Home Ranges and Movements of Elk (*Cervus canadensis*) Restored to Southern Ontario, Canada

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During 2000 and 2001, Elk (*Cervus canadensis*) were restored to the Bancroft, Ontario area. The objective of this study was to determine the home range and movements of six social units of Elk, 5–12 years after restoration, in an area of about 2500 km^2 near Bancroft. Home range and movements were calculated from 40 221 Global Positioning System locations acquired from 56 collared Elk (16 bulls and 40 cows) between 2006 and 2013. Annual home ranges were found to be significantly greater (mean 110.3 km^2, standard error [SE] 11.2) for Elk in areas where winter feeding by humans did not occur compared with those (mean 51.0 km^2, SE 9.0) where winter feeding was prevalent. Elk in winter feeding areas had smaller ranges in winter than other seasons. On a seasonal basis, home range size was larger for Elk in areas where winter feeding did not occur; mean winter home range for Elk in non-feeding areas was 73.4 km^2 (SE 34.0) compared with 8.3 km^2 (SE 2.6) for Elk in areas where winter feeding occurred. The 20 Elk that were monitored for multiple years exhibited home range fidelity among years. The entire range of all radio-collared Elk within the social groups studied covered 1716.4 km^2 during 2006–2013. Average daily movements of Elk in the study area ranged from 1.0 to 2.1 km/day with greatest movements occurring during spring and summer. However, some Elk were capable of moving an average of 5–7 km in a 12-h interval. Movements (about 5 km) to winter range occurred during October to December each year. Cows moved to calving areas in May with mean movements of Elk to spring/summer range about 6 km. Cow/calf groups moved to fall ranges by early September with mean movements of about 4 km. During the rut, mean bull movements of 16.0 km to cow groups over 1–5 days occurred in early September. Hunting of Elk during the fall of 2011 and 2012 did not appear to significantly affect the movements and dispersion of Elk in the study area.

Key Words: *Cervus canadensis*; Elk; home range; movements; population restoration; southern Ontario

Introduction

Elk (*Cervus canadensis*) are fairly mobile animals; they are generally capable of extensive movement and have large home ranges (Irwin 2002; Raedeke *et al*. 2002). For example, in some areas of western North America, home ranges of > 350 km^2 have been documented (Benkobi *et al*. 2005); however, in other jurisdictions such as Manitoba, Elk have extremely small ranges < 20 km^2 (Brook 2010). Although the movement of Elk in established ranges of western North America has been well documented (Irwin 2002; Raedeke *et al*. 2002), only a few studies have reported ranges and movements of restored populations in eastern North America (Larkin *et al*. 2004; Fryxell *et al*. 2008; Haydon *et al*. 2008).

In 1998, Ontario embarked on an Elk restoration program as the species had been extirpated in the province (as well as in the rest of eastern North America) during the late 1800s (Rosatte *et al*. 2002, 2007). During 1998–2001, 443 Elk from Alberta were released in four areas of Ontario (Rosatte *et al.* 2007; Rosatte 2013, 2014). These animals included 120 Elk with very high frequency radio-collars that were released near Bancroft, Ontario in 2000 and 2001 (Rosatte *et al.* 2007). In 2000, the Elk were "hard released" immediately on their arrival in Ontario. Extensive movements by those Elk were documented during the initial years (2000–2004) of the restoration program (Fryxell *et al*. 2008; Haydon *et al*. 2008; Ryckman *et al*. 2010). In fact, during 2000 and 2001, the Elk dispersed over 27 000 km^2 of southern Ontario (Rosatte *et al*. 2007; Yott *et al*. 2011). Eventually, the restored Elk became acclimated to their new habitat, and, by the mid-2000s, their movement became less extensive (Fryxell *et al*. 2008; Haydon *et al*. 2008).

During 2006–2012, 56 of the Bancroft area Elk (progeny of the original restored herd) were captured and fitted with Global Positioning System (GPS) collars. The objective was to determine the home range and movements of six social units in an area of about 2500 km^2 near Bancroft, during 2006–2013, 5–12 years after restoration. A secondary objective was to determine the impact of winter feeding on Elk movements as well as the impact of hunting on Elk dispersion.

Study Area

The study area was centred at 44°58'N, 77°33'W near Bancroft, Ontario. The region is influenced by a temperate continental climate with cold winters and warm summers. The elevation is about 200–400 m above sea level. The study area lies within the Great Lakes–St. Lawrence Forest Region (Chambers *et al.* 1997). The habitat includes mixed deciduous and conifer forests with small pockets of agricultural lands in the northern part of the study area. Dominant forest cover species include Sugar Maple (*Acer saccharum* Marshall), Red Maple (*Acer rubrum* L.), Yellow Birch (*Betula alleghaniensis* Britton), Eastern Hemlock (*Tsuga canadensis* (L.) Carrière), and Eastern White Pine (*Pinus strobus* L.; Chambers *et al.* 1997). Snow accumulation during the winter averages 30–50 cm/month. Additional information on the study area, as well as winter severity data, has been documented by Rosatte (2014).

Methods

The telemetry study was conducted during 2006–2013 and involved six social units of Elk in an area of about 2500 km^2 that was termed the Bancroft area core Elk zone (Figure 1). A social unit of Elk usually consisted of mature cows, immature bulls and cows, and calves. The location of individual social units was determined by telemetry and observation. Because of the small sample sizes of some social units, winter feeding of Elk and White-tailed Deer (*Odocoileus virginianus*) in the Bancroft area, and habitat differences (see Rosatte [2014] for differences), the data were pooled for purposes of analysis into two groups of Elk: Lingham and Bancroft. The Lingham group occupied the southern part of the Elk range in the Bancroft area core Elk zone and included the Mephisto and Lingham social units. The Bancroft group occupied the northern part of the core Elk zone and included the Hartsmere, New Carlow/Boulter, Little Ireland, and Turriff social units.

From March 2006 to February 2012, 56 Elk were fitted with GPS collars (Lotek 3300, Lotek Engineering, Newmarket, Ontario, Canada) and random access satellite sensor link GPS/satellite collars (North Star Science and Technology, King George, Virginia, USA) to allow us to investigate their home range and movements. For the purposes of collaring, Elk were captured either by helicopter using a net gun (Bighorn Helicopters Inc., Cranbrook, British Columbia, Canada; Pathfinder Helicopters, South Woods Cross, Utah, USA; Ontario Ministry of Natural Resources and Forestry [OMNRF] Air Services, Sudbury, Ontario, Canada) or by OMNRF staff stalking Elk on the ground and immobilizing them via a dart gun using a tiletamine-zolazepam/xylazine mixture of drugs in a 5-mL dart (for methods see Rosatte 2007). GPS accuracy was tested before collaring by placing four collars in a variety of habitats and acquiring locations using the collars, as well as a handheld GPS unit and topographic maps to confirm them. Accuracy of collar locations was ± 5 m and, for most of the time, was not affected by habitat as Elk tended to use forest openings with a clear view to the satellites.

