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Abstract

Understanding population structure and resource selection is essential for wildlife management and conservation. We assessed the population structure of elk (*Cervus elaphus* L., 1758) in central Ontario. We used fuzzy and hierarchical cluster analyses to elucidate elk population structure based on spatial data collected from 41 radio-collared elk. We assessed space use between core and satellite subpopulations with the minimum convex polygon (MCP) and fixed kernel methods. Both fuzzy and hard clustering indicated that elk in this part of Central Ontario occur in a metapopulation that includes 5 subpopulations. The largest cluster consisted of a core group containing 22 radio-collared elk located in Burwash, with several satellite subpopulations spread along a 50 km long north-south axis and a small subpopulation to the west located in Worthington. Survival rates among subpopulations were similar ranging from 0.71 to 0.83; and anthropogenic causes of mortality were predominant only in the Burwash subpopulation. Space use and density of elk differed between core and satellite subpopulations. Understanding population structure is important to develop appropriate management plans. Our results support the conclusion that metapopulation structure can be reliably assessed using spatial data.

KEY WORDS

Elk, *Cervus elaphus* metapopulation, fuzzy clustering, spatial distribution, reintroduction

Introduction

Accurate delineations of populations are paramount for understanding of population ecology and applications to wildlife management and conservation. Populations, previously defined as an entity (Berryman 2002), are becoming increasingly viewed conceptually as they change with the parameters used to define them, such as spatial extent (Schaefer 2006). Accordingly, populations are increasingly being defined by the spatial arrangement of individuals (Bethke et al. 1996; Mauritzen et al. 2002; Kamler et al. 2013). The most appropriate scale to evaluate spatial structure will vary depending on the objectives or questions being addressed (Thomas and Kunin 1999). Recent research has identified the subpopulation as an appropriate spatial scale to obtain information meaningful to biological processes, such as population dynamics (Schaefer et al. 2001; McLoughlin et al. 2002; Edwards et al. 2008).

Populations without any apparent spatial structure are deemed continuous or panmictic, where all individuals within the population freely mix and densities are uniform (Gilpin 1996). In the simplest terms, a metapopulation is a population of populations that is spatially structured (Hanski 1998). Originally coined by Levins (1969), metapopulation theory was modelled after the theory of island biogeography, characterized by different local extinction and recolonization rates of suitable habitat patches, based on patch size and distance to source populations (MacArthur and Wilson 1967). In classic metapopulation theory, each habitat has an equal probability of a dispersal event, the rate of colonization is proportional to the fraction of unoccupied habitats, and each sub-population has the same extinction probability (Levins 1969; Levins 1974). Therefore, population persistence is a function of the rate of colonization being greater than the extinction probability. The Levins model assumes that there is no spatial

correlation between the state of habitat patches, and that there are only two recognized states (vacant or at carrying capacity). However, Hanski (1991), and others (Harrison 1991; Simberloff 1995; Wiens 1996) state that relatively few natural systems conform to this model of metapopulation dynamics. More commonly, natural metapopulations consist of habitat patches of varying size and quality, indicating different extinction probabilities and thus more accurately reflect source-sink dynamics (Pulliam 1988; Hanski 1991). Hanski (1991) further illustrates this example by describing four classes of metapopulations: 1) patchy, effectively a single population; 2) classical, following Levins' model; 3) non-equilibrium, where patches operate as separate metapopulations; and 4) mainland-island, where a large subpopulation that is relatively immune to extinction is surrounded by smaller satellite subpopulations that have higher extinction probabilities.

At its inception, metapopulation theory did not capture much attention of the scientific community. It was not until almost 20 years later that interest in the metapopulation concept began to grow (Metz and Gyllenberg 2001). The explanation is simple; as habitat fragmentation increased globally at an alarming rate, many species occurred in habitat patches isolated from surrounding populations, thus forming metapopulations (Gutiérrez and Harrison 1996; Stith et al. 1996; Hunter 2002; Baguette and Schtickzelle 2003; Wiegand et al. 2005; Cushman 2006). Analysis of population structure has often been focused on populations in highly fragmented landscapes, or species that are highly endangered (Beier 1996; Tero et al. 2003). Many conservation initiatives, including restoration ecology, have used the framework of metapopulations, and often practitioners have no choice but to restore species in remaining local habitat patches (Bleich et al. 1996). Few studies have assessed spatial population structure in continuous landscapes, and even fewer have looked at the population structure of a reintroduced

species. Wildlife restoration is becoming increasingly popular in conservation biology and post-release monitoring has largely focused on dispersal and survival (Kurzejeski et al. 1988; Warren et al. 1996; Carrie et al. 1999; Gross et al. 2000; Young 2002; Ryckman et al. 2010; Yott et al. 2011); however, few studies have addressed the spatial distribution of restored populations. Here we assess the spatial structure of elk (*Cervus elaphus* L., 1758) 15 years after re-introduction, in a mostly forested landscape. We hypothesized that elk spatial structure would be panmictic because of the lack of physical and ecological barriers in the study area.. If there are no physical or ecological barriers, dispersal throughout the study area should be high. Previous research in the study area has described two distinct groups of elk, one in Burwash and one occupying the French River delta (Ranta 1979; Brown 1998), therefore at most we would expect to find two distinct spatially structured subgroups.

Materials and Methods

Study Population

Elk were reintroduced in Ontario in the early 1900s by the Ontario Ministry of Natural Resources (Ranta 1979). Concerns over liver fluke (*Fascioloides magna*, Ward, 1917) transmission to cattle led to the removal of most elk populations in Ontario by the late 1950's, however a small relic population of elk persisted in Burwash, and along the French River estimated at 100 individuals in 1954 (Ranta 1979, Brown 1998; Jost 1999). In the late 1990s, elk were reintroduced at four different locations in Ontario over a four year period from Elk Island National Park, Alberta (Rosatte et al. 2007). Burwash received 172 elk between 1998 and 2001 (Rosatte et al. 2007). Elk were released over 15 years ago in Ontario and are now considered acclimatized to their new environment (Martin 2011).

