Urban Ecosystems, 8: 191–202, 2005
© 2005 Springer Science + Business Media, Inc. *Manufactured in The Netherlands.*

Movement patterns of rural and suburban white-tailed deer in Massachusetts

CHRISTOPHER R. GAUGHAN* gaughan@lamar.colostate.edu
USGS Massachusetts Cooperative Fish and Wildlife Research Unit and Department of Natural Resources Conservation, Holdsworth Natural Resources Center, University of Massachusetts, Amherst, MA 01003, USA

STEPHEN DESTEFANO† sdestef@forwild.umass.edu
USGS Massachusetts Cooperative Fish and Wildlife Research Unit, Holdsworth Natural Resources Center, University of Massachusetts, Amherst, MA 01003, USA

Abstract. We used satellite land cover data and the program FRAGSTATS to quantify land cover types and calculate the amount of forest edge available in suburban and rural regions of northeastern and northwestern Massachusetts. Cover categories included forest cover, open canopy vegetation, and non-deer habitat. We calculated all edge segments where forest cover abutted open canopy cover. Our open canopy vegetation category was calculated both with and without low intensity suburban development. We then compared these findings to movement data from 53 (13 males, 40 females) adult radio-marked white-tailed deer *(Odocoileus virginianus)* monitored biweekly and diurnally from January 2001 to January 2003. The range of movements of suburban deer in eastern Massachusetts showed no difference to that of suburban deer in western Massachusetts ($P = 0.7$). However, the ranges for suburban deer in both eastern and western Massachusetts were 10 times less than those of deer in rural western Massachusetts ($P = 0.001$). Our findings suggest that landscape configuration, as described by the amount and distribution of edge due to suburban development, which is related to the amount and distribution of resources such as food and cover, affects migratory behavior of white-tailed deer, allows deer to have smaller ranges, and contributes to high deer densities. Inclusion of suburban edge in habitat models will increase our understanding of deer-habitat relationships for management of deer in urbanizing environments.

Keywords: cover, movements, rural, suburban, white-tailed deer

Introduction

The white-tailed deer (*Odocoileus virginianus*) is a generalist herbivore that exists in rural, suburban, and some urban areas throughout much of North America. White-tailed deer often shift from open canopy vegetation to forested cover seasonally and according to different food availability. For example, during early spring, open canopy vegetation provides herbaceous forage, during summer deer may browse in wetland areas, and in autumn deer often prefer hardwood forests if a mast crop is available (McCullough, 1984). For these reasons, the white-tailed deer is a species that often thrives in the transition between forest and open canopy vegetation, or edge habitat (Alverson *et al.*, 1988). Traditionally, edge was

**Present address*: Colorado Natural Heritage Program, 254 General Services Bldg, Colorado State University, Fort Collins, CO 80523-8002, USA.
†Author to whom all correspondence should be addressed.

more often thought of as the boundary between forest and an area cleared for agriculture (Leopold, 1933:131–132). However, the forest/open canopy edge also occurs at the forest transition to areas such as landscaped suburban yards, parks, or playing fields where low intensity residential development is spreading into once rural farmed or forested areas. As land use shifts from forest, agricultural fields, and pasture to single family dwellings and recreational areas such as golf courses and playing fields, so too must our perception and management of deer habitat.

Urbanization (i.e., the processes that convert landscapes from natural or rural conditions to suburban or urban developments) can influence the presence, distribution, and demographic characteristics of wildlife populations in different ways (DeStefano and DeGraaf, 2003). As landscapes are transformed to human-dominated environments, animals can respond by altering their spatial use and movement patterns. Large-scale movements of animals are often grouped into two broad categories (White and Garrott, 1990). Migration is a regular, round-trip movement of an individual between two or more areas or seasonal ranges. Dispersal is a one-way movement of individuals from their natal site or an area that has been occupied for a period of time. Reasons proposed for migratory behavior in northern populations of white-tailed deer include snow depth (Tierson *et al.*, 1985), ambient temperature change (Verme, 1973), or a complex combination of seasonal changes including photoperiod, vegetative response, snow depth, and temperature (Nelson, 1995). Van Deelen *et al.* (1998) observed that migratory and non-migratory deer can co-occur in the same areas.