Only Elk with a minimum of 300 GPS locations, spaced across all seasons during the tracking period were used for annual (12-month) home range calculations. This exceeds the number of fixes recommended by Seaman *et al*. (1999; ≥ 30 locations) and Horne and Garton (2006; ≥ 50 locations) for home range estimation. Telemetry locations were assumed to be independent as individual Elk were tracked daily via GPS collars for 10–36 months, with 6–12 h between daily

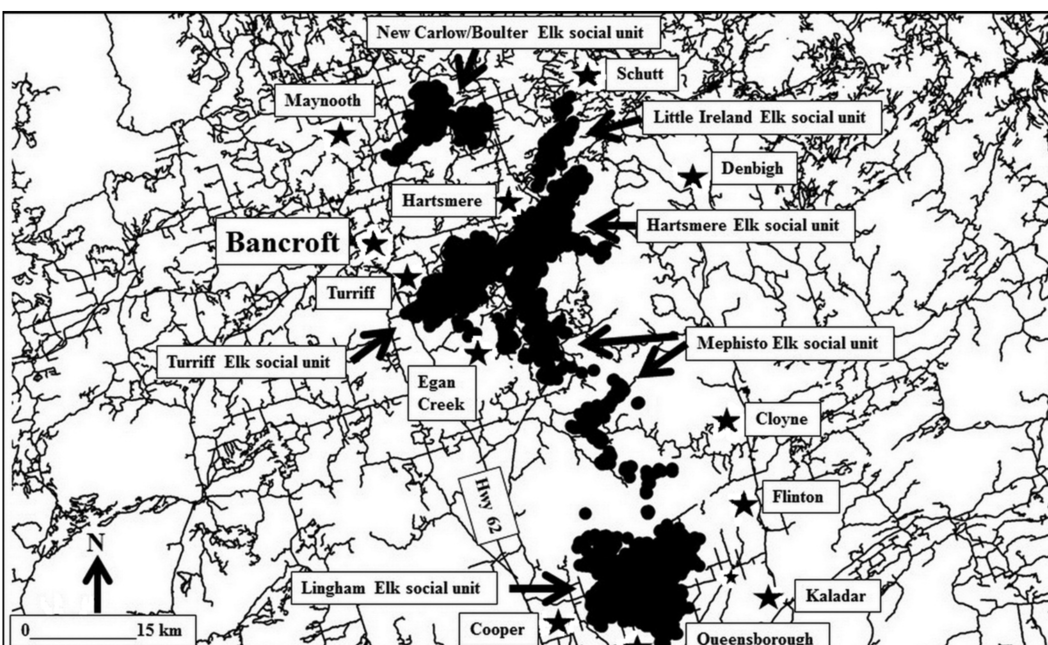

FIGURE 1. Location of Elk (*Cervus canadensis*) social units (based on 39 760 telemetry fixes) within the Bancroft, Ontario, area core Elk zone, 2006–2013. Locations of towns/villages (stars) are approximate. Locations of Elk social units are denoted by the black areas of the figure, which represent telemetry fixes.

fixes (White and Garrott 1990). For seasonal home range analyses (3–5 months in duration), only Elk with a minimum of 80 fixes over the season were used for range calculations.

A 100% minimum convex polygon (MCP), created using Hawth's tools (Beyer 2004), was used to estimate total annual, as well as seasonal, range use for each Elk. We used the MCP model, as it is generally the estimator most frequently reported in the literature and allowed comparisons with Elk home ranges in other North American jurisdictions. Seasonal home ranges were determined for each of three periods based on the ecology of Elk in Ontario (Rosatte 2014): spring/summer range, 1 April to 31 August; fall range, 1 September to 30 November; winter range, 1 December to 31 March. The total annual population range for each social unit of Elk was also calculated using locations from all collared Elk in the unit. If more than 75% of among-year annual ranges overlapped, the animal was assumed to exhibit annual range fidelity.

We also used a 95% fixed kernel (Gaussian bivariate normal), determined using Home Range Extension for Arcview (Esri, Redlands, California, USA; Rodgers *et al*. 2005), to calculate annual home ranges for Elk, as this method removes outlying fixes that may result in overestimates. Schoener, Swihat, and Slade indices were calculated to determine the independence of the telemetry data (Rodgers *et al.* 2005). The smoothing factor for the kernel analysis was based on variance of the x and y coordinate data. The data were rescaled, and the bandwidth or smoothing factor for the kernel was selected using a proportion of the reference bandwidth.

The maximum movement distance across seasonal and annual ranges and movement to and from the centre of one seasonal range to the next were calculated using the measuring tool in ArcGIS 9.2 (Esri). Total cumulative movement on a seasonal basis, daily movement, and the greatest distance moved between fixes was calculated using ArcGIS 9.2, ArcMap, and Hawth's tools (Esri). To determine the impact of the September 2011/12 recreational hunt on Elk dispersion, the distance from the centre of their pre-hunt range to the maximum distal movement during the hunt and two weeks post-hunt was calculated using the ArcGIS 9.2 measuring tool. Significant movements followed by a cessation of movements by cow Elk during May and June of any given year indicated the timing of parturition (as per the methods of Allan 2013).

Ranges and movements of GPS-collared Elk within social groups of Elk in the Lingham and Bancroft areas were analyzed separately then compared, as winter feeding by residents in the Bancroft area was expected to have a significant impact on Elk movements. There are also habitat differences between the two areas as noted under Study Area, above, and by Rosatte (2014). Home range and movement data were analyzed using analysis of variance (ANOVA) models in Statistica 6.0 software (Dell, Round Rock, Texas, USA). ANOVAs are robust and not seriously affected by a lack of normality (Zar 1999). However, the data were first screened using Statistica (StatSoft, Tulsa, Oklahoma, USA) to verify the normality assumption and to test for heterogeneity of variances (Levene's test). Where assumptions were not met, i.e., the data were not normally distributed, the data were transformed using a Box-Cox power transformation (maximum likelihood estimation), which transforms the data as close to normality as possible. A repeated measures ANOVA was used for multiple variable comparisons, e.g., sex and age, home range and movements (Zar 1999). A Friedman ANOVA was used for comparisons in an individual sex and age class. Where two variables were being compared and the data met normality assumptions, a one-way ANOVA was used. If a statistical difference was noted, *post hoc* analyses were conducted using a Tukey test (Zar 1999). A Student t test for independent variables was used to compare bull movement to rutting areas in the Lingham and Hartsmere Elk groups, as well as differences in movements of cow and bull Elk during the parturition period. Dispersion of GPS-collared Elk was monitored and analyzed to determine when bull Elk moved to cow groups during the rutting period as well as when bulls left the cow groups after the rut was complete. This was accomplished by using simultaneous GPS locations (± 5 m accuracy) of Elk plotted in Google Earth (Google, Mountainview, California, USA). Sightings of Elk in eastern Ontario by OMNRF biologists and members of the public were tabulated and plotted on a map to depict their occurrence outside the Bancroft area core Elk zone.