Study Area

Our study took place in central Ontario, from Georgian Bay north to Highway 17 near the City of Greater Sudbury (Figure 1). The study area is located in the Great Lakes-St. Lawrence Eco-Region, dominated by forests interspersed with lakes, rivers and wetlands. The area is typical of post-glacial Precambrian Shield landscape, with numerous granite ridges and shallow soils. Climate is classified as continental, consisting of cold temperatures, warm summers and the absence of a dry season (Peel et al. 2007). Mean annual temperature at the Sudbury airport from 1981 to 2010 was 4.1°C (Environment Canada 2013). Snowfall occurs from November to March and snow depth in the study area during the winter of 2012-2013 frequently exceeded 60cm. Forested regions are a mix of deciduous *Populus spp.*(L.), *Acer spp.*(L.), *Quercus spp.*(L.), *Betula spp.*(L.), and coniferous *Pinus spp.*(L.), *Picea spp.*(A.), and *Abies balsamea* (L. Mill) tree species. The study area consists mostly of forested areas with a major highway to the east and trans-Canada highway bisecting the area east-west on the northern fringe. A railway line runs north-south through the center of the study area.

Animal Capture/Monitoring

At the onset of the present research, 24 adult females with functioning VHF collars were already present in the study site (Martin 2011). Elk were captured using net guns fired from helicopters. In February 2012, 13 elk (2 males and 11 females) were fitted with VHF radio-collars (LMRT, Lotek Wireless, Newmarket, ON), equipped with a mortality sensor. In addition, 6 adult females were fitted with GPS collars (Iridium, Lotek Wireless, Newmarket, ON) programmed to record a location every hour. All animal handling was approved under animal care protocol # 2012-01-01 by Laurentian University. We attempted to distribute collars

evenly among groups throughout the landscape, and to deploy the 6 GPS collars on elk that resided within the core study site. Elk groups were located using a combination of aerial surveys from helicopters and reports from the public. Elk herds were located from previously radio-collared cows that still had functioning VHF collars and by aerial surveys in locations that may contain elk. All radio-collared elk were located weekly using standard radio-telemetry techniques (White and Garrott 1990). Azimuths were recorded from the highest possible local elevation point using the loudest signal method (Springer 1979). Azimuths were recorded using a Silva compass with the declination adjusted to 10°W. Locations were estimated using 3 azimuths and triangulation was completed using 1:50,000 UTM, Zone 17 topographic maps. Elk were radio tracked during daylight hours from 2 hours after sunrise to 2 hours prior to sunset. Telemetry error was evaluated by placing dummy collars throughout the study area. We had a mean location error of 170 m (SE $\pm$ 20.5 m, $n=56$). Mortality signals were investigated immediately upon change in pulse rate to determine cause of death. Cause of death was determined by the presence of predator sign (scat, tracks), external injuries and field necropsies were conducted when predation was not evident. Aerial surveys were flown twice a year in early winter and late winter using an EC 130 Ministry of Natural Resources (MNR) helicopter. GPS collar data were sub-sampled to retrieve 4 fixes per day separated by 6 hour intervals, thus retaining four fixes per 24 hour period at 04:00, 10:00, 16:00 and 22:00 hours, respectively. Only fixes that had a positional dilution of precision ≤ 5 and 3 dimensional vertical fix status were used in the analysis.

Spatial Analysis

Annual home range sizes were calculated for each individual that had a sufficient number of relocations. To determine sufficient relocations, each individual home range size was

calculated using a minimum convex polygon (MCP) (Mohr 1947) and bootstrapped using 100 iterations. MCP was chosen because it is the oldest and most widely used estimate and it allows for comparison to older studies (Harris et al. 1990; Laver and Kelly 2008). Individual home range size estimates that did not reach an asymptote were discarded. Asymptotes were typically obtained between 25 and 50 radio locations for VHF collared elk. Fixed kernel home range size estimates were calculated for each elk that had sufficient relocations. Fixed kernel estimates with the least squares cross validation (LSCV) method were used to calculate the utilization distribution for 0.95, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 probabilities to assess space use throughout the utilization distribution. Kernel estimates were also used because they provide more accurate home range estimates. Sample sizes varied among individuals; however, evidence suggests that differences in home range size estimates are explained more by variance among individuals than by different home range estimation methods, once a sufficient number of relocations is obtained (Borger et al. 2006). Home range size of elk in the core subpopulation was compared to satellite groups using an unpaired *t*-test. Elk association was assessed using Assoc1 software to meet the assumptions of animal independence (Weber et al. 2001). Of the elk that were closely associated (within 200 m, 70% of the time), only one was randomly selected for analysis.

Cluster Analysis

Fuzzy clustering (Odeh et al. 1992) was used to assess the spatial organization of elk in the study area. Individuals used for cluster analysis required at least 7 months of data. We calculated the median easting and northing in the Universal Transverse Mercator coordinate system for each animal to perform the cluster analysis similar to Bethke (1996) and Schaefer et al. (2001). The median was chosen as the most appropriate measure of central tendency, because

it is unbiased to non-normal distributions and not sensitive to outliers (Bethke 1996; Zar 1999). Applying Fuzzy c Means Clustering to a data set requires selecting a weighting exponent (m), which determines the degree of fuzziness applied to the membership coefficients. At $m=1$, the algorithm equates to a hard clustering analysis where membership is exclusive. Previous work has shown that m performs optimally from 1.5 to 3 (Bedzek et al 1984). We chose $m = 2$ to obtain relative fuzzy classification. Results were investigated by varying m from 1.5 to 3 and consistent results were obtained across the spectrum. To determine the appropriate number of clusters, the average silhouette width of 2 to 15 clusters was calculated. The average silhouette width is a validation for cluster analysis and measures tightness and separation of each cluster (Rousseeuw 1987). Average silhouette width is maximized when the appropriate number of clusters is selected (Rousseeuw 1987).

Hard clustering was used for comparative purposes. We used hierarchical clustering (Ward's method) with Euclidean distance. Hard clustering evaluates clusters based on all or nothing, where members either are, or are not part of a cluster, as there is no graded membership assigned. We determined the appropriate number of clusters by comparing the sum of squared error for a number of cluster solutions and identified an elbow in the plot (Everitt and Hothorn 2009). The elbow in the plot indicates that additional clusters do not have a strong impact in reducing the sum of squared error. Results were displayed using a dendrogram. Hard and fuzzy cluster analysis was performed using the Cluster package in R (Maechler et al. 2013).