Massachusetts is one of the most populated and urbanized states in the country. Yet most of the suburban growth occurs in the eastern part of the commonwealth, with large sections of western Massachusetts still being forested and rural. We contrasted the amount of adjacent open canopy and low intensity residential (suburban) areas with forested vegetation to describe and quantify edge habitat, and related this to the diurnal movements and spatial use patterns of white-tailed deer in rural and suburban regions of Massachusetts. We hypothesized that patterns and extent of movements would be different for deer in suburban areas versus deer in rural areas due to extensive edge habitat created by suburban development, as well as climatic and cultural differences within suburban versus rural environments.

Study areas

The Massachusetts Division of Fisheries and Wildlife (MDFW) developed Deer Management Zones (DMZs) in 1983 to better manage the deer population. Our study focuses on two of these zones: NW Massachusetts or DMZ 2, and NE Massachusetts or DMZ 10 (figure 1; inset).

Northwestern study area (DMZ 2)

This study area encompassed 1,500 km^2, with elevations ranging from 120–750 m. Average winter temperature was −4°C; average summer temperature was 19°C, with mountains remaining cooler than lowlands. Average annual precipitation was 109 cm, including 180 cm average snowfall (Scanu, 1988). Distance from the coast and high elevations resulted in higher average snow depths persisting later in the season than the northeast study

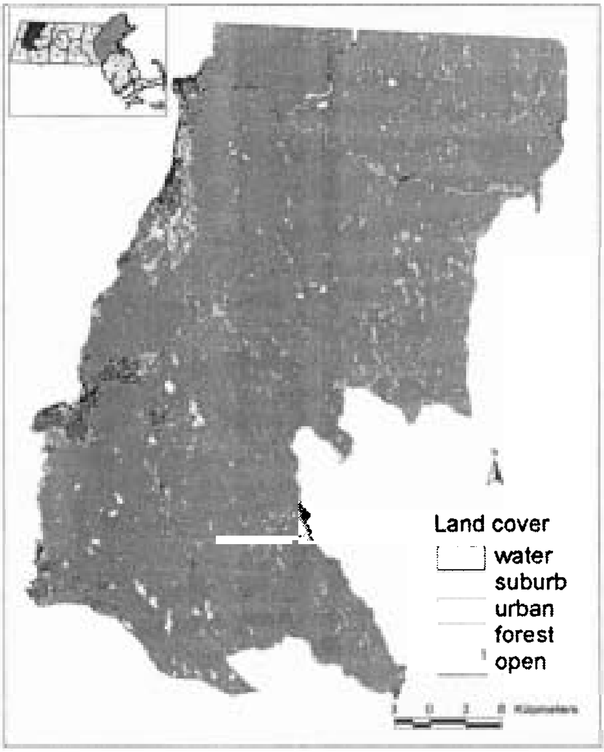

Figure 1. Aggregated multi-resolution land classifications (MRLC) in northwestern Massachusetts (deer management zone [DMZ] 2).

area. Coarse monthly snow depth averages (cm) from 2002 are as follows: January 25–50, February 25–50, March 25–50, April 5–10 (NOAA, 2005).

The forested landscape consisted predominantly of northern hardwoods-spruce (*Picea* spp.) and northern hardwoods forest regions at higher elevations, and transitional hardwoods-white pine (*Pinus strobus*) forest region at lower elevations (DeGraaf *et al.*, 1989). Major northern hardwoods species included American beech (*Fagus grandifolid*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*). Paper birch (*B. papyriferd*), quaking aspen (*Populus tremuloides*), and big tooth aspen (P. *grandidentatd*) were early successional species occurring in the region. Major species of the transitional hardwoods were yellow birch, paper birch, beech, sugar maple, red maple (*Acer rubrum*), and white pine. Warmer, drier sites were dominated by oaks (*Quercus* spp.) and hickories (*Carya* spp.), cooler well-drained sites included hemlock (*Tsuga canadensis*), and poorly drained sites often contained red maple, black ash (*Fraxinus nigra*), and American elm (*Ulmus americana*) (DeGraaf *et al.*, 1989).