Results

Annual and Seasonal Home Ranges of Individual Elk

Between 1 March 2006 and 31 March 2013, 56 GPS-collared adult Elk (40 cows, 16 bulls) were monitored for an average of 345 days (standard deviation [SD] 110) in the Bancroft area core Elk zone. The number of Elk fitted with collars each year was six in 2006, four in 2007, five in 2008, six in 2009, nine in 2010, 20 in 2011, and six in 2012. The total number of locational fixes for all collared Elk was 40 221 and the mean number of fixes per Elk was 731 (SD 596). The GPS collars were successful in transmitting a locational fix 85% of the time (40 221 times in 47 153 attempts).

Mean annual home ranges were significantly greater for Elk in the Lingham group (MCP 110.3 km^2) than in the Bancroft group (51.0 km^2) during 2006–2013 (Table 1, Appendix S1). No differences in mean annual home ranges were found between bulls (94.7 km^2) and cows (116.9 km^2) in the Lingham group (Table 1). Statistical differences were also not detected between bull ranges in the Lingham and Bancroft Elk groups. However, mean annual home ranges for bulls (117.5 km^2) in the Bancroft area were significantly larger than those for cows in that area (33.7 km^2; Table 1). In addition, annual MCP ranges for cows in the Lingham area were significantly larger than those for cows in the Bancroft area (Table 1, Appendix S1). Statistical analysis of the 95% kernel home range data yielded similar results to the MCP analysis (Table 1, Appendix S1).

Seasonal home ranges: For the Bancroft social group, bull and cow ranges during spring/summer and fall were significantly greater than their winter ranges. Bull ranges in Bancroft were also greater than cow ranges during spring, summer, and fall, but not during winter (Table 1, Appendix S2). Bull and cow Elk ranges in the Bancroft area were extremely small (mean 8.3 km^2) during the winter (Table 1).

Seasonal home ranges for the Lingham Elk group (bulls and cows) were significantly larger than ranges for the Bancroft Elk group during spring/summer, fall, and winter (Table 1). In particular, mean Elk ranges during the winter were dramatically larger in the Lingham area (73.4 km^2) than in the Bancroft area (8.3 km^2). Lingham cow ranges were significantly greater than Bancroft cow ranges during all seasons, but only greater than Bancroft bull ranges during the winter. Lingham bull ranges were significantly larger than Bancroft bull ranges only during the winter, but were greater than Bancroft cow ranges during all seasons (Table 1, Appendix S2).

Home range fidelity: Twenty cow Elk were monitored for 2–3 years: eight from the Lingham social unit, four from the Hartsmere unit, and two each from the Turriff, New Carlow, Mephisto, and Little Ireland Elk social units. All 20 exhibited annual range fidelity with > 75% of their among-year ranges occupying the same area as in previous years (2009–2013).

Population range: The entire population range of all radio-collared Elk in the social units and groups that were studied covered 1716.4 km^2 within the 2500-km^2 core Elk zone study area (ranges for individual social units are provided in Appendix S3). This estimate was based on a sample of 46 radio-collared Elk and 39 760 locational fixes during 2006–2013 (Table 2). The entire range of collared Elk in the Bancroft area core Elk zone included an area from Maynooth east to Schutt in the north, south about 82 km to the Queensborough area (Figure 1). The width of the range was approximately 20–30 km in the Bancroft/Harstmere area and about 16 km in the Lingham area. The population range 5–12 years after restoration was significantly smaller (by an order of magnitude; $P < 0.05$) than the range of Elk (> 27 000 km^2) during the restoration phase of the program in 2000 and 2001 (as documented by Yott *et al.* 2011).

Annual and seasonal movements of Elk

Examination of the annual and seasonal movements of the Bancroft and Lingham Elk groups revealed significant interaction. Further testing showed the interaction to be primarily because movements of the Lingham Elk group (mean 1.5 km/day) were significantly greater than those of the Bancroft group (mean 1.0 km/day) during the winter (Table 3, Appendix S4). In the Bancroft Elk group, mean annual bull and cow movements were significantly different: 1.7 km/day versus 1.2 km/day, respectively (Table 3, Appendix S4). In fact daily bull movements in the Bancroft area were greater than cow movements during spring/summer and fall, but not during winter (Table 3). Such differences were not detected in the Lingham Elk group daily movement data, either seasonally or annually (Table 3, Appendix S4). Further analysis of the movement data with respect to between-area and sex comparisons revealed that Lingham cow movements were significantly greater than Bancroft cow movements annually as well as during the winter but not during spring/summer or fall (Table 3, Appendix S4).

Movements between seasonal home ranges: Elk in the Bancroft and Lingham areas exhibited movements

TABLE 1. Annual and seasonal home ranges of social groups of Elk (*Cervus canadensis*) in the Bancroft, Ontario area, 2006–2013, based on 40 211 telemetry fixes.

Elk group*	Winter feeding	Age/sex	$n^{\dagger}$	Mean home range, km^2 (SE) Annual MCP	Annual 95% kernel	SpSu MCP	Fall MCP	Winter MCP
Bancroft bulls	Yes	AM	6	117.5 (14.0)	92.2 (11.2)	60.9 (10.1)	70.0 (15.7)	3.1 (3.4)
Bancroft cows	Yes	AF	23	33.7 (7.2)	27.9 (5.7)	28.0 (5.5)	17.0 (9.0)	9.5 (1.7)
Bancroft group	Yes	M/F	29	51.0 (9.0)	41.2 (7.5)	35.4 (5.0)	30.2 (8.3)	8.3 (2.6)
Lingham bulls	No	AM	6	94.7 (20.0)	80.1 (18.3)	46.7 (9.8)	53.9 (18.1)	60.7 (11.9)
Lingham cows	No	AF	14	116.9 (13.5)	93.4 (12.0)	48.6 (6.7)	42.7 (9.4)	76.0 (5.3)
Lingham group	No	M/F	20	110.3 (11.2)	89.4 (9.0)	48.0 (6.0)	45.1 (9.3)	73.4 (3.4)

*The Bancroft group consisted of social groups in the Turriff, New Carlow/Boulter, Little Ireland, and Hartsmere areas; the Lingham group consisted of those in the Lingham and Mephisto Lakes areas.