Based on the results of the cluster analysis, individuals were assigned to the cluster where they had the highest membership coefficient. All relocations of elk belonging to a cluster were pooled. Space use for each cluster was evaluated with a fixed kernel method for 95% and 50% (core) probabilities to visualize spatial distribution of the cluster using the smoothing parameter

plugin in Geospatial Modeling of the Environment (Beyer 2012). The plugin smoothing parameter was used instead of LSCV because several elk were pooled resulting in large numbers of relocations near boundaries and LSCV often fails to converge (Gitzen et al. 2006). The degree of overlap was calculated for clusters that had overlapping boundaries at the 95% level. Overlap was calculated using the “utilization distribution overlap index” (UDOI), because it also considers the probability of use in the estimation (Fieberg and Kochanny 2005). Measures of UDOI were calculated in R using “adehabitatHR” (Calange 2006). Distances among core use areas (50% fixed kernel) were calculated for each cluster and finite survival rates were calculated for each identified cluster.

Results

From December 2011 to August 2013, 3059 VHF relocations were obtained from 36 individual elk. Number of individual elk relocations ranged from 4 to 155 (Table 1). Of the 6 GPS collars, 5 experienced failure prior to the projected retrieval date of February 2014. GPS collar activity ranged from 7 to 18 months. We were unable to retrieve the failed collars and therefore do not know the cause of the premature failure. Fix success was high averaging 98.5% however, 8% of the radio fixes were discarded due to inaccuracy. GPS accuracy for fixes retained was $\pm 3\text{m}$. Over the course of the study 79% of collars had more than 1 year of data.

Cluster Analysis

Fuzzy c means clustering and hard clustering provided consistent groupings for elk spatial data. Both fuzzy and hard clustering resulted in 5 clusters (Figures 2 and 3). Average silhouette width was highest (0.7) for 5 clusters (Figure 2), indicating a good resolution into well-defined clusters (Figure 4). Average maximum membership coefficient for each

subpopulation was 0.76 and ranged from 0.61 to 0.98 (Table 2). Raft Lake and Sled Lake were the two subpopulations with the closest linkage distance (Figure 5).

Dispersal events between subpopulations were not frequently observed. Only one elk dispersed from one subpopulation to another during the course of the study. Elk 151.781 an adult female, spent two winters with the Burwash subpopulation, but dispersed to the Worthington subpopulation in August 2013. Each subpopulation occupied spatially distinct areas (Figure 6). Elk in the Burwash subpopulation had range overlap with the Sled Lake subpopulation only during winter. Elk from Burwash and Sled Lake subpopulations were occasionally observed together in winter; however, members of the Burwash subpopulation moved south each spring with no spatial overlap in any other season. Members of the Sled Lake subpopulation were never found in the Burwash field complex. Only the French River subpopulation contained elk whose individual home ranges did not overlap with other members of the same subpopulation.

From December 2011 to August 2013, 9 mortality events were investigated. Wolf (*Canis lupus lycaon* Schreber, 1775) predation and train collision were the most common sources of mortality (Table 3). The Burwash sub-population contained the largest number of animals and had the highest incidence of mortality, accounting for 55% of the detected mortality events. The most common cause of death in Burwash was train collision, accounting for 60% of the mortality events, followed by wolf predation (20%), and gunshot (20%). There is no open season for elk in this study area and the gunshot mortality was a case of mistaken identity by a hunter. Raft Lake, Sled Lake, and French River subpopulations each had one wolf predation event. One elk in the Sled Lake subpopulation died of unknown causes. The unknown cause of death occurred 2 months after capture, so post capture myopathy was ruled out. Throughout the duration of the study, there were several confirmed elk sightings outside of the current known elk distribution

range (Figure 1). In October 2012, a young bull elk washed up on the shore of Badgley Island, west of Killarney, approx. 50 km from the closest subpopulation. In February 2013 a young bull elk was photographed on a farmer's field in New Liskeard, approx. 150 km northeast of any known elk subpopulation. Also, in February 2013, two cow elk were seen by the regional Ministry of Natural Resources biologist in Gogama, approx. 150 km north of any known elk subpopulation. Hunters regularly report elk sightings and breeding activity (bugling) around Agnew Lake, approximately 30 km west of the Worthington subpopulation. In August 2012, a young bull from the north shore population, one of the other release sites in Ontario, was photographed outside of the town of Webwood, over 80 km from its herd and approximately 40 km west of the Worthington subpopulation. On February 29, 2014 a radio collared elk from Elliot Lake was found killed by wolves south of Fairbanks Lake less than 10 km from Worthington.

Space Use and Density

The Burwash subpopulation had the highest density of elk, as determined by aerial surveys, and occupied the smallest range area with the exception of Worthington. Members of the Worthington group were collared in February 2013 and we obtained only 7 months of spatial data for those animals. Higher density resulted from the limited space used by the 2 collared elk and limited time of observation. One of the elk was re-collared from the original release in 1999, and likely restricted its space use due to old age. Thus data from the Worthington subpopulation should be viewed with caution. Population densities were low and ranged across subpopulations from 0.05 elk/km² at French River to 0.88 elk/km² at Burwash (Table 4).

Out of the 5 subpopulations identified by the cluster analysis, 3 had population ranges with some degree of mutual overlap (Figure 6). The Sled Lake subpopulation range overlapped with the Raft Lake subpopulation to the north, and with the Burwash subpopulation to the south. The UDOI overlap for the Sled Lake subpopulation was greater for Raft Lake (0.39) than for Burwash (0.14). There was no overlap between 50% core use areas among any subpopulations. Distances between core use areas among subpopulations ranged from 11.1 to 58.1km (Table 5).

To compare individual home range sizes between subpopulations, elk in satellite groups were pooled because of low sample sizes. This resulted in the comparison of individual home ranges from the core Burwash subpopulation with individual elk home ranges from surrounding satellite subpopulations. Worthington was excluded from this analysis because it had less than one year of data. In total, 39 elk had a sufficient number of radio telemetry locations for home range analyses. Of the 39 elk, 22 belonged to the core (Burwash subpopulation) and 17 were pooled from surrounding satellite groups. Of the 17 elk from satellite groups, 4 were from the French River subpopulation, 6 were from Raft Lake and 7 were from Sled Lake. Space use was consistently larger for satellite subpopulations compared to the core (Burwash subpopulation) for MCP ($P < 0.01$), 95% fixed kernel ($P < 0.01$), 50% core use areas ($P < 0.01$), and throughout the utilization distribution (Figures 7 and 8).