The topography of DMZ 2 included rolling hills cut by dendritic drainages flowing east into the Deerfield, south into the Westfield, and west into the Housatonic rivers. Areas of higher elevation generally received more snow and had lower human population densities. Agricultural activities were found over a wide range of elevations in the area, from the valleys into the hill towns. Farmland, orchard, pasture, and valley cities and towns with shopping centers, yards, and public parks fragmented the forested areas. Major highways were all 2-lane roads without median strip barriers and the road density was low (0–3 km/km^2) (Steel, 1999).

Northeastern study area (DMZ 10)

This study area encompassed 3,700 km^2, with elevations ranging from 0–560 m. The climate was milder than the northwestern study area: average winter temperature was −2.7°C and average summer temperature was 20°C. Average annual precipitation was 114 cm. Average snowfall was 116 cm but was highly variable year to year and often melted quickly resulting in lower average snow depths than in DMZ 2. Coarse monthly snow depth averages (cm) from 2002 are as follows: January 10–23, February 10–23, March 5–10, April 0 (NOAA, 2005). Climate varied noticeably in urban areas where vast amounts of asphalt and concrete absorbed and stored heat. Thus, the microclimate in urban areas may be 3–6°C warmer than areas with intact natural vegetation land cover (Peragallo, 1989).

The forested landscape consisted primarily of the central hardwoods-hemlock-white pine forest region, but also contained transitional hardwood-white pine forest region (DeGraaf *et al.*, 1989). The central hardwoods region was predominantly composed of red oak (*Q. rubra*), black oak (*Q. velutina*), and white oak (*Q. alba*), hickories, gray birch (*Betula populifolia*), yellow birch, and black birch (*B. lenta*), and beech. Major conifers were white pine and hemlock. On wetter sites red maple dominated the canopy. Pitch (*Pinus rigida*) and red (*P. resinosa*) pines were found on sandy glacial outwashes (DeGraaf *et al.*, 1989). The transitional hardwoods—white pine forest region was similar to that found at lower elevations in the northwest study area.

Topography was mostly flat but with remnant glacial moraines, meandering rivers, and scattered wetlands. The coastal hills and Boston basin physiographic regions dominated the topography of northeastern Massachusetts (Peragallo, 1989). Forested areas in DMZ 10 were often highly fragmented by suburban homes, multi-lane highways with median barriers, 2-lane roads, shopping centers, cities and towns, public parks, and to a lesser extent, public parks, farmland, orchards, and pasture. The road density was generally medium (3–5 km/km^2) to very high (up to 70 km/km^2) on a gradient from west to east (Steel, 1999).

Methods

In general, we looked at the percent of forest and open canopy cover types and their spatial association across the landscape to quantify amount of edge in two ways. First, edge segments were calculated using the traditional forest-field definition. Then low-intensity residential (suburban) areas were included as edge. We also collected independent range data from radio-collared deer to compare deer characteristics to the change in amount of suburban edge within the landscape (Garshelis, 2000).

