). Although our Golden Eagles arrive at their breeding grounds when bodies of water are still frozen, the presence of caribou carcasses and migrant Ptarmigan might sustain the birds until the arrival of waterfowl and the availability of hibernating mammals in late April and May (Watson and Langslow 1989; S. Brodeur et al., unpubl.). Most avian prey species identified as part of the Golden Eagles' diet in this area migrate during the months of August, September and early October. Some mammalian prey species hibernate or restrict their movements in fall. Reduced prey availability and shortened days constraining hunting activities might explain the eagles' departure in October. Food might also explain why eagle 2 stayed so long in the area of Akimiski Island before flying to its nesting territory. Seal bones have been identified in the prey remains of Golden Eagles (Brodeur et al., unpubl.) and seal carcasses are left by native hunters on this island (J. G. Ricard, pers. comm.).

ACKNOWLEDGMENTS

This study was financially supported by Hydro-Quebec as part of the Grande-Baleine hydroelectric project studies. We wish to thank Michel Lepage, Raymond McNicholl, Laurier Breton (Min. de l'Environnement et de la Faune), Susan Klugman (U.S. Fish and Wildlife Service), William Seegar (U.S. Army), Daniel Lambert and Francois Morneau (G.R.E.B.E. Inc.), Paul Dubois (pilot, HéliExpress), John Cummings (U.S. Department of Agriculture, Denver, CO), Paul Howey (Microwave Telemetry Inc.) and Luc Mercier (Environment Canada) who all contributed to the success of our study. Supplementary financial assistance from The Wilson Society, Province of Quebec Society for the Protection of Birds, and FCAR helped for the completion of this study. Paul Kerlinger, Richard Perreault and Marcel Laperle kindly reviewed the manuscript.

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