Average MCP home range estimate for elk from the Burwash subpopulation was 47.1 km² (SE = 4.3). Average MCP home range estimate for members of satellite groups was 74.6 km² (SE = 8.4; Figure 6). Average space use using the 95% fixed kernel method for core and satellite groups was 47.9 km² (SE=6.3) and 86.4 km² (SE = 13.3), respectively. Mean core use area estimates (50% fixed kernel) were 11.3 km² (SE = 1.6) and 21.5 km² (SE = 3.6) for core and

satellite groups, respectively. Space use was consistently larger across the utilization distribution for satellite individuals, as compared to those from the core (Figure 8).

Discussion

We found strong evidence of an elk metapopulation in the study area. Both hard and fuzzy clustering methods found optimal solutions at 5 clusters. Of the different metapopulations described by Harrison (1991), elk in the Sudbury area appear to resemble the mainland-island structure, with an obvious core surrounded by smaller with regard to numbers, satellite groups. Subpopulations surrounding the core were smaller in regards to numbers and density, but used a larger area. Low density of elk in all subpopulations is not surprising as Burwash has one of the lowest population growth rates for reintroduced elk in eastern North America (Popp et al. 2014). In the studied elk population, there were no physical barriers among subpopulations and spatial structure could be regulated by density-dependent habitat selection (Morris 1989). This study was limited to mostly female spatial behaviour. Only 2 young males (both under 2.5 years of age) were radio-collared. Although in some populations young males are more likely to disperse (Greenwood 1980), both males remained in their designated subpopulations. It is possible that the metapopulation structure would be somewhat different if adult males were included in the analysis as they occupy different habitats during most seasons and have larger home ranges. The mating system in elk is characterized by mature bulls competing for harems of cows. Despite bull dominance over harems movement patterns of calf:cow groups during the rut is primarily dictated by one or more adult females. Subpopulation formation in elk may be driven by female spatial behaviour, as seen in caribou (*Rangifer tarandus* L., 1758) (Schaefer et al. 2001).

True metapopulation structures, following the original definition of Levins (1969), are rarely observed in natural populations (Harrison 1991). Variations described by Harrison (1991) are more commonly found. The Tule elk (*Cervus elaphus spp. nannodes*), similar to other elk across North America, was almost hunted to extinction. The current population of Tule elk went through an extreme bottleneck, and has since been translocated into numerous areas across California (McCullough et al. 1996; Williams et al. 2004). A metapopulation of Tule elk in California has been created by translocation; however, natural metapopulations have been identified in restoration areas, specifically in the Owens Valley population (McCullough et al. 1996). Most identified metapopulations have resulted from landscapes becoming highly fragmented (Wiegand et al. 2005; Cushman 2006). Central Ontario and Tule elk established metapopulations after translocation, demonstrating the validity of the metapopulation model, also in habitats that are not highly fragmented.

Metapopulations are not static regardless of the model they resemble. Metapopulation persistence is influenced by demographic, genetic and environmental stochasticity (Shaffer 1981), predation, competition (Levins 1974), habitat (Harrison 1991), and anthropogenic disturbances (Ehrlich and Ehrlich 1981). A great utility of applying graded membership within and among subpopulations is the potential for identifying underlying mechanisms related to dispersal and metapopulation dynamics (Schaefer and Wilson 2002). In this study, the duration and sample size were insufficient to identify meaningful demographic trends in any subpopulation. Longer term studies, however, may be able to use fuzzy clustering to monitor temporal changes in metapopulations. We found a strong 5 cluster solution; however, one cluster (Sled Lake) had a higher degree of fuzziness associated with its cluster. Lower individual membership coefficients and the lowest average silhouette width, could mean different extinction

and dispersal probabilities for this subpopulation. Individuals with a reduced maximum membership coefficient could also be more likely to disperse. Alternatively, overall heterozygosity may be greater in subpopulations that have lower membership coefficients from reduced philopatry and possibly increased gene flow. Incorporating fuzzy analysis into metapopulation models could reveal deterministic cause-and-effect relationships. Intense monitoring of populations could relate changes in fuzzy clustering analysis to changes in population density, habitat alterations, and other influential factors. Recently, fuzzy clustering analysis has been applied in numerous locations to identify population structures of caribou (Schaefer et al. 2001; Schaefer and Wilson 2002; Courtois et al. 2007; Shuter and Rogers 2012; Schaefer and Mahoney 2013) and white tailed deer (Klaver et al. 2008). We applied fuzzy clustering to elk for the first time to reveal spatial population structure. The ability of fuzzy clustering to incorporate ambiguity among natural populations should make it a powerful tool for unraveling the dynamics and spatial structure of populations (Schaefer and Wilson 2002).

The probability of extinction in each subpopulation may vary and the studied elk population structure may also reflect possible source – sink dynamics (Pulliam 1988). The higher density of elk in Burwash, along with the atypical habitat (the abandoned field complex), may represent higher habitat quality, and thus a source. The low densities of elk and increased space use of surrounding satellite subpopulations may reflect lower habitat qualities, with some possibly representing sinks. However, habitat quality was not directly measured in this study. Sinks can only be identified with long-term trends in reproductive success and dispersal rates. Using population density as an indicator of habitat quality, however, can be misleading (Van Horne 1983). Animal densities can be a misleading indicator of habitat quality when estimates are not taken during the limiting season (e.g. winter), when multi-annual variability in

populations is caused by small scale variation in food abundance and exclusion of subordinates from high quality habitats by dominant individuals (Van Horne 1983). Our estimates were derived from early and late winter aerial surveys, circumventing the first concern. Since all elk subpopulations were in relatively close proximity to one another, small scale changes in food abundance due to abiotic factors were likely to equally affect all subpopulations. Lastly, territorial behaviour is largely limited to prime bulls during the breeding season (late summer to early fall). The other possibility, however, is that higher density exists in Burwash because this is the location of one of the release sites. This is unlikely, because 2 additional release sites were located near Halifax Lake, approximately 14 km west of Burwash and elk from these release sites dispersed either to Burwash or outlying areas, and opted not to winter in the release area. If the surrounding subpopulations were identified as sinks, this would impact elk management decisions. Sink habitats are known to have high abundances of predators (Lloyd et al. 2005). In this study area, predation by wolves occurred in all elk subpopulations, indicating that predators were present throughout the area. Density of wolves among subpopulations may differ and predation risk may also contribute to elk spatial distribution.