Vegetation grid analysis

The United States Geological Survey (USGS) has compiled a set of 30 m resolution land cover classifications interpreted from multi-resolution land classification (MRLC) satellite imagery (MRLC, 2000). Twenty land cover types from the national land cover data were represented in our 2 study areas. We reclassified these 20 MRLC cover types into 3 aggregate deer habitat categories: forested cover, open canopy vegetation, and non-deer habitat. We included deciduous, coniferous, and mixed deciduous-coniferous cover types as forested cover. To quantify the impacts of rapidly spreading suburban growth on deer habitat, we grouped our second aggregate category, open canopy vegetation, with two different approaches. The first included the MRLC classes of transitional, shrubland, orchards/vineyards, grasslands/herbaceous, pasture/hay, row crops, fallow, urban/recreational grasses, woody wetlands, and emergent herbaceous wetlands. In the first approach we assumed low intensity residential land cover as non-deer habitat. The second approach included only one change: the addition of low intensity residential as open cover. Low intensity residential classification included areas with a mixture of human development and vegetative cover, and most commonly included single-family housing units. Development accounted for 30–80% of the cover, while vegetation accounted for 20–70% of the cover (MRLC, 2000).

Non-deer habitat (our third aggregate of MRLC cover types) included high intensity residential, commercial/industrial/transportation, bare rock/sand/clay, open water, and quarries/strip mines/gravel pits (we recognize that deer do utilize areas such as gravel pits; however, for this analysis these types were not used). Low intensity residential was included in the first approach, and then not included in second approach as described above.

We defined edge as segments where forest cover abutted open canopy vegetation, and used the computer program FRAGSTATS (McGarigal and Marks, 1995) to calculate the amount of edge where forest cover abutted open cover. Due to the size difference of the two study areas, edge density (m/ha) rather than total edge length was used to compare them. Edge density is the sum of all the edge segments between open canopy vegetation and forest cover, divided by the total landscape area (McGarigal and Marks, 1995).

Capture and marking

We established capture sites in both study areas during the end of December 1997–2001, and captured and marked deer from January to April. Stationary and feeding deer were captured by remote drug immobilization. Darts containing a 3 ml mixture of telazol (Tiletamine HCl/Zolazepam HCl), xylazine HCl, and sterile water were administered using model 171 dart rifles (Pneu-dart, Inc., Williamsport, PA). Dosages were about 4.4 mg/kg telazol and 2.0 mg/kg xylazine (A. J. DeNicola, White Buffalo, Hamden, CT, USA, personal communication). The drug at this rate subdues the animal for about 1.5 hours, which is sufficient time to find and collar the darted animal. Shooters sat in tree stands <30 m from the animals to ensure accuracy, and did not discriminate by age or sex of the deer. Deer were fitted with collar-mounted telemetry radios, equipped with a mortality sensor (Advanced Telemetry Systems, Inc., Isanti, MN). The capture protocol was approved by the University of

Massachusetts Institutional Animal Care and Use Committee (IACUC approval # 21-02-05) and is on file at the University of Massachusetts, Amherst.

Radio monitoring

We used radio-telemetry and Global Positioning System (GPS) technologies to monitor and track adult radio-marked deer. We recorded radio signals biweekly to obtain status (alive or dead) and locations for each animal (White and Garrot, 1990). A mortality sensor functioned on a switch within the radio collar that sounded double time when the collar was stationary for >8 hours. When a mortality signal was detected we retrieved the collar, determined cause of death if possible, and recorded the location.

To locate deer from the ground by triangulation we used a hand-held directional antenna to obtain 3 directional signals (vectors) from 3 known locations on U. S. Geological Survey topographic maps. We drew each vector on the map from the location it was taken to form an error polygon, indicating the apparent location of the animal (Kenward, 2001).

We relocated migrated or dispersed deer from the air in a Cessna 172 Skyhawk mounted with two-element Yagi antennas on each wing bracket (Samuel and Fuller, 1994). A minimum of three aerial searches for each missing deer were conducted before it was censored from the study (White and Garrott, 1990). Aerial locations were used only for signal monitoring and general relocation of missing deer.