†Sample sizes for annual home ranges only. For seasonal ranges, sample sizes were 6, 24, and 30 for Bancroft bulls, cows, and the group, respectively; sample sizes were 3, 15, and 18 for Lingham bulls, cows, and the group, respectively.

Note: AF = adult female; AM = adult male; M/F = adult males and adult females; MCP = minimum convex polygon; SE = standard error; SpSu = spring summer.

TABLE 2. Population range of social units and social groups of radio-collared Elk (*Cervus canadensis*) in the greater Bancroft, Ontario area, 2006–2013.

Elk social unit/group	Years	Number collared Elk	Number telemetry fixes*	Population range, km²	Maximum distance across range, km
Hartsmere unit	2006–2012	17	22 159	607.8	41.0
Turriff unit	2009–2012	4	2 607	39.9	9.4
New Carlow unit	2009–2012	3	2 168	82.6	14.5
Bancroft group	2006–2012	24	26 934	941.9	50.5
Lingham unit	2010–2013	20	11 762	400.5	35.0
Mephisto unit	2011–2012	2	1 064	84.8	17.2
Lingham group	2010–2013	22	12 826	724.3	58.7
All Elk	2006–2013	46	39 760	1716.4	81.6

*One cow from Little Ireland and one bull from Madoc were not included in range calculations.

TABLE 3. Annual and seasonal daily movements of Elk (*Cervus canadensis*) in the Bancroft and Lingham areas, Ontario, 2006–2013, based on 40 221 telemetry fixes.

Elk group*	Winter feeding	Age/ sex	*n*	Movement, mean km/day (SE)			
				Annual	SpSu	Fall	Winter
Bancroft bulls	Yes	AM	7	1.7 (0.2)	2.0 (0.2)	2.1 (0.3)	1.2 (0.2)
Bancroft cows	Yes	AF	22	1.2 (0.1)	1.4 (0.1)	1.4 (0.2)	1.0 (0.1)
Bancroft group	Yes	M/F	29	1.3 (0.1)	1.6 (0.1)	1.6 (0.1)	1.0 (0.1)
Lingham bulls	No	AM	6	1.5 (0.1)	1.5 (0.1)	1.6 (0.1)	1.2 (0.2)
Lingham cows	No	AF	16	1.4 (0.1)	1.3 (0.1)	1.3 (0.1)	1.5 (0.1)
Lingham group	No	M/F	22	1.4 (0.1)	1.4 (0.1)	1.4 (0.1)	1.5 (0.1)

*The Bancroft group consisted of social units in the Turriff, New Carlow/Boulter, Little Ireland, and Hartsmere areas; the Lingham group consisted of those in the Lingham and Mephisto Lakes areas.
Note: AF = adult female, AM = adult male, M/F = adult males and adult females, SE = standard error, SpSu = spring summer.

to seasonal ranges during the year. Movements from fall to winter ranges generally occurred during October to December. Movements to spring/summer ranges were less distinct for bulls; however, cows usually moved to their spring/summer range for calving in May. Following calving, cows rejoined their social units in July/August and moved to fall ranges by early September. Bulls joined the social units during early to mid-September, which coincided with the rut on the fall range. Bulls usually left the social group by late October (except in areas where winter feeding occurred).

Elk in the Bancroft area had separate seasonal ranges every year from 2006 to 2012 (see Figure 2 for an example). Bancroft area bull Elk travelled significantly greater distances (mean 13.5 km) from winter range to spring/summer range than adult cow Elk (mean 4.5 km) (Table 4, Appendix S5). Bulls also travelled farther than cows from spring/summer to fall ranges and from fall to winter ranges in the Bancroft area (Table 4). Bancroft area bull movements were significantly greater than Lingham area bull movements from winter to spring range. No differences in movements to seasonal ranges were detected between Lingham and Bancroft area cow Elk or between bull and cow Elk in the Lingham area (Table 4, Appendix S5).

Movement potential of Elk: No differences were detected in mean 12-h movement distances by Elk in spring/summer (5.4 km, SE 0.4), fall (6.0 km, SE 0.6), or winter (6.8 km, SE 0.6; Appendix S5). There were also no differences in mean 12-h movements between bulls (6.1 km, SE 0.6) and cows (5.9 km, SE 0.4; Appendix S5). However, mean movements in a 12-h period were greater for Elk in the Lingham area (6.9 km) than those in the Bancroft area (5.3 km; Table 4, Appendix S5). Among 54 Elk, 25 (48%) had the greatest 12-h movements during the spring/summer, 15 (28%) during the fall, and 13 (24%) during the winter.

Directional movement of Elk: Elk travelled a mean distance of 9.9 km (SD 6.0) from the point of radio-collaring. No significant differences in mean bearing of annual movements were detected between bulls (176.4°, SE 1.6) and cows (173.6°, SE 1.0; $P = 0.14$); however, there was a significant difference between Bancroft area Elk (176.5°, SE 1.0) and Lingham area Elk (171.3°, SE 1.2; $P = 0.001$).

Movements among social groups: Of the 56 Elk that received GPS collars during 2006 and 2012, 16 (29%) moved into the home range of another social unit while they were being monitored. There was very little movement of Elk from the Bancroft area to the Lingham area and vice versa. In fact, only two bulls were documented travelling 10 km and 50 km, from the Hartsmere area south to the Mephisto and Queensborough areas (Lingham Elk social group), respectively, during 2006–

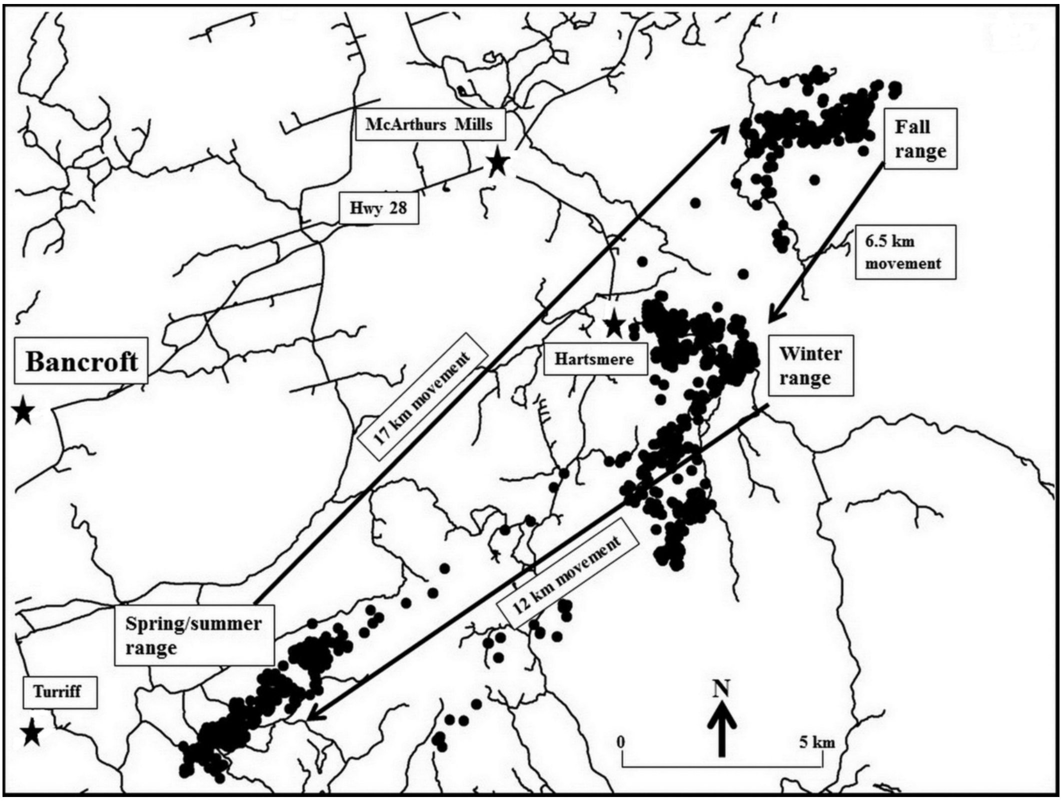

FIGURE 2. An example of the location of spring/summer, fall, and winter ranges (based on 2786 telemetry fixes) of a mature bull Elk (*Cervus canadensis*) in the Bancroft, Ontario area from 1 April 2006 to 31 March 2007.

TABLE 4. Distance moved between seasonal home ranges and maximum distance moved during any 12-h period by Elk (*Cervus canadensis*) in the Bancroft and Lingham areas, Ontario, 2006–2013.

				Distance moved, mean km (SE)			
Elk group*	Winter feeding	Age/ sex	*n*	From winter to SpSu range	From SpSu to fall range	From fall to winter range	Maximum in 12 h during time tracked†
Bancroft bulls	Yes	AM	5	13.5 (1.3)	10.5 (1.2)	10.5 (2.0)	6.8 (0.7)
Bancroft cows	Yes	AF	19	4.5 (0.7)	2.6 (0.6)	3.7 (1.0)	4.8 (0.4)
Bancroft group	Yes	M/F	24	6.4 (1.0)	4.3 (1.0)	5.1 (1.0)	5.3 (0.4)
Lingham bulls	No	AM	2	2.5 (3.6)	5.6 (3.9)	4.7 (1.9)	5.3 (0.9)
Lingham cows	No	AF	15	6.3 (1.2)	4.2 (1.3)	5.2 (0.7)	7.5 (0.6)
Lingham group	No	M/F	17	5.8 (1.2)	4.4 (1.1)	5.1 (1.0)	6.9 (0.5)

*The Bancroft group consisted of social units in the Turriff, New Carlow/Boulter, Little Ireland, and Hartsmere areas; the Lingham group consisted of those in the Lingham and Mephisto Lakes areas.
†For these calculations, sample sizes were 7, 24, 31 for Bancroft bulls, cows, and the group, respectively, and 7, 16, and 23 for Lingham bulls, cows, and the group, respectively.
Note: AF = adult female, AM = adult male, M/F = adult males and adult females, SE = standard error, SpSu = spring summer.

2013. In addition, two cow Elk from the Lingham herd moved 25 km north to the Hartsmere Elk social unit range.

Significant movement of bulls and cows among the various social units of Elk in the Bancroft area was documented. Three Hartsmere bulls moved 23 km to the Turriff social unit range and three other bulls moved 10 km to the Little Ireland social unit range between 2006 and 2012. In addition, four cows moved 10 km from the Hartsmere social unit to the Little Ireland unit, and two Hartsmere cows moved 10 km to the Turriff social unit range between 2006 and 2012 (Figure 1).

Movement of bull Elk to cow groups during the rut: Collared bull Elk ($n = 6$) travelled to cow units for the rut in the Lingham Lake area during 7–15 September 2012 (Figure 3). Travel time averaged 2.1 days (SD 1.43; range 0.5–4 days). Mean movement of six collared bulls to the rutting areas was 6.4 km (SD 0.49, range 6.0–7.1 km). One mature bull was documented travelling 10 km in three days to visit three different social units of cows (which were 5 km apart). Bull Elk ($n = 5$) in the Bancroft area moved to cow social units for breeding during 4–19 September 2006–2009. Mean movement of bulls to rutting areas was 16.0 km (SD 9.08, range 5.2–26.9 km). The average time to travel to rutting areas was 2.2 days (SD 1.79, range 1–5 days). Bull Elk in the Bancroft area travelled significantly greater distances to rutting areas than did bull Elk in the Lingham area ($P = 0.03$).

Impact of the hunt on Elk dispersion: During 2011, 22 cow Elk with functioning GPS collars moved an average of 2.0 km (SD 0.67; range 1.1–3.7) from the centre of their fall pre-hunt range during the two weeks before the hunt (5–18 September 2011). During the hunt (19–25 September 2011), those Elk moved an average of 1.0 km (SD 0.79, range 0.1–3.1) outside their pre-hunt range. Of those Elk, 20 (91%) returned to their pre-hunt range within two weeks of the end of the hunt.

During 2012, 22 Elk (17 cows, five bulls) with functioning GPS collars moved an average of 2.6 km (SD 1.43, range 0.8–5.3) from the centre of their fall pre-hunt range during the two weeks before the hunt (3–16 September 2012). During the hunt (17–30 September 2012), those Elk moved an average of 2.0 km (SD 1.56, range 0.3–6.4) outside their pre-hunt range. Again, 91% returned to their pre-hunt range within two weeks following the end of the hunt.

Elk use of hydro corridors for movement: Elk used hydro corridors for movement as well as for foraging in the Lingham area during 2006–2013. Of 23 Elk collared in the Lingham area, 10 (six cows, four bulls) used hydro corridors based on GPS locations from their collars. One cow moved 9 km along a corridor during calving season (Figure 4). Movements along hydro corridors occurred during all seasons, but use was more frequent (nine of 10 Elk) during spring and summer.

Elk sightings outside the southern Ontario core Elk range

During 2003–2012, 206 Elk sightings (usually accompanied by photographs for verification) were reported to the author by the public and by OMNRF staff. That included individual Elk as well as groups of up to nine Elk. These Elk represent individuals and their progeny that dispersed from the 2500 km^2 core Elk area near Bancroft, Ontario. The locations of the Elk sightings are depicted in Figure 5 and occurred over approximately 50 000 km^2 of southern Ontario.

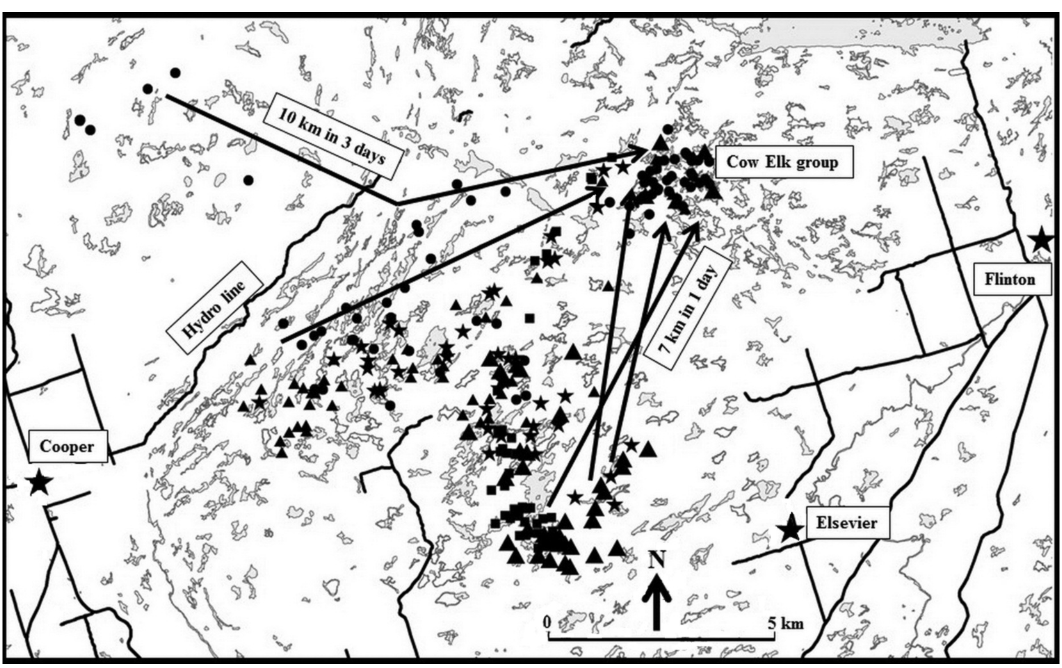

FIGURE 3. Example of movements of five collared bull Elk (*Cervus canadensis*), based on 210 telemetry fixes, toward a large cow Elk social unit before and during the rutting period in the Lingham Lake area, 23 August to 15 September 2012. Movements by bulls of 6–10 km occurred over 0.5–4 days, during 7–15 September 2012. A sixth collared Bull Elk followed the same route to the cow Elk area as one of those depicted but is not shown.

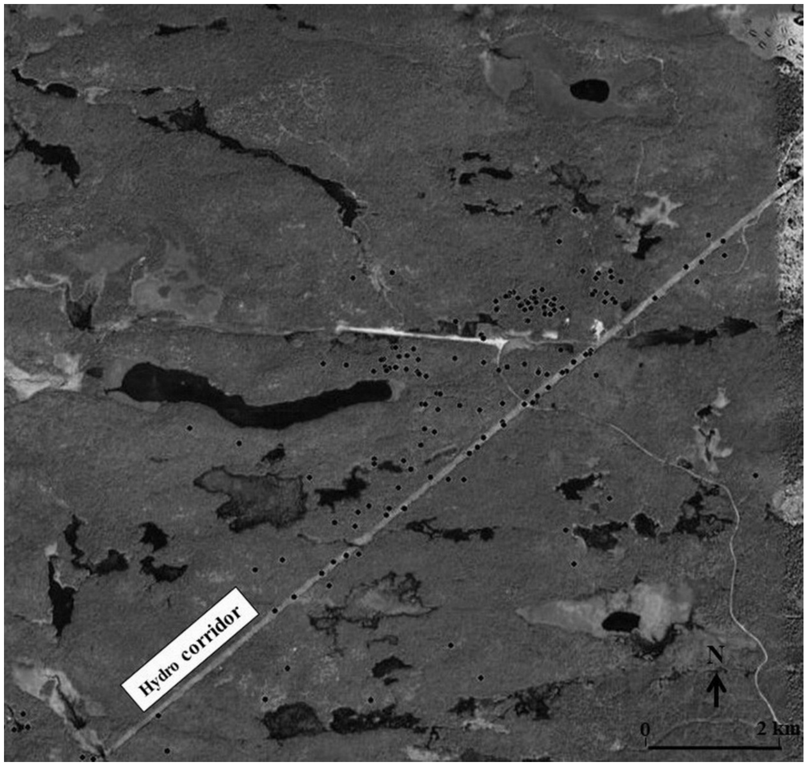

FIGURE 4. Example of a cow Elk (*Cervus canadensis*) using hydro corridors to travel north of Lingham Lake, Ontario, as indicated by telemetry fixes.

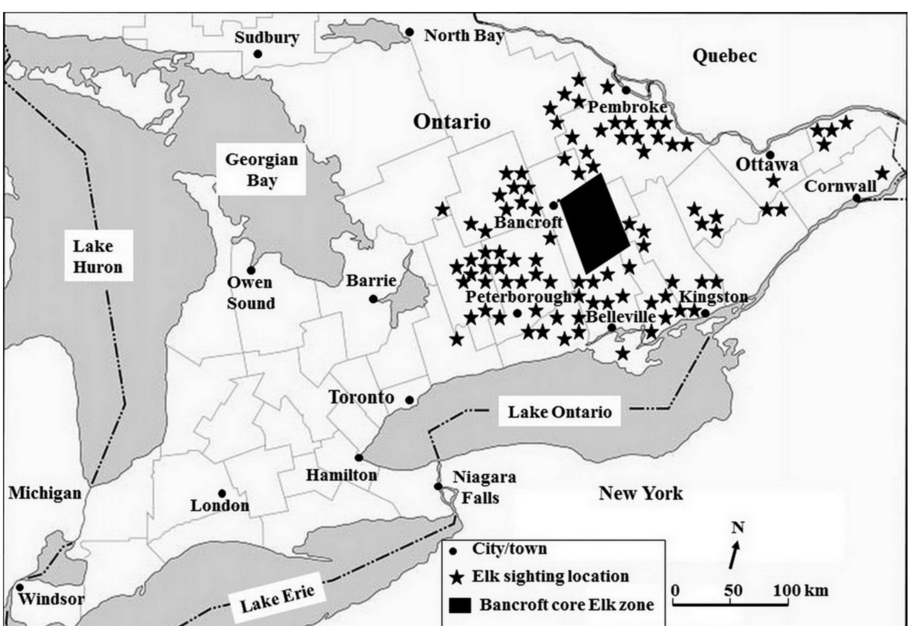

FIGURE 5. County map of southern Ontario, Canada, showing the Bancroft area core Elk zone (the black rectangle) and approximate locations of Elk (*Cervus canadensis*) sightings outside of the core zone, indicating range expansion during 2003–2013.

Discussion

During the late 1800s, Elk were extirpated from eastern North America, including Ontario, because of unregulated hunting, habitat loss resulting from the conversion of land for the production of cattle and crops, and conflicts with humans (Bryant and Maser 1982; Ranta *et al*. 1982; Bosveld 1996; Bellhouse and Rosatte 2005). During the most recent restoration, Elk were acquired from Elk Island National Park, Alberta, and released in four areas of Ontario during 1998–2001 (Rosatte *et al.* 2007; Rosatte 2013). Elk are currently doing exceptionally well in two of the release areas (populations have more than quadrupled), including the Bancroft area in southern Ontario, which was the focus of this study (Rosatte *et al*. 2002, 2007; Rosatte 2013, 2014).

When Elk were released in the Bancroft area in 2000, the herd quickly fragmented and dispersed over a 10 000–27 000 km^2 area (Haydon *et al*. 2008; Yott *et al.* 2011). More than 50% of the animals dispersed more than 40 km from the release site with males and females having annual ranges totalling 15 000 km^2 and 19 000 km^2, respectively (Yott *et al*. 2011). This was a direct result of an unintentional "hard release", i.e., Elk were not held in an enclosure for a recovery or acclimatization period before release as they escaped from the holding pen (Rosatte *et al*. 2007). However, after 2–3 years of a dispersive phase, Elk moved into a home range phase with fewer extensive movements (Fryxell *et al.* 2008). This was confirmed during the current study, as the population range of adult Elk (1716 km^2) 5–12 years after restoration was significantly smaller than the range (> 27 000 km^2) during the restoration phase of the program in 2000 and 2001 (Yott *et al*. 2011). A smaller range is an advantage, as Elk remain in the area where they were intended to be restored.

In this study of the Bancroft and Lingham area Elk groups, average annual home ranges (MCP) for bulls and cows 5–12 years after restoration ranged between 34 km^2 and 118 km^2. Annual kernel ranges (95%) were 79% to 84% that of MCP annual ranges. The kernel ranges are more representative of the core range used by Elk in the Bancroft area, as that analytical method removes outlying telemetry locations that are not part of the core range.

Home range sizes for cow Elk during the 1990s in the Burwash/French River area of Ontario were about 25–50 km^2 with bulls having larger ranges than cows (Hamr and Filion 1996; Bellhouse and Broadfoot 1998). In Manitoba, mean home ranges of cow Elk in forest and agricultural, forested, and farmland areas were 18 km^2, 4.7 km^2, and 4.5 km^2, respectively, in 2002–2005 (Brook 2010). At the other end of the spectrum, cow Elk annual ranges in Colorado and New Mexico were large, averaging 250 km^2 (Webb *et al.* 2011).

The study by Webb *et al*. (2011) also noted a between-year home range overlap of 68%. In the Bancroft study, all cow Elk that were monitored for multiple years exhibited range fidelity. Range fidelity is advantageous for Elk as they have previous knowledge of forage resources and security cover (Webb *et al*. 2011). This is also beneficial from a restoration perspective as Elk remain in an area when released. Range fidelity also facilitates monitoring of Elk populations as survey staff can go to the general areas that Elk have been using for several years.

Home ranges for Elk groups in the Bancroft area core Elk range averaged 30–50 km^2 during spring/summer and fall. However, during winter, ranges in areas where winter feeding occurred averaged only 8 km^2 compared with 73 km^2 in areas where winter feeding did not occur. Although not always the case, Geist (2002) suggests that home ranges in some habitats during winter may be larger than ranges in summer as resources are more restricted in winter making Elk travel farther to meet their energy requirements. In support of this, the home ranges of a migratory herd of Elk in South Dakota averaged 163 km^2 in summer and 355 km^2 in winter (Benkobi *et al*. 2005). Anderson *et al.* (2005) also found an inverse relationship between forage biomass and winter and summer home ranges for Elk in Alberta and Wisconsin. In contrast, ranges in the Bancroft area were smaller in winter, likely because sufficient resources were available as a result of feeding by residents. However, if Elk are confined to a small area in winter, contact among them is increased, which will facilitate the spread of disease and parasites.

Factors other than winter feeding may also affect the size of the winter range. In Yellowstone National Park during the late 1960s, the ranges of cow Elk were 0.3–3.9 km^2 in winter; 1.8–6.2 km^2 in spring; 3.1–16.8 km^2 in summer; and 5.2–16.6 km^2 in fall. In this situation, small winter ranges were a result of movement restriction by deep snow (Craighead *et al.* 1971). Moran (1973) postulated that Elk movements were restricted when snow depth exceeded 46 cm in Michigan. In general, in the current study, snow depth did not appear to affect winter Elk movements in the Lingham area south of Bancroft given the large winter range of those Elk.

In some areas of western North America, Elk migrate from 2.4 km to 150 km between seasonal ranges (Irwin 2002; White *et al*. 2010). Generally, in those areas, spring migrations occur during May/June and fall migrations from September to December (Irwin 2002; White *et al*. 2010). Usually, initiation of migration is stimulated by snow depth (about 20 cm) and snow compaction, which reduces forage availability and increases energy demands (Benkobi *et al.* 2005). The timing of forage green-up can also influence the initiation of spring migration (White *et al*. 2010). The direction of movement may depend on the forage quality and quantity of the habitat and the duration of migration can be 7–43 days in some areas (Benkobi *et al.* 2005; White *et al*. 2010). Elk in the French River area of Ontario migrated about 20 km from summer to winter ranges, whereas Elk at Burwash did not migrate

(Bellhouse and Broadfoot 1998). Similarly, parts of the Yellowstone herds were non-migratory and movements were generally less than 1.6 km in 24 h (Craighead *et al.* 1971). In the current study, Elk groups in the Bancroft area moved about 4–6 km between seasonal ranges. Whether this small distance can be classed as migration depends on one's definition of migration.

With the initiation of the rut during the fall in the Bancroft area, bull Elk moved considerable distances to find groups of cows for breeding. Bull Elk in the Bancroft area moved greater distances to rutting areas than those in the Lingham area. This was probably a function of the dispersion of Elk social groups in the two areas; social units of cows were spatially farther apart in the Bancroft area than in the Lingham area. In the current study, bull Elk in the Bancroft area migrated a mean distance of 11 km between fall and winter ranges and 13 km from winter to spring/summer ranges. Whether this can be classed as migration or simply movement from one part of an annual range to another is debatable. Most movements to winter range occurred during December with the accumulation of snow; however, movement to winter range in the Bancroft area occurred during late October and continued into December because of the initiation of supplementary feeding by some residents.

During an Elk restoration program in Kentucky, Larkin *et al*. (2004) noted that adult and young Elk moved on average 16 km and 9 km, respectively, during the 12 months after release. Ryckman *et al.* (2010) found that, during the early stages of a restoration program in Ontario (including areas other than Bancroft), Elk dispersed 13–22 km, on average, from the point of release. When data from the four release sites in that study were pooled, both adult males and females remained about 20 km from the release sites during 1998–2004 (Ryckman *et al*. 2010). Two years following restoration (2002 and 2003), a cow and a bull Elk dispersed 180 km and 275 km, respectively, from Bancroft, Ontario, into Quebec (R. Rosatte, unpublished data). In the current study, which took place several years post-restoration, there were no significant movements by radio-collared Elk. Most Elk in the Bancroft area core range moved about 10 km from the site where they were radio-collared, travelled about 1–2 km a day, and migrated about 4–6 km from one seasonal range to another. However, it must be noted that this was 5–12 years after restoration and extensive movements would not be expected as Elk had moved from a dispersive phase shortly following restoration to a more encamped, home range phase (Fryxell *et al*. 2008).

In this study, about 30% of collared Elk were documented moving among social units. Houston (1982) noted that Elk in the northern part of Yellowstone National Park also demonstrated movement into the ranges of some of the other nine Elk herds in the park. Smith and Anderson (2001) also found this behaviour in the Jackson Elk herd. Interdemic movement of Elk will ultimately affect the demographics of the social units as well as mortality rates. In fact, Haydon *et al.* (2007) found that the greater the distance Elk moved from their home range in the Bancroft area, the higher the mortality. Smith and Anderson (2001) also found that mortality was higher in Elk that dispersed to new herd segments than in those that did not disperse out of Grand Teton National Park. Interdemic movement may also be an advantageous behaviour, as it will likely decrease the chances of inbreeding depression in a population that is not geographically isolated. Williams *et al.* (2002) warned of the consequences of rapid population growth and the resultant genetic diversity issues including a decrease in heterozygosity, and no unique and few rare alleles, in a re-introduced Elk herd in Pennsylvania. However, this should not be an issue with Elk populations in southern Ontario because of the interdemic movement of Elk among social groups.

In this study, movements of Elk tended to be at a mean bearing of 177° in the Bancroft area. As Yott *et al.* (2011) noted, this may have been because of a tendency to face into the prevailing wind to scent predators. It may also have been a result of the orientation of the landscape and the use of hydro corridors for movement. Kie *et al*. (2005) noted that the directional movements of Elk are affected by topography and Elk tend to move parallel to major drainages. Rivers and streams in the northern part of the Bancroft area core Elk range flow to the east; however, they flow south in the southern part of the core Elk range, similar to the direction that Elk moved. Regardless, resource managers can expect Elk to move southward from the Bancroft area into other areas of southern Ontario (which they have done) where they will need to be managed to prevent conflict with humans.

In some jurisdictions, Elk appear to be sensitive to hunting pressure as evidenced by their movements during the hunting season. During a Montana study in 2007–2009, Cleveland *et al.* (2012) found that movement rates of Elk increased with hunting pressure. In addition, Elk in Montana were reported moving to refuges to avoid hunters (Conner *et al*. 2001; Vieira *et al.* 2003). Conversely, in Ontario, hunting during September 2011 and 2012 had little impact on the dispersion and movements of Elk in the greater Bancroft area. Collared Elk moved < 3 km before and during the hunt (over 3–4 weeks) and most Elk (91%) returned to their fall range after the hunt. Essentially, Elk did not significantly alter their fall range in response to the Elk hunt. This may be explained partly by the fact that the restored Elk in the Bancroft area are used to hunting activity (for other species) during the fall. Before the opening of Elk hunting season in 2011 in the Bancroft area, Elk had been exposed to hunting activity during the one-week Moose (*Alces americanus*) gun hunt (late October), the two-week deer gun hunt (early November), the three-month Black Bear (*Ursus americanus*) hunt (1 September to 30 November), as well as the archery-only seasons for Moose and deer (early October and October–December, respectively). Even though Elk are not being hunted during Moose and deer hunting seasons, they will still be disturbed by hunter activity and the use of all-terrain vehicles and dogs for deer hunting. Minimal movements of Elk during the fall Elk hunt may simply be a reflection of the fact that they are used to disturbances during the fall as hunting has occurred annually in the area since Elk were released in 2000 and 2001. However, movement rates and dispersion of Elk in the Bancroft area could change with an increase in hunting pressure (i.e., more hunters and more tags) or an extension of the season.

Management implications

Several social units of Elk have emerged on the landscape since the restoration of Elk in the greater Bancroft area during 2000 and 2001. These units have established traditional seasonal ranges to which they return annually, and knowledge of these locations will aid in their management. As winter feeding of Elk in some areas near Bancroft, Ontario, has dramatically affected their movements and ranges, feeding should be restricted to severe winters. Hunting pressure currently (2014) does not appear to be affecting Elk movements or dispersion; however, an increase in hunting pressure or season length could influence Elk movements in the Bancroft area. Resource managers will need to remain vigilant as Elk numbers increase and their range expansion in the Bancroft area occurs to the point that is socially unacceptable. In view of this, it is recommended that research and monitoring programs continue, but expand beyond the Bancroft area core Elk zone to include social groups of Elk that have become established in other regions of southern Ontario as was noted in the sighting data.

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Supplementary Material:

Appendix S1. Comparison of annual home ranges of Elk (*Cervus canadensis*) in the Bancroft, Ontario area, 2006–2013.

Appendix S2. Comparison of seasonal homes ranges of Elk (*Cervus canadensis*) in the Bancroft, Ontario area, 2006–2013.

Appendix S3. Home ranges of Elk (*Cervus canadensis*) in individual social units and groups in the Bancroft core Elk zone, 2006–2013.

Appendix S4. Comparison of annual and seasonal movements of Elk (*Cervus canadensis*) in the Bancroft, Ontario area, 2006–2013.

Appendix S5. Comparison of Elk (*Cervus canadensis*) movements between seasonal ranges in the Bancroft, Ontario area, 2006–2013.