Metapopulations and source-sink dynamics can be influenced by density-dependent habitat selection (Morris 1989). In our study, elk subpopulations may have been structured on the basis of density dependent habitat selection and the ideal free distribution. The ideal free distribution theorizes that individuals should distribute themselves across the landscape at all times to maximize their fitness (Fretwell and Lucas 1970; Fretwell 1972). As the core subpopulation density increases, individual reproductive success would be expected to decrease (Morrison 1989; Coulson et al. 1997). Elk may occupy lower quality habitats in surrounding

subpopulations without incurring any loss in fitness if they follow the ideal free distribution model.

A major issue in evaluating the spatial structure of a population is that it is scale sensitive (Thomas and Kunin 1999). Populations can exist on multiple scales and vagueness among them is the cornerstone to a more inclusive population concept (Schaefer 2006). We studied population structure at the local scale and scaling up would likely produce different results. There were four elk release areas in Ontario (Rosatte et al. 2007), separated by 200 km or more. Evaluating the population structure at a regional level may reduce the metapopulation structure in the Burwash/French River region into a single panmictic population. Determining the population structure throughout the province could provide insights into the success and status of elk. If elk were to establish metapopulations at a larger scale, it would have a positive impact on restoration of elk in Ontario. One of the essential requirements in metapopulation dynamics is the genetic connectivity among subpopulations (Levins 1969). If the Ontario elk subpopulations showed even low levels of connectivity at a larger scale, it would enhance their genetic diversity and reduce extinction probabilities.

Conclusions and Management Implications

Elk spatial distribution in the Sudbury area reflects a metapopulation structure. Subpopulations are spatially structured and dispersal to even the farthest separated subpopulations was observed. Because of the spatial structure, management decisions implemented in one subpopulation cannot be assumed to impact neighbouring subpopulations. The observed metapopulation structure is most similar to the mainland/islands metapopulation model. In metapopulation management, this would translate into differing conservation

priorities. The Burwash subpopulation was identified as an obvious core (and potential source) and thus, is most important to manage for the continued persistence of the metapopulation.

Human-induced mortality was the greatest cause of reduced survival in the Burwash subpopulation. Therefore we recommend that mitigation of human-caused mortality in the core area be a priority. Understanding the whole metapopulation dynamics could also have important management implications. Incorporating remote sensing data such as NDVI and direct measures of habitat quality would assist in conserving this metapopulation. Further studies focusing on fine-scale predator dynamics would help understand the population structure as predation and predation risk can effect distribution and group size of elk (Hebblewhite and Pletcher 2002; Creel and Winnie 2005). Lastly, genetic information would be of great value to assess the amount of gene flow between each subpopulation.

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Literature Cited

- Baguette, M., and Schtickzelle, N. 2003. Local population dynamics are important to the conservation of metapopulations in highly fragmented landscapes. *J. Appl. Ecol.* **40**:404-412.
- Beier, P. 1996. Metapopulation models, tenacious tracking, and cougar conservation. *In* Metapopulations and Wildlife Conservation. *Edited by* D.R. McCullough Island Press, Covelo, California, USA pp. 293-324.
- Berryman, A.A. 2002. Population: a central concept for ecology? *Oikos*, **97**:439-442.
- Bleich, V.C., Wehausen, J.D., Ramey, R.R., and Rechel J.L. 1996. Metapopulation theory and mountain sheep: implications for conservation. *In* Metapopulations and Wildlife Conservation. *Edited by* D.R. McCullough Island Press, Covelo, California, USA pp. 353-373.
- Bethke, R., Taylor, M., Amstrup, S., and Messier, F. 1996. Population delineation of polar bears using satellite collar data. *Ecol. Appl.* **6**:311-317.
- Beyer, H.L. 2012. Geospatial Modelling Environment (Version 0.6.0.0). (software).
- Bezdek, J.C., Ehrlich, R., and Full W. 1984. Fcm - the Fuzzy C-Means Clustering-Algorithm. *Comp. Geosci.* **10**:191-203.
- Borger L., Franconi, N., Michele, G.D., Gantz, A., Meshci, F., Mancina, A., Lovari, S., and Coulson, T. 2006. Effects of sampling regime on the mean and variance of home range size estimates. *J. Anim. Ecol.* **75**:1393-1405.
- Brown, G.S. 1998. Spatial Behaviour and habitat utilization of wapiti (*Cervus elaphus*) in the French River and Burwash Regions of Ontario. MSc thesis School of graduate studies and research Laurentian University, Sudbury, Ontario.
- Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecol Modell.* **197**: 516-519.
- Carrie, N.R., Conner, R.N., Rudolph, D.C., and Carrie, D.K.. 1999. Reintroduction and Postrelease Movements of Red-Cockaded Woodpecker Groups in Eastern Texas. *J. Wildl. Manage.* **63**:824-832.
- Creel S., and Winnie, J.A. JR. 2005. Responses of elk herd size to fine-scale spatial and temporal variation in the risk of predation by wolves. *Anim. Behav.* **69**: 1881-1189.
- Coulson, T., Albon, S., Pilkington, J., and Clutton-Brock, T.. 1999. Small-scale spatial dynamics in a fluctuating ungulate population. *J. Anim. Ecol.* **68**:658-671.

- Courtois, R., Ouellet, J.P., Breton, L., Gingras, A., and Dussault, C. 2007. Effects of forest disturbance on density, space use, and mortality of woodland caribou. *Ecoscience*, **14**:491-498.
- Cushman, S.A. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biol. Conserv.* **128**:231-240.
- Edwards, M.A., Nagy, J.A., and Derocher, A.E. 2008. Using subpopulation structure for barren-ground grizzly bear management. *Ursus*, **19**:91-104.
- Ehrlich, P.R., and Ehrlich A.H. 1981. *Extinction: the causes and consequences of the disappearance of species*. New York, Random House.
- Environment Canada. 2013. Meteorological Service of Canada. , 2012. Atmospheric Environment Service, Environment Canada. http://weather.gc.ca/canada_e.html
- Everitt, B.S., and Hothorn, T. 2009. *A Handbook of Statistical Analyses Using R*. Chapman and Hall.
- Fieberg, J., and Kochanny, C.O. 2005. Quantifying Home-Range Overlap: The importance of the utilization distribution. *J. Wildl. Manage.* **69**:1346-1359.
- Fretwell, S.D. and Lucas, H.L. 1970. On terrestrial behaviour and other factors influencing habitat distribution in birds. *Acta Biotheor.* **19**:16-36.
- Fretwell, S. D. 1972. *Populations in a seasonal environment*. Princeton University. Press, Princeton, NJ.
- Gilpin, M. 1996. Metapopulations and wildlife conservation: approaches to modelling spatial structure. *In Metapopulations and Wildlife Conservation. Edited by D.R. McCullough* Island Press, Covelo, California, USA pp 11-28.
- Gitzen, R.A., Millspaugh, J.J., and Kernohan. B.J. 2006. Bandwidth Selection for Fixed-Kernel Analysis of Animal Utilization Distributions. *J. Wildl. Manage.* **70**:1334-1344.
- Greenwood, P. J. 1980. Mating systems, philopatry and dispersal in birds and mammals. *Anim. Behav.* **28**: 1140-1162.
- Gross, J.E., Singer, F.J., and Moses M.E. 2000. Effects of disease, dispersal, and area on bighorn sheep restoration. *Restor. Ecol.* **8**:25-37.
- Hanski, I. 1998. Metapopulation dynamics. *Nature*, **396**:41-49.
- Hanski, I. 1991. Single-species metapopulation dynamics: concepts, models, and observations. *Biol. J. Linn. Soc.* **42**: 17-38.

- Hanski, I., Pakkala, T., Kuussaari, M., and Lei, G.. 1995. Metapopulation persistence of an endangered butterfly in a fragmented landscape. *Oikos*, **72**:21-28.
- Hanski, I., and Gilpin M. 1991. Metapopulation dynamics: brief history and conceptual domain. *Biol. J. Linn. Soc.* **42**:3-16.
- Harris , S., Cresswell, W.J., Forde, P.G., Trewhella, W.J., Woolard, T., and Wray, S.. 1990. Home range analysis using radio-tracking data- a review of the problems and techniques particularly as applied to the study of mammals. *Mammal Rev.* **20**:97-123.
- Harrison, S. 1991. Local extinction in a metapopulation context: an empirical evaluation. *Biol. J. Linn. Soc.* **42**:73-88.
- Hebblewhite M., and Pletscher, D.H. 2002. Effects of elk group size on predation by wolves. *Can. J. Zool.* **80**: 800-809.
- Hunter, M.D. 2002. Landscape structure, habitat fragmentation, and the ecology of insects. *Agric. Forest Entomol.* **4**:159-166.
- Jost, M.A., Hamr, J., and Mallory F.F. 1999. Forage selection by elk in habitats common to the French River – Burwash region of Ontario. *Can. J. Zool.* **77**: 1429-1438.
- Kamler, J.F., Gray, M.M., Oh, A., and D. W. Macdonald D.W. 2013. Genetic structure, spatial organization, and dispersal in two populations of bat-eared foxes. *Ecol. Evol.* **3**:2892-2902.
- Klaver, R.W., Jenks, J.A., Deperno, C.S., and Griffin, S.L. 2008. Associating seasonal range characteristics with survival of female white-tailed deer. *J. Wildl. Manage.* **72**:343-353.
- Kurzejeski, E.W., and Root, B.G. 1988. Survival of reintroduced ruffed grouse in north Missouri. *J. Wildl. Manage.* **52**:248-252.
- Laver, P.N., and Kelly, M.J. 2008. A Critical Review of Home Range Studies. *J. Wildl. Manage.* **72**(1):290-298.
- Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bull. Entomol. Soc. Am.* **15**: 237-240.
- Levins, S., 1974. Dispersion and population interactions. *Am. Nat.* **108**: 207-228.
- Lloyd, P., Martin, T.E., Redmond, R.L., Langner, U., and Hart, M.M. 2005. Linking demographic effects of habitat fragmentation across landscapes to continental source-sink dynamics. *Ecol. Appl.* **15**: 1504-1514.
- MacArthur, R.H., and Wilson E.O. 1967. The theory of island biogeography. Princeton: Princeton University Press.

- Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M., and Hornik, K. 2013. Cluster: Cluster Analysis Basics and Extensions. R package version 1.14.4
- Martin, M. 2011. Spatial behavior and habitat use by elk (*Cervus elaphus*) in response to highway construction and interprovincial relocation. MSc thesis, School of Graduate Studies Laurentian University, Sudbury, Ontario.
- Mauritzen, M., Derocher, A.E., Wiig, Å., Belikov, S.E., Boltunov, A.N., Hansen, E., and Garner, G.W. 2002. Using satellite telemetry to define spatial population structure in polar bears in the Norwegian and western Russian Arctic. *J. Appl. Ecol.* **39**:79-90.
- McCullough, D.R., Fischer, J.K., and Ballou J.D. 1996. From bottleneck to metapopulation: recovery of the tule elk in California. *In* Metapopulations and Wildlife Conservation. *Edited by* D.R. McCullough Island Press, Covelo, California, USA pp. 375-403.
- McLoughlin, P.D., Cluff, H.D., Gau, R.J., Mulders, R., Case, R.L., and Messier, F. 2002. Population delineation of barren-ground grizzly bears in the central Canadian Arctic. *Wild. Soc. Bull.* **30**:728-737.
- Metz, J.A.J., and Gyllenberg, M. 2001. How should we define fitness in structured metapopulation models? Including an application to the calculation of evolutionarily stable dispersal strategies. *P. Roy. Soc. Lond. B. Bio.* **268**:499-508.
- Mohr, C.O. 1947. Table of equivalent populations of North American small mammals. *Am. Midl. Nat.* **37**: 223-249.
- Morris, D. 1989. Density-dependent habitat selection: testing the theory with fitness data. *Evol. Ecol.* **3**:80-94.
- Odeh, I.O.A., Chittleborough, D.J., and McBratney, A.B. 1992. Soil pattern recognition with fuzzy-c-means: application to classification and soil-landform interrelationships. *Soil Sci. Soc. Am. J.* **56**:505-516.
- Peel, M.C., Finlayson B.L., and McMahon, T.A. 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **11**:1633-1644.
- Popp, J.N., Toman, T., Mallory, F.F., and Hamr, J. 2014. A Century of Elk Restoration in Eastern North America. *Restor. Ecol.* **22**:723-730.
- Ranta, B. 1979. Range and habitat relationships of wapiti (*Cervus Canadensis*) in the Burwash-French River area of Ontario. M.Sc. Thesis, Carleton Univ., Ottawa.

- Richards, V.P., Greig, T.W., Fair, P.A., McCulloch, S.D., Politz, C., Natoli, A., Driscoll, C.A., Hoelzel, A.R., David, V., Bossart, G.D., and Lopez J.V. 2013. Patterns of population structure for inshore bottlenose dolphins along the eastern United States. *J. Hered.* **104**:765-778.
- Rousseeuw, P.J. 1987. Silhouettes - a Graphical Aid to the Interpretation and Validation of Cluster-Analysis. *J. Comput. Appl. Math.* **20**:53-65.
- Rosatte, R., Hamr, J., Young, J., Filion, I., and Smith, H.. 2007. The Restoration of Elk (*Cervus elaphus*) in Ontario, Canada: 1998–2005. *Restor. Ecol.* **15**:34-43.
- Ryckman, M. J., Rosatte, R.C., McIntosh, T., Hamr, J., and Jenkins, D. 2010. Postrelease Dispersal of Reintroduced Elk (*Cervus elaphus*) in Ontario, Canada. *Restor. Ecol.* **18**:173-180.
- Schaefer, J. A., Veitch, A.M., Harrington, F.H., Brown, W.K., Theberge, J.B., and Luttich, S.N. 2001. Fuzzy structure and spatial dynamics of a declining woodland caribou population. *Oecologia*, **126**:507-514.
- Schaefer, J.A., and Wilson, C.C. 2002. The fuzzy structure of populations. *Can. J. Zool.* **80**: 2235-2241.
- Schaefer, J.A. 2006. Towards maturation of the population concept. *Oikos*, **112**:236-240.
- Schaefer, J.A., and Mahoney, S.P. 2013. Spatial dynamics of the rise and fall of caribou (*Rangifer tarandus*) in Newfoundland. *Can. J. Zool.* **91**:767-774.
- Schaffer, M.L. 1981. Minimum population size for species conservation. *Bioscience*, **31**: 131-134.
- Shuter, J.L., and Rodgers A.R. 2012. Delineating demographic units of woodland caribou (*Rangifer tarandus caribou*) in Ontario: cautions and insights. *Rangifer*, **32**: 159-182.
- Simberloff, D. 1995. Habitat fragmentation and population extinction of birds. *Ibis*, **137**: 105-111.
- Springer, J.T. 1979. Some sources and bias and sampling error in radio triangulation. *J. Wildl. Manage.* **54**:169-174.
- Stith, B.M., Fitzpatrick, J.W., Woolfenden, G.E., and Pranty, B. 1996. Classification and conservation of metapopulations: a case study of the Florida scrub jay. *In* Metapopulations and Wildlife Conservation. *Edited by* D.R. McCullough Island Press, Covelo, California, USA pp 187-215.

- Tero, N., Aspi, J., Siikamäki, P., Jäkäläniemi, A., and Tuomi, J. 2003. Genetic structure and gene flow in a metapopulation of an endangered plant species, *Silene tatarica*. *Mol. Ecol.* **12**:2073-2085.
- Thomas, C.D., and Kunin, W.E. 1999. The spatial structure of populations. *J. Anim. Ecol.* **68**:647-657.
- Warren, C.D., Peek, J.M., Servheen, G.L., and Zager, P. 1996. Habitat use and movements of two ecotypes of translocated caribou in Idaho and British Columbia. *Conserv. Biol.* **10**:547-553.
- Weber, K. T., Burcham, M., and Les Marcum, C.. 2001. Assessing independence of animal locations with association matrices. *J. Range Manage.* **54**:21-24.
- Wiegand, T., Revilla E., and Moloney, K.A. 2005. Effects of habitat loss and fragmentation on population dynamics. *Conserv. Biol.* **19**:108-121.
- Wiens, J.A. 1996. Wildlife in patchy environments: metapopulations, mosaics and management. *In Metapopulations and Wildlife Conservation. Edited by D.R. McCullough* Island Press, Covelo, California, USA pp 53-84.
- Williams, C.L., Lundrigan, B., and Rhodes, O.E. Jr. 2004. Microsatellite DNA variation in Tule elk. *J. Wildl. Manage.* **68**:109-119.
- Young, T.P. 2000. Restoration ecology and conservation biology. *Biol. Conserv.* **92**:73-83.
- Yott, A., Rosatte, R., Schaefer, J.A., Hamr, J., and Fryxell, J. 2011. Movement and spread of a founding population of reintroduced elk (*Cervus elaphus*) in Ontario, Canada. *Restor. Ecol.* **19**:70-77.
- Zar, J. H. 1999. Biostatistical Analysis. Prentice Hall, Upper Saddle River, New Jersey, USA.

Figure 1. Elk (*Cervus elaphus* L.,1758) range consisting of a minimum convex polygon around all elk radio locations and confirmed elk sightings.

Figure 2. Average silhouette width for clusters 2 to 15 of spatial data for 41 elk (*Cervus elaphus* L.,1758) in the Sudbury area. Appropriate number of clusters is defined when average silhouette width is maximized (K=5).

Figure 3. Within group sum of squares for clusters 2 to 15 using Ward's method. Appropriate number of clusters is indicated by a bend, or elbow in plot (K=5).

Figure 4. Silhouette plot for fuzzy membership coefficients of 41 elk (*Cervus elaphus* L.,1758) in the Sudbury area. The plot shows 5 clusters with S_i = average silhouette width for each cluster 1:5 (Cluster 1 = Burwash, cluster 2 = French River, cluster 3 = Raft Lake, cluster 4 = Sled Lake, cluster 5 = Worthington).