Movement analyses

Movement data were collected to document and compare movements of deer in suburban areas with moderate human densities in both NW (DMZ 2) and NE Massachusetts (DMZ 10), and a rural forested area with low human densities in northwestern Massachusetts (DMZ 2) only. Ground-based field data were transferred to digital format within a Geographical Information System (GIS) on scanned 1:24,000 topographic maps in Massachusetts State Plane projection, downloaded from MassGIS (MassGIS, Boston, Massachusetts, USA). Each radio-marked deer was assigned a shape file within an ArcView database (ESRI, Redlands, California, USA). Deer were captured incrementally during the study, therefore deer caught later in the study had fewer relocations and a minimum sample of 20 relocations with points from all 4 seasons was required for each deer used in the analysis. Each animal's movement over time was then processed with AnimalMovement 1.0 (U. S. Geological Survey, Biological Resources Division, Anchorage, Alaska, USA). We used 95% ellipse areas as comparative range values for each deer. Deer were classified into 3 a priori groups dependent on whether the location (wintering area) where they were captured was suburban or rural. The first group consisted of deer captured within suburban areas in the townships of Carlisle and Bedford, both suburbs of Boston, Massachusetts. The second group was captured within suburban areas in the township of Dalton, a suburb of Pittsfield, Massachusetts. The final group was captured within areas of agricultural or forested rural areas in the townships of Cheshire, Charlemont, Dalton, Hawley, and Hinsdale, Massachusetts. The capture locations were made prior to GIS analysis and therefore are based on researcher observations of the sites proximity to suburban development. Range comparisons relative to these groups were assessed with t-tests (Mendenhall *et al.*, 1999).

Results

Vegetation grid analysis

Forest cover accounted for 83% of NW Massachusetts (DMZ 2), compared to 45% in NE Massachusetts (DMZ 10) (Table 1). With low intensity residential areas categorized as non-deer habitat, 12% of NW and 15% of NE Massachusetts were considered open canopy. However, when low intensity residential was included as open canopy, 16% of NW and 42% of NE Massachusetts were considered open canopy.

The amount of forest edge in NW Massachusetts rose from 7,944 to 9,408 km when low intensity residential was included within open canopy, a 16% increase (figure 1). In NE Massachusetts the amount of edge changed from 18,257 to 35,746 km, a 49% increase (figure 2). Edge density for NW Massachusetts was 56 m/ha with low intensity residential areas included in non-deer habitat and 64 m/ha with low intensity residential included as open canopy. In NE Massachusetts, edge density was 82 m/ha when low intensity residential was categorized as non-deer habitat and 113 m/ha, or 44% more edge per ha as in NW Massachusetts, with low intensity residential included as open canopy (Table 1).

Deer movements

We used data from 53 (13 males, 40 females) captured and marked deer. Deer were monitored during each season for two years from 2001 to 2003. Suburban deer from NE Massachusetts (5 males, 19 females) had a mean range of 610 ha (32–4,770). Deer in suburban areas from NW Massachusetts (2 males, 11 females) had a mean range of 743 ha (176–3,307) and

Table 1. Vegetative cover analysis for NE (DMZ 10) and NW (DMZ 2) Massachusetts derived from Multi-Resolution Land Characterization Consortium (MRLC) data

Zone	DMZ area (ha)	Non-deer habitat area	Non-deer habitat %	Open canopy Area	Open canopy %	Forest cover area	Forest cover %	Edge (km)[c]	Edge Density (m/ha)[d]
DMZ 2[a]	150,643	8,484	5	17,793	12	124,365	83	7,944	56
DMZ 2[b]	150,643	4,301	2	21,976	15	124,365	83	9,408	64
DMZ 10[a]	369,272	147,711	39	58,110	16	163,450	45	18,257	82
DMZ 10[b]	369,272	52,487	13	153,333	42	163,450	45	35,746	113

[a]Low intensity residential run as non-deer habitat.
[b]Low intensity residential run as open canopy.
[c]Sum of all edge segments between open and forest categories.
[d]Sum of edge segments divided by the total landscape area.

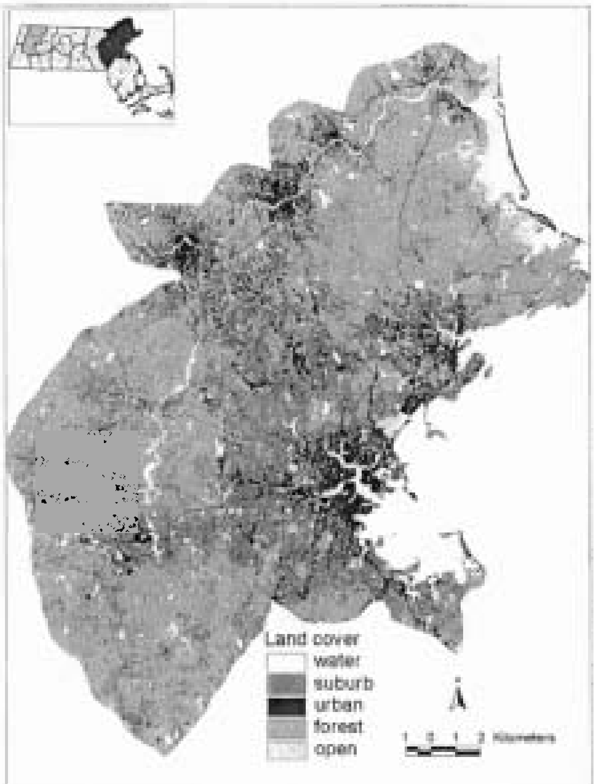

Figure 2. Aggregated multi-resolution land classifications (MRLC) in northeastern Massachusetts (deer management zone [DMZ] 10).

deer in rural areas from NW Massachusetts (6 males, 10 females) had a mean range of 8,087 ha (113–17,323) (Table 2). Ranges for suburban deer from the NE were not different from those of suburban NW ($P = 0.7$), but the ranges for suburban deer in both parts of the state were different than those of the rural deer in NW Massachusetts ($P = 0.001$) (figure 3).

Discussion

Low intensity residential development in Massachusetts has expanded at a rapid rate during the last half century (Steel, 1999). Marked increases in forest fragmentation with only slight increases in human population density have had large effects on edge habitat in New England (Vogelman, 1995). This creates a suite of conditions that likely supports deer and often protects them from sources of mortality such as predation and hunting. Danielson *et al.* (1997) observed higher levels of bird nest predation by larger predators (e.g., black bear *Ursus americanus*) within edge in rural areas of Massachusetts compared with suburban

Table 2. Average range differences of radiocollared adult white-tailed deer monitored in suburban NE (DMZ 10) and suburban and rural NW (DMZ 2) Massachusetts, January 2001–January 2003

			Mean		
Area	Sex	No. of Deer	Locations	Area (ha)	Data range (ha)
NE (DMZ 10) Suburban	Female	19	29	425	32–3,670
	Male	5	25	1,311	117–4,770
NW (DMZ 2) Suburban	Female	11	27	799	176–3,307
	Male	2	25	435	284–587
NW (DMZ 2) Rural	Female	10	26	7,329	113–16,745
	Male	6	24	9,350	2,014–17,323

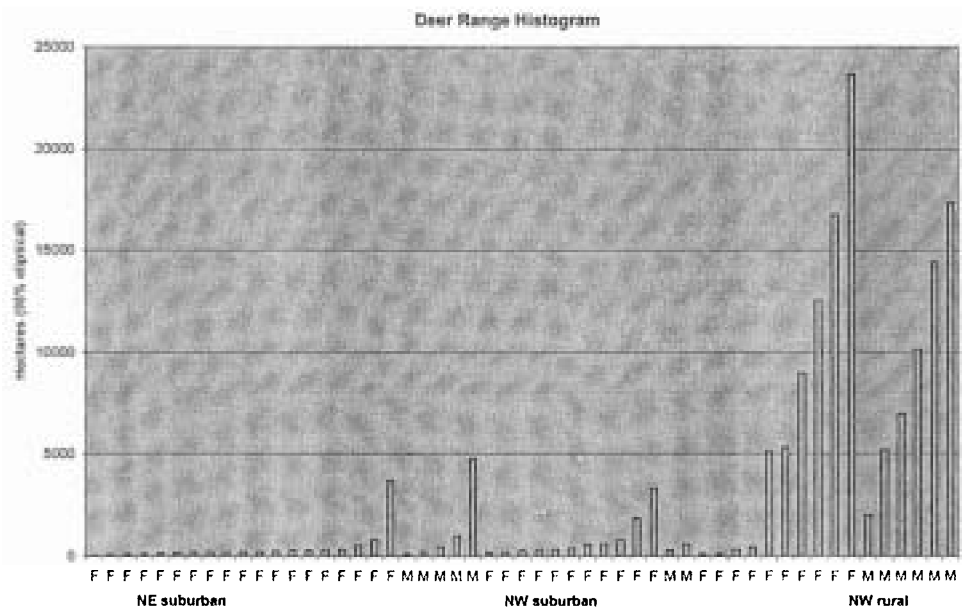

Figure 3. Ranges (ha) of individual female (F) and male (M) deer captured in suburban or rural areas of northeastern and northwestern Massachusetts.

areas. Lower rates of predation on deer, including fawns, in suburban environments may also be true for deer. Other factors influencing survival of suburban (e.g., housing densities being too high to allow firearm discharge) versus rural deer (e.g., out of season permits that farmers may obtain to harvest deer if they damage crops) add to the population growth of deer in more developed areas.

Over a quarter (26%) of the land area in NE Massachusetts (DMZ 10) was classified as low intensity residential, making this the largest open canopy vegetation type in that study area. As most of the open land in the NE, and a growing portion of the land in the NW, are no longer agricultural but suburban, deer are often able to use this forest/residential interface with less hunting pressure.

Large areas of low intensity residential development often create higher quality habitat for species that prefer edge habitat. However, species that have succeeded where suburban development has mimicked traditional forest edge conditions must also be adaptable to human impacts on the landscape. An effect of increased edge may be to decrease species richness and favor adaptable species (Dickman, 1987; Yahner, 1988). Because suburban residents are less likely to manage adaptable game species through harvest due to local bylaws and/or cultural or philosophic ideals, these areas can often promote high population growth rates of adaptable species (Alverson *et al.*, 1988).

In separate studies, deer movements in suburban (Kilpatrick and Spohr, 2000) versus rural (Tierson et al., 1985) areas seemed quite different. In our study, however, we were able to document deer movements in both suburban and rural areas. We suspected that deer in eastern Massachusetts had become accustomed to residing within human communities, especially in areas of low intensity residential development bounded by patches of undeveloped forested or cleared land. However, we were less sure of the movements of deer using suburban development bounded by large expanses of rural forested or agricultural lands in western Massachusetts. We found that the marked deer using suburban developments in NW Massachusetts in our study were non-migratory and maintained small ranges within or on the edges of human habitation versus rural deer. These small ranges were similar to the deer utilizing suburban areas in NE Massachusetts where development was more widespread and little or no rural or unfragmented open-space existed. The difference between the two groups of deer utilizing suburbia was in their proximity to the rural landscape and to other migratory deer. Sabine *et al.* (2002) found that migratory behavior among a northern (obligate migratory) and southern (conditional migratory) population of white-tailed deer in eastern Canada was largely dependent on winter severity. During our study, the winter of 2000–2001 was abnormally cold with high snow depths, while the winter of 2001–2002 was relatively mild with low snow depths. Despite this climatic variation, suburban deer in both the NE and NW maintained small ranges relative to the rural deer during both years, while non-suburban deer migrated to wintering areas during both years.

Our findings suggest that the option of living year round in suburbia is one that deer are not forced into by habitat fragmentation. Rather, some deer may use these suburban areas because of the resources (e.g., food) or the conditions (e.g., protection from hunting) that exist there. Marzluff *et al.* (2001) reported that corvid populations are increasing worldwide in response to agriculture and urbanization. American crow (*Corvus brachyrhynchos*) populations peak in urban and suburban areas, probably because abundant food draws exurban crows into cities and towns and permits adult crows to have smaller home ranges and to breed at higher densities (Marzluff *et al.*, 2001; McGowan, 2001). This phenomenon of "habitat packing" has been observed in some species for other reasons (e.g., spotted owls [*Strix occidentalis*] in remnant old-growth stands), and may be occurring with other species, like white-tailed deer and crows, that are adapted to the resources and conditions present in suburban environments.

Acknowledgments

Funding for this project was provided by the Massachusetts Division of Fisheries and Wildlife. We thank Robert Deblinger, William Woytek, Ken Berger, Brian Guerin, the district staff of MDFW, and private landowners for their invaluable assistance. Todd K. Fuller and William P. Kuvlesky, Jr. reviewed earlier drafts of the manuscript.

References

Alverson, W.S., Waller, D.M. and Solheim, S.L. (1988) Forests too deer: Edge effects in northern Wisconsin. *Conserv. Biol.* **2**, 348–358.

Danielson, W.R., DeGraaf, R.M. and Fuller, T.K. (1997) Rural and suburban forest edges: Effect of egg predators on nest predation rates. *Landscape and Urban Planning* **38**, 25–36.

DeGraaf, R.M., Yamasaki, M., Leak, W.B. and Lanier, J.W. (1989) New England wildlife: Management of forested habitats. Northeastern Forest Experiment Station General Technical Report NE-144, Amherst, MA.

DeStefano, S. and DeGraaf, R.M. (2003) Exploring the ecology of suburban wildlife. *Frontiers in Ecol. and the Environ.* **1**, 95–101.

Dickman, C.R. (1987) Habitat fragmentation and vertebrate species richness in an urban environment. *J. Applied Ecol.* **24**, 337–351.

Garshelis, D.L. (2000) Delusions in habitat evaluation. In *Research techniques in Animal Ecology* (L. Boitani and T.K. Fuller, eds.), pp. 111–164. Colombia Univ. Press, New York, NY.

Kenward, R.E. (2001) *A Manual for Wildlife Radio Tagging.* Academic Press, Inc., London, UK.

Kilpatrick, H.J. and Spohr, S.M. (2000) Movements of female white-tailed deer in a suburban landscape: a management perspective. *Wildl. Soc. Bull.* **28**, 1038–1045.

Leopold, A. (1933) *Game Management.* University of Wisconsin Press, Madison.

Marzluff, J.M., McGowan, K.J., Donnelly, R. and Knight, R.L. (2001) Causes and consequences of expanding American crow populations. In *Avian Ecology and Conservation in an Urbanizing World* (J.M. Marzluff, R. Bowman and R. Donnelly, eds.), pp. 331–363. Kluwer Academic Publ., Boston, MA.

McCullough, D.R. (1984) Lessons from the George Reserve Michigan. In *White-Tailed Deer: Ecology and Management* (L.K. Halls, ed.), pp. 211–242. Stackpole Publ., Harrisburg, PA.

McGarigal, K. and Marks, B.J. (1995) *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure.* USDA Forest Service General Technical Report PNW-351.

McGowan, K.J. (2001) Demographic and behavioral comparisons of suburban and rural American crows. In *Avian Ecology and Conservation in an Urbanizing World.* (J.M. Marzluff, R. Bowman and R. Donnelly, eds.), pp. 365–381. Kluwer Academic Publ., Boston, MA.

Mendenhall, W., Beaver, R.J. and Beaver, B.M. (1999) *Introduction to Probability and Statistics.* Duxbury Press, Pacific Grove, CA.

Multi-Resolution Land Characterization Consortium (MRLC). (2000) National land cover data. http://www.epa.gov/mrlc/nlcd.html (16 March 2000).

Nelson, M.E. (1995) Winter range arrival and departure of white-tailed deer in northeastern Minnesota. *Canadian J. Zool.* **73**, 1069–1076.

NOAA. (2005) National Operational Hydrological Remote Sensing Center. http://www.nohrsc.noