

Tracking Local and Seasonal Movements of Wintering Bald Eagles *Haliaeetus* *leucocephalus* from Arizona and Michigan with Satellite Telemetry

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ABSTRACT

In 1990, two wintering, 3rd-year female Bald Eagles were captured in Arizona and Michigan, and fitted with 95g, backpack, satellite transmitters and conventional 8g, tailmount transmitters. The Arizona eagle ranged over 40,387km² between 24 January - 26 March (35°N) and used at least 23 different roost locations in the Ponderosa Pine forests of north-central Arizona. From 3 - 27 March, the Michigan eagle covered ≥ 21,768km² between Lakes Michigan and Huron (45°N). Both birds migrated over 400km about 27 March, the Michigan eagle to remain north of Lake Superior (50°N) within a 55,160km² summer range. The Arizona eagle migrated 3,020km in 37 days (15 days migrating ≥ 100km north interspersed with 22 days of local or non-northward movements) to a 56,022km² summer range along Great Slave Lake, North-west Territories, Canada (65°N). Both transmitters expired in June. Eight grand checks of the Arizona PTT yielded a mean error distance of 24.4km (s.d. = 24.2). Advantages and limitations of satellite telemetry for large raptor study are also considered.

INTRODUCTION

Satellite telemetry for wildlife tracking has been developing since its first experimental application on Elk (*Cervus elaphus*) in 1970 (Craighead *et al.* 1972). Most early efforts were necessarily associated with larger terrestrial and marine mammals (Fancy *et al.* 1988) because of the size of transmitter units. It was not until the mid-1980s that technology permitted effective deployment on several large avian species, including Mute, Trumpeter and Tundra Swans *Cygnus olor*, *C. buccinator*, *C. columbianus*, Antarctic Giant-Petrel *Macronectes giganteus*, and Bald Eagle *Haliaeetus leucocephalus* (Strikwerda *et al.* 1985, 1986; Howey 1992). Since then,

Wandering Albatross *Diomedea exulans* (Jouventin & Weimerskirch 1990), Golden Eagle *Aquila chrysaetos*, (McIntyre *et al.* 1991) and Gyrfalcon *Falco rusticolus* (Seegar *et al.* 1990) have also been successfully satellite instrumented and tracked.

As part of the field testing and developmental application of a new generation of avian-borne, satellite transmitters by Microwave Telemetry, Inc. (MTI)¹, and in association with continuing, independent Bald Eagle research by the USDA Forest Service in Arizona and Michigan State University in the Great Lakes, we radio-equipped two immature, migrant eagles during the winter of 1990. Daily, night roost locations were the primary goal of the Arizona study, while both projects shared common objectives of determining local movement, winter and summer ranges, migratory paths and source breeding populations. Simultaneous monitoring of two eagles of the same age and sex also permitted intraspecific comparison between two widely separated regions of this species' geographic range.

METHODS

Satellite telemetry currently uses the Argos Data Collection and Location System, which is a co-operative international project of the Centre National d'Etudes Spatiales of France, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). This system includes equipment on two Tiros-N satellites (currently NOAA-11 and NOAA-12), and a network of satellite tracking stations and communications links that transfer satellite data to processing centres in Landover, Maryland, and Toulouse, France. These centres distribute results to users via telephone modem/computer, diskette and/or print-out. The near-polar, sun-synchronous orbits of Tiros-N satellites permit coverage of a specific geographic area at approximately the same time each day. Location of a transmitter, called a platform transmitter terminal (PTT), is estimated from the Doppler shift in its carrier frequency (401.650 MHz). For normal processing, Argos requires four transmissions, or messages, during an overpass to calculate location, but special processing for wildlife research estimates locations from as few as two Doppler measurements. Argos grades locations according to precision (i.e. 68% of a series of locations expected within the given distance) with location quality indices (LQ): LQ3 - 150m, LQ2 - 350m, LQ1 - 1km, and LQ0 - undetermined/animal tracking. Within LQ0, Argos also provides an interpretative index, which helps in assessing estimated locations by explaining why normal processing failed (summarized from Harris *et al.* 1990).

During the winter of 1990, in Coconino County, Arizona, we captured a 3rd-year (McCullough 1989) female Bald Eagle with a rocket net (Grubb 1988) on 24 January; and on 3 March, in Manistee County, Michigan, using a bow-net (Bloom 1987), we captured a second, seasonal migrant of the same age class and sex. Both birds were fitted with experimental, MTI PTT100 series, satellite transmitters. Each unit weight 95g and measured 9.4 x 3.3 x 3.0cm, with a 17.8cm antenna protruding posteriorly at a 45° angle. The PTT's were attached as backpacks with teflon ribbon and sewn with biodegradable cotton thread. Transmitter life can be varied with timer setup, as well as battery power: the Arizona unit was set on an 8 hours on/16 off schedule with a 28-week life expectancy, while the Michigan unit was set on 4/44 for a potential life of 112 weeks. Both transmitters were active 1200-1600 with the Arizona unit continuing 1600-1800 to facilitate night roost location. All times are local: for Arizona, Mountain Standard Time (MST), and for Michigan, Eastern Standard Time (EST). Both eagles were also fitted with conventional (165 MHz) 8g, tail-mounted transmitters for initial ground tracking, but due to logistical and budgetary constraints we were limited to following only the Arizona bird on its winter range.

Data on our eagles gathered by ARGOS in France were transferred to MTI in Maryland via telephone modem/computer. Locations were then telephoned to the field, sometimes within as little as 30 minutes after a satellite pass, and later followed with a hard copy and/or diskette. Date, time, grade of fix (LQ), number of messages, latitude, longitude and bird identification were then compiled in a Lotus 1-2-3¹ spreadsheet (Lotus Development Corp. 1986). Local date and time were calculated and, with the aid of maps, spurious data were eliminated. Next any remaining

¹ The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Dept. of Agriculture or Michigan State University to the exclusion of others that may be suitable.

unreplicated, distant, outlying fixes were culled. We excluded any fixes with <4 messages from the Arizona PTT, but because of limited data we had to include 2-message locations for the Michigan bird. Data were plotted by hand on United States Geological Survey (USGS) 1:500,000 Base Maps, and Defense Mapping Agency (DMA) Aerospace Center 1:5,000,000 Global Navigation and Planning Charts.

Software programme Home Range¹ (Ackerman *et al.* 1989) was used to calculate areas of minimum convex polygons (100%, 95% and 75%) and mean distances from locations to the arithmetic centre, and to plot chronological movements. (Chronological = date/time ordered locations, which may not be consecutive; consecutive = next day locations.) All locations were included in winter and summer range calculations, but calculations on the Arizona eagle's migration were made using only one fix per day, subjectively determined by a consideration of the LQ, number of messages and time of day (later being more likely representative of the day's net movement). Daily movements during migration were categorised as migratory if ≥ 100 km northerly, and local if <100km northerly or non-northerly. For winter roost locations in Arizona we used only fixes after 1700 MST.

RESULTS

Table 1. Satellite telemetry coverage of two Bald Eagles captured as winter migrants in Arizona and Michigan in 1990.

Period	State or Province	Dates	Days	Fix ¹ Days	Fixes	Fixes/Days
Eagle captured in Arizona (PTT 8 h on/16 h off):						
Winter	Arizona	24 Jan-26 Mar	62	41	63	1.5
Migration		27 Mar-02 May	37	37	95	2.6
Summer	NW Terr.	03 May-08 Jun	37	22	47	2.1
Totals		24 Jan-08 Jun	136	100	205	2.1
Eagle captured in Michigan (PTT 4 h on/44 h off):						
Winter	Michigan	03 Mar-28 Mar	26	8	5	0.6
Migration	-	29 Mar	1	1	2	2.0
Summer	Ontario	30 Mar-29 Jun	92	15	20	1.3
Totals		03 Mar-29 Jun	119	24	27	1.1

¹ Number of days with usable, satellite-derived fixes (locations).

We tracked the Bald Eagle captured in Arizona for 136 days, 24 January - 8 June, and the eagle from Michigan for 119 days, 3 March - 29 June (Table 1). The first PTT operated to full term but the second ceased functioning prematurely. Mean number of fixes per day ranged between 0.6 - 2.6, was highest during migration, and increased with latitude. The 8/16 PTT deployed in Arizona provided more fixes/day (2.1 versus 1.1) and better coverage (74% of 136 possible fix-days versus 20% of 119) than the 4/44 unit used in Michigan. Eleven ground checks of the Arizona PTT before and after deployment yielded a mean error distance of 50.7km (s.d. = 58.3, Table 2). Two-message fixes had the largest error distance and were the least reliable. Without them, the mean error distance was 24.4km (s.d. = 24.2).

Table 2. Ground verifications of satellite location data for a PTT before and after being deployed on a wintering Bald Eagle in Arizona, 1990. Actual transmitter location while in hand, or as determined by conventional triangulation and visual confirmation, follow below the satellite data.

Date	Time ¹	Location Quality	Number Messages	Latitude (N)	Longitude (W)	Distance (km)
19 Jan	1948	0	5	35.259	111.793	4.5
	1948			35.250	111.750	
20 Jan	1400	0	6	35.262	111.789	3.4
	1400			35.250	111.750	
21 Jan	1921	0	2	34.977	114.477	202.2
	1921			35.250	111.750	
	1349	0	6	35.224	111.951	
	1349			35.250	111.750	
22 Jan	1341	0	3	35.384	111.349	35.4
	1341			35.250	111.750	
24 Jan	1935	0	9	35.094	112.350	47.0
	1900			35.083	112.875	
30 Jan	1900	0	4	35.018	111.474	4.3
	2203			35.025	111.467	
31 Jan	1833	0	2	35.904	110.509	115.5
	2127			35.058	111.497	
06 Feb	1244	0	7	35.592	111.030	74.4
	1620			35.025	111.467	
24 Feb	1427	1	4	35.504	113.053	7.4
	1345			35.450	113.111	
26 Feb	2026	0	2	34.317	111.233	44.8
	1950			34.892	111.431	

¹ Mountain Standard Time

Between January and March the Arizona eagle ranged over 40,000km² in north-central Arizona (35°N), while the Michigan eagle covered about 22,000km² between Lakes Michigan and Huron in March (45°N, Table 3). The Arizona bird wandered widely across its winter range (Fig. 1). The chronological plot shows roughly four cycles of movements between north-west and south-east areas of heavier activity. The Michigan eagle appeared to move more progressively (Fig. 2), but data are too limited to be conclusive. The winter range in Arizona was approximately twice the area estimated for Michigan.

Table 3. Winter and summer range estimates from Program Home Range (Ackerman *et al.* 1989) for two Bald Eagles equipped with satellite transmitters in Arizona and Michigan in 1990.

Date	Days	State or Province	Area (km ²) of Percent			Distance Centre ¹ (km)
			Minimum 100%	Convex 95%	Polygons 75%	
Eagle captured in Arizona:						
24 Jan-26 Mar	62	Arizona	40,387	26,431	16,526	77.8
03 May-08 Jun	37	NW Terr.	56,022	47,280	33,713	100.4
Eagle captured in Michigan:						
03 Mar-28 Mar	26	Michigan	21,768	11,106	3,618	103.9
30 Mar-29 Jun	92	Ontario	55,160	53,946	25,276	127.4

¹ Mean distance from fixes in 100% polygon ($n = 62, 47, 9, 28$) to arithmetic centre of plot.

The eagle wintering in Arizona used at least 23 different night roost locations between January and March; 21 of these were new, i.e. previously unrecorded (Grubb *et al.* 1989). The same roost was used a second night twice in the 18 pairs of consecutive nights for which location data were available. These were the only roosts occupied more than once during the period. The mean distance between night roosts was 50.7km (s.d. = 38.7, range 0-144km). There were 19 pairs of afternoon (mean time = 1430) and evening (mean time = 1926) fixes, with an average separation of 61.8km (s.d. = 42.1, range 0-177km). No winter same-day fixes were recorded in Michigan, and comparable consecutive night distances could not be calculated from the 4/44 PTT operation pattern.

The Arizona and Michigan eagles began their northward, spring migration with flights of 410 and 435km respectively, within two days of each other (27 and 29 March). The Michigan bird reached its summering grounds north of Lake Superior in Ontario, Canada (50°N), after only one apparent day of migration across the lake (Fig. 3). The Arizona eagle continued northward, covering 3,032km (direct distance) in 37 days, essentially following the Rocky Mountains to north of Great Slave Lake in the North-west Territories, Canada (65°N, Fig 4). Fifteen days of migratory movements were interspersed with 22 days of local movements, totalling an additional 1,509km (Table 4). Migratory moves lasted 1-4 days and local moves 4-7 days (Fig. 5). Local meandering accounted for 33.2% of the total distance covered (4,541km) and 59.5% of the total time spent en route. Migratory flights averaged three times the length of local movements ($t = 4.00$, $P = 0.001$) and were 10% less variable.

From 3 May - 8 June the Arizona eagle ranged over 56,022km², while the Michigan bird covered 55,160km² from 30 March - 29 June (Table 3). The summer ranges of both eagles were larger than winter and showed greater spread, as indicated by the mean distance to arithmetic centres. Chronological movements of the Arizona bird (Fig. 1) indicated heavier use in the south-east portion of its range near Great Slave Lake, and one long, meandering sojourn off to the north-west. Twenty-four pairs of same day fixes yielded a mean flight distance of 64.8km (s.d. = 54.9, range 11-232), which was comparable to the 62.8km average for winter in Arizona (s.d. = 43.0, range 0-123, $n = 22$ pairs; $t = 0.13$, $P = 0.895$). The six pairs of consecutive evening fixes (mean time = 1930) had a mean separation of 98.1km (s.d. = 47.4, range 23-102), approximately twice the winter figure ($t = 2.39$, $P = 0.026$). The Michigan eagle wandered back and forth across its summer range in a northwest-southeast pattern with no definitive area of consistent use (Fig. 2). Length of within day movements (mean = 96.3km, s.d. = 40.3, range 26-154, $n = 5$ pairs) appeared greater than that for the Arizona eagle, but results were not significant ($t = 1.17$, $P = 0.250$).

Table 4. Migratory (100km northward) and local (<100km northward or non-northward) movements during the migration of a Bald Eagle tracked via satellite telemetry from Arizona to the North-west Territories, Canada, in 1990.

Type of Movement	Total Distance (km)	Days	Mean Distance /Day	Std.Dev.	Coeff. Var.	Range (km)
Migratory	3,032	15	202.1	118.7	59%	96-435
Local	1,509	22	68.6	47.3	69%	13-160
Total	4,541	37	122.7	106.5	87%	13-435

DISCUSSION

Until this study the origins of Bald Eagles wintering in Arizona and Michigan were uncertain. Presumably both marked birds returned to their natal areas to summer. The wide-ranging movements across their summer ranges are not surprising for immature non-breeders (Gerrard *et al.* 1980). Weather (Richardson 1978), prey availability (Fretwell 1980), and social interactions (Newton 1979) influence movements on both summer and winter ranges, as well as affect the pattern, distance and duration of migration. The differential migration of these two satellite-tracked eagles gives intraspecific verification of the established tendency for avian species, or individuals within a species, breeding at higher latitudes to migrate further south for the winter (Welty 1975; Newton 1979).

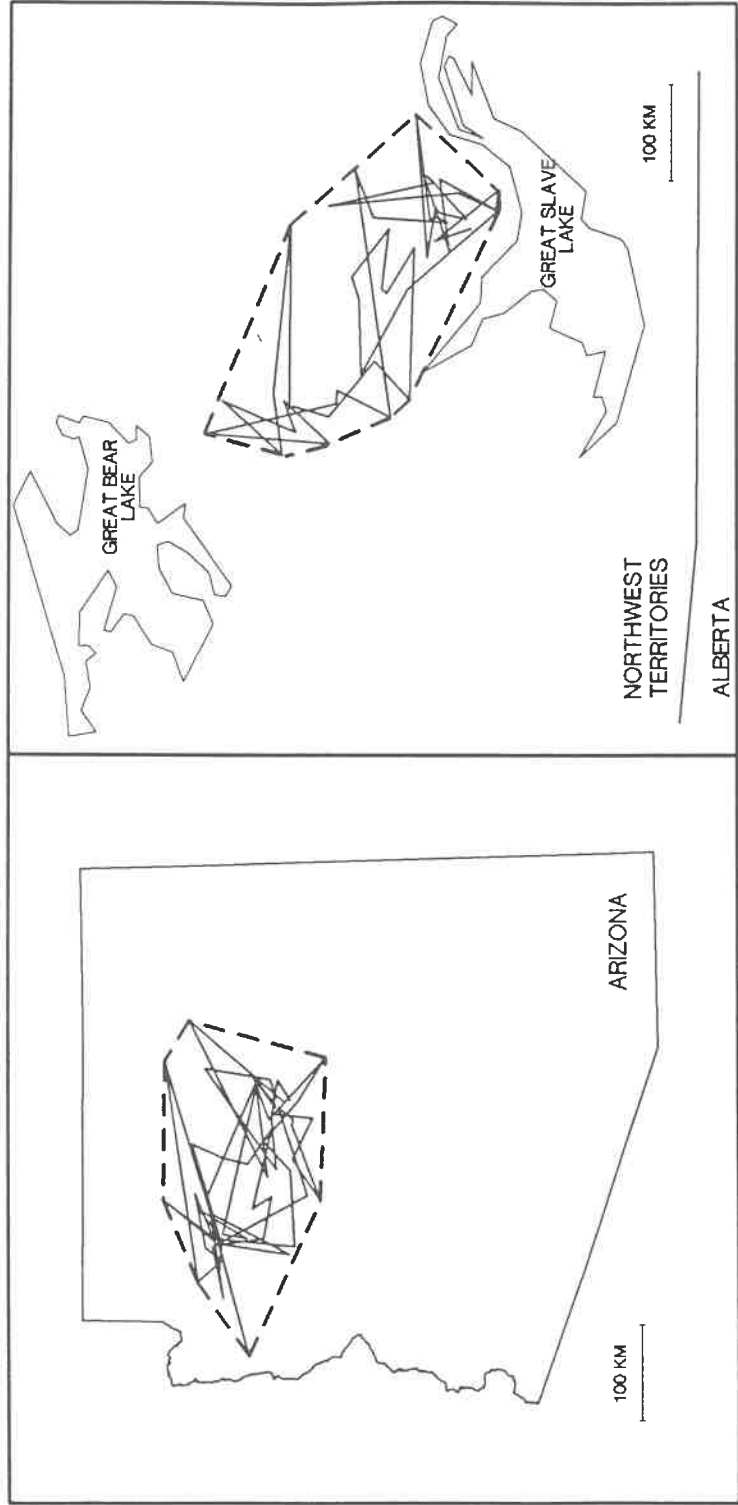
The route followed by the Arizona eagle appears typical. It closely approximates flight paths of 14 Bald Eagles from wintering areas across the intermountain states moving to summer locations in northern Alberta and the North-west Territories (Young 1983). Also, the remains of another, conventionally marked, eagle from the Arizona study were recovered in south-western Montana in November 1990, not far from the satellite track. Our daily migration distances are consistent with the findings of Harmata (1984), who found daily migratory flights ranged from 33-435km and averaged 180km ($n = 10$), for four wintering eagles tracked 1,968-2,077km from Colorado to northern Saskatchewan.

Through our culling procedures, we tried to be conservative in using the satellite data for determining local and seasonal movements, and home ranges. Coverage of the Arizona eagle was sufficient to provide reliable results, but the smaller number of fix days and total fixes, as well as a lack of consecutive and same day data for the Michigan bird, must qualify resultant estimates. The 4/44 operational period was limiting, and we suspect the PTT was not functioning properly. In addition, winter coverage was brief. The chronological movement pattern in Michigan could reflect gradual northward migration rather than winter range movements. The associated area estimates are conservative at best and, because of the small sample size, inconclusive. Even so, the large winter range is likely related to physiographic features and a tendency to wander back and forth between the Great Lakes. Winter meandering in Arizona is explained by an ephemeral prey source, mostly large ungulate carrion, and shifts between higher elevation ponderosa pine (*Pinus ponderosa*) forest and lower pinon (*P. edulis*) - juniper (*Juniperus sp.*) grassland. The extensive summer wandering of both birds may relate to abundant prey and territorial exclusion by breeding adults.

Our winter range sizes are much larger than any previously determined. Young (1983) reported a mean of 761km² (range 4-2,471, $n = 7$) and Harmata (1984), 311km² (range 61-795, $n = 12$). Based solely on roosting locations, previous work in Arizona (Grubb *et al.* 1989), estimated a mean minimum winter range of 401km² (range 292-593, $n = 4$). However, with conventional telemetry, the birds were out of range 51% of the time. Satellite telemetry offers better coverage and greater continuity, especially for long-distance and peripheral movements or when continuous tracking is not otherwise possible.

Although from a small sample, our ground verification results provide a good indication of the

Figure 1. Winter and summer ranges in Arizona and the North-west Territories, Canada, shown as 100% minimum convex polygons with chronological movements, derived from satellite data from a Bald Eagle captured in Arizona in winter, 1990.



WINTER RANGE

SUMMER RANGE

Figure 2. Winter and summer ranges across Michigan and in Ontario, Canada, shown as 100 % minimum convex polygons with chronological movements, derived from satellite data from a Bald Eagle captured in Michigan in winter, 1990.

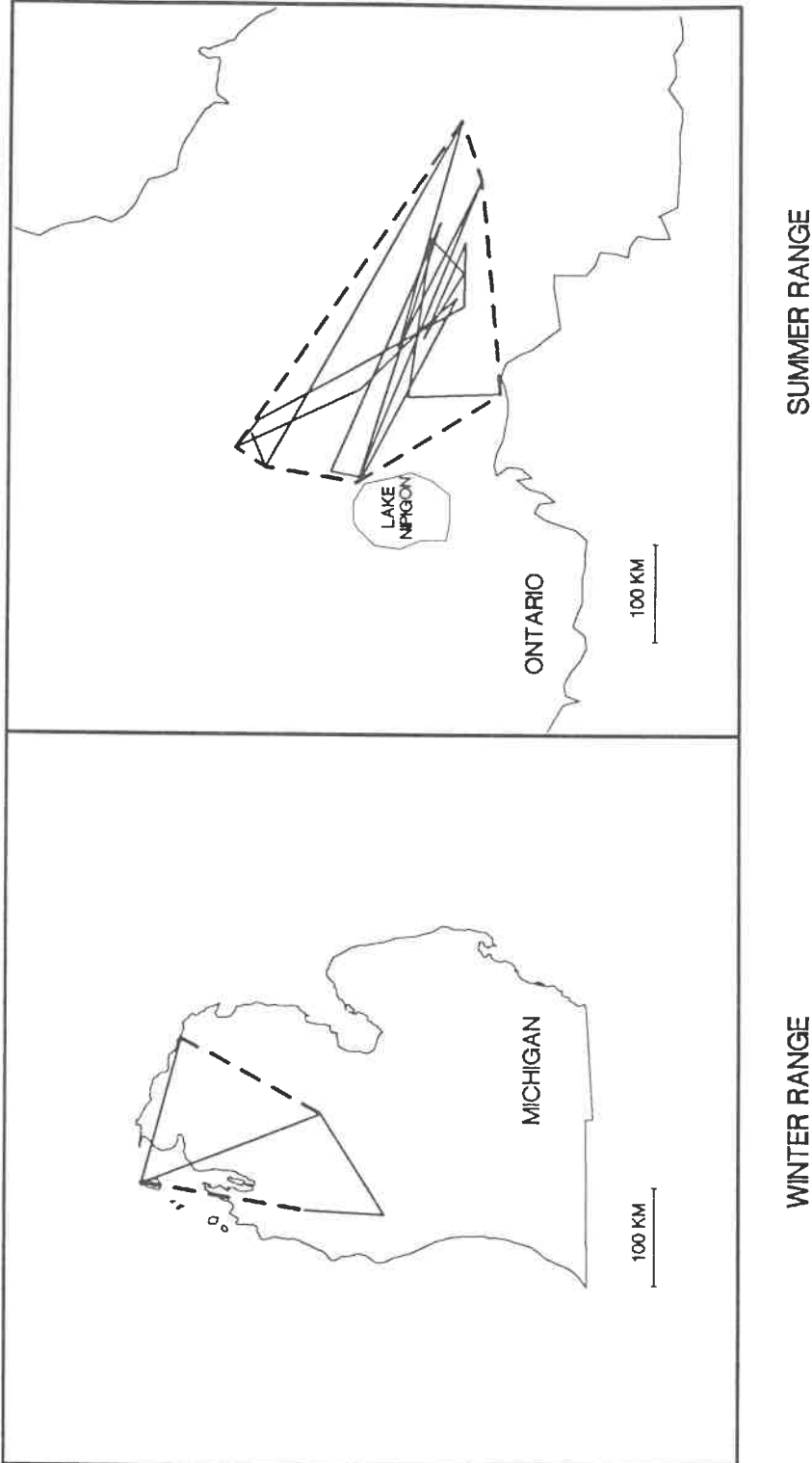


Figure 3. Migration route between winter and summer ranges for a Bald Eagle captured in Michigan in winter, 1990, as determined by satellite telemetry.

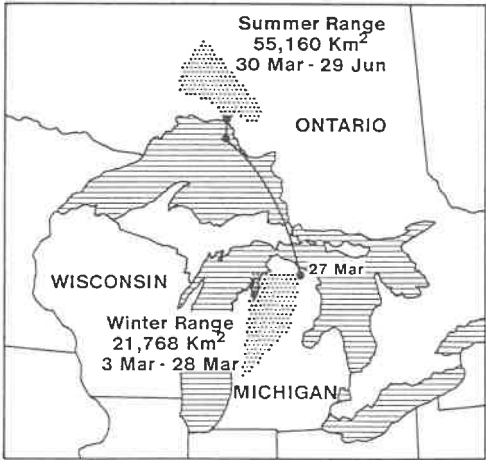


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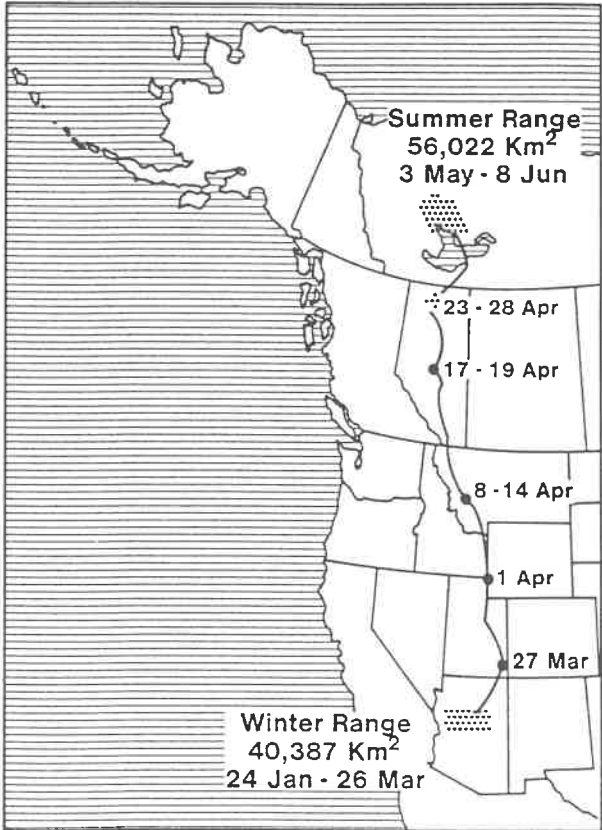
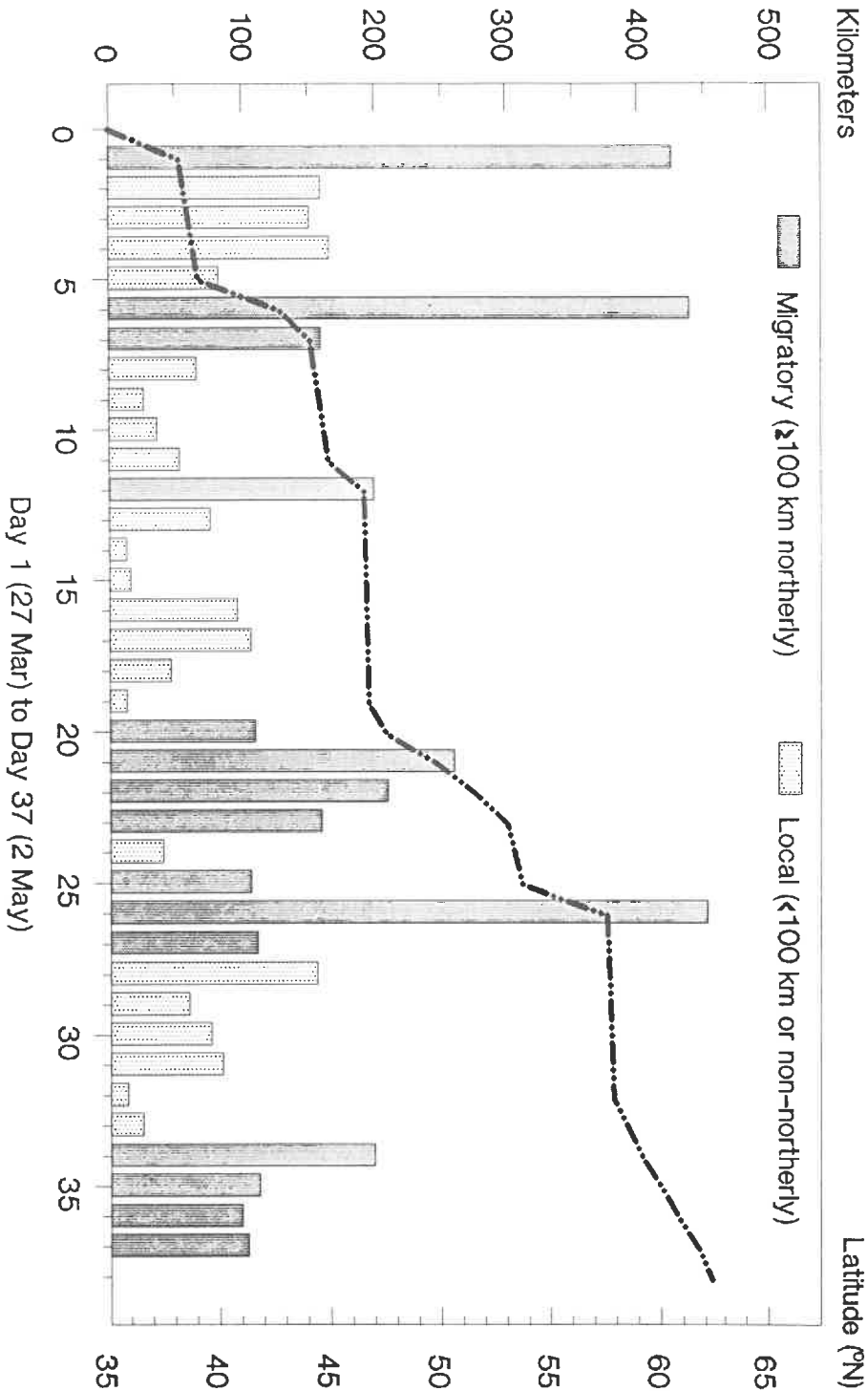


Figure 5. Pattern of local and migratory movements during northward migration of a 3rd-year, female Bald Eagle captured in Arizona in winter, 1990.



variability in accuracy for wildlife tracking via satellite. Attachment of a small conventional transmitter remains mandatory for conventional triangulation, exact location and visual contact. These were necessary elements of the Arizona study. The greatest advantage of satellite tracking in this case is the constant, remote surveillance, which accommodates the inevitable breaks in field tracking due to weather, logistics, administration, etc. A second advantage is being able to get a satellite fix less than an hour old via telephone on the way to the field (or even from the field in some situations). This significantly increases the efficiency of relocation and ground tracking. A conventional transmitter is not needed for home range and migration tracking; for this work, satellite telemetry is unsurpassed in efficiency and effectiveness.

We found, as already indicated, a 4/44 PTT operational cycle provided too few data for certainty in determining the validity of individual fixes, necessary for accurate home range and daily movement determination. The 8/16 cycle was excellent for assessing within day movements, but it tended to provide more data than necessary, which confounded the process of eliminating erroneous or superfluous locations. Better, more diagnostic programmes are improving output, but at the time of this analysis the culling process was tedious and time consuming and, unfortunately, fairly subjective. Although aided by a series of diagnostic keys, the user ultimately assesses the validity of any given fix. Thus a thorough knowledge of the target species and attendant conditions are prerequisite. Although daily locations are sacrificed, experience has shown an 8/40 cycle to be most efficient and effective. PTT's provide better tracking data when kept on as long as possible, and 8/40 gives a 1-year life expectancy. Typical of satellite telemetry, we received more and better fixes as our birds moved north and also during migration, when they were more often airborne and therefore more visible to the satellite.

We believe satellite telemetry is an invaluable technique for tracking the movements of large birds of prey; however, there are several limiting considerations. The questionable accuracy of wildlife-type fixes and the difficulties of data compilation have been mentioned. The number and timing of fixes within the PTT operational period varies from day to day. Quality of fix is affected by several satellite parameters and by the orientation, location and movement of the transmitter on the ground. There are often gaps in the data, resulting from days when no fixes were possible. PTT's are at present larger and less streamlined than conventional transmitters, and require antennas that protrude at a 45° angle rather than contour down the back and tail. Thus satellite units should be used with discretion and attached with great care. They have shorter life cycles than comparable-sized conventional transmitters, but solar-powered units are becoming available to improve longevity. Satellite telemetry is initially expensive: PTT100 series units cost about \$2,900 each, and data processing/tracking approximately another \$1,500. However, this technique is more than cost effective when compared to conventional long distance tracking, which involves tracking equipment, field personnel, vehicle and aircraft expenses, and is subject to myriad logistical, administrative, weather and telemetry related limitations.

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