Figure 5. Cluster dendrogram of elk (*Cervus elaphus* L.,1758) collar frequencies in the Sudbury area binned into a 5 cluster solution using hierarchical agglomerative clustering (Ward's method) based on Euclidean distance (A=Burwash, B= French River, C= Worthington, D= Sled Lake, E= Raft Lake).

Figure 6. Elk (*Cervus elaphus* L.,1758) metapopulation structure in the Sudbury region. Gray dashed lines represent Worthington, black dashed represent Raft Lake, Gray solid represent Sled Lake, Black solid represent Burwash, Double solid represent French River. Thick outline represent pooled individuals that have a maximum fuzzy membership coefficient > 0.7 for that subpopulation and thinner outline represent pooled individuals that have a maximum membership coefficient < 0.7 . Subpopulation boundaries are delineated using 95% fixed kernel estimates and the Plugin smoothing parameter.

Figure 7. Mean home range size estimates (MCP) for elk (*Cervus elaphus* L.,1758) belonging to core and satellite groups. Error bars represent 95% C.I.

Figure 8. Elk (*Cervus elaphus* L.,1758) space use across the utilization distribution for core and satellite subgroups in the Sudbury area. Bars represent standard error of the mean. Diamonds represent the core subpopulation and squares represent the satellite groups.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

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Figure 6

Figure 7

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Figure 8

Table 1. Number of relocations for each radio collared elk (*Cervus elaphus* L., 1758) by season from December 2011 to August 2013

Frequency	Type	Sex	Class	Spring	Summer	Fall	Winter	Total
148.135	VHF	F	ADULT	48	33	23	44	148
148.200	VHF	M	SUBAD	40	27	20	31	118
148.201	VHF	F	ADULT	37	33	25	45	140
148.260	VHF	F	ADULT	8	5			13
148.290	VHF	F	ADULT	24	12	13	24	73
148.781	VHF	F	ADULT	21	14	13	25	73
148.839	VHF	F	ADULT	22	14	13	25	74
149.022	VHF	F	ADULT	47	22	28	45	142
149.126	VHF	F	ADULT	17	15	13	23	68
149.299	VHF	F	ADULT	17	12	12	13	54
149.310	VHF	F	ADULT	27	15	14	17	73
149.320	VHF	F	ADULT	16	12	6	6	40
149.321	VHF	F	ADULT	7				7
149.329	VHF	F	ADULT	55	32	27	31	145
149.341	VHF	F	ADULT	49	32	27	32	140
149.350	VHF	F	ADULT	13	12	13	10	48
149.360	VHF	F	ADULT	7	7	6		20
149.370	VHF	F	ADULT	4			7	11
149.371	VHF	F	ADULT	7				7
149.389	VHF	F	ADULT	15	13	13	10	51
150.120	VHF	F	ADULT	37	24	30	45	136
150.131	VHF	F	ADULT	13	9	11	23	56
150.239	VHF	F	ADULT	40	27	28	39	134
150.281	VHF	F	ADULT	19	16	11	24	70
150.720	VHF	F	ADULT	21	13	14	25	73
150.762	VHF	M	SUBAD	41	26	23	26	116
150.781	VHF	F	ADULT	46	31	28	44	149
150.810	VHF	F	ADULT	14	19	27	40	100
150.840	VHF	F	ADULT	50	34	27	44	155
150.921	VHF	F	ADULT	31	26	28	42	127
151.005	GPS	F	ADULT	486	283	346	333	1448
151.015	GPS	F	ADULT	521	313	333	298	1465
151.025	GPS	F	ADULT	426	296		128	850
151.035	GPS	F	ADULT	333	303	127		763
151.045	GPS	F	ADULT	515	327	346	334	1522
151.055	GPS	F	ADULT	326	195			521
151.159	VHF	F	ADULT	37	24	26	32	119
151.421	VHF	F	ADULT	33	17	14	35	99
151.440	VHF	F	ADULT	20	18	28	30	96

151.781	VHF	F	ADULT	15	5	28	40	88
151.811	VHF	F	ADULT	1			3	4
151.892	VHF	F	ADULT	11	16	26	39	92
Total				3517	2332	1767	2012	9628

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Table 2. Average maximum fuzzy membership coefficients for 5 subpopulations of elk (*Cervus elaphus* L.,1758) in the Sudbury area. SE = standard error of the mean, N= number of collared elk assigned to cluster.

Subpopulation	Mean (SE)	Min	Max	N
Burwash	77.6 (3.2)	47	92	22
French River	75.8 (3.0)	70	81	4
Raft Lake	82.3 (7.1)	48	94	6
Sled Lake	61.2 (4.5)	43	76	7
Worthington	98 (0)	98	98	2

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Table 3. Cause-specific mortality events for 4 subpopulations of radio collared elk (*Cervus elaphus* L., 1758) in the Sudbury region in 2012/2013.

Cause of Mortality	Number of Cases	Year	Subpopulation
Wolf predation	4	2012/2013	Burwash (1), French River (1), Sled Lake (1), Raft Lake (1)
Train collision	3	2013	Burwash (3)
Gunshot	1	2012	Burwash (1)
Unknown	1	2012	Sled Lake (1)
Total	9		Burwash (5), French River (1), Sled Lake (1), Raft Lake (1)

Table 4. Elk (*Cervus elaphus* L.,1758) density and survival rate among the 5 subpopulations in the Sudbury area.

Subpopulation	elk/km ²	SE	Survival rate
Worthington	0.51	0.21	N/A
Sled	0.22	0.05	0.71
Raft	0.17	0.03	0.83
French	0.05	0.01	0.75
Burwash	0.88	0.06	0.78

*N/A – survival rate not available

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Table 5. Distance (km) between core use areas (50% fixed kernel) of 5 elk (*Cervus elaphus* L., 1758) subpopulations in the Sudbury area.

	Burwash	French River	Sled Lake	Raft Lake
Burwash				
French River	17.8			
Sled Lake	11.1	28.4		
Raft Lake	18.3	39.2	11.6	
Worthington	47.2	58.1	36.9	39.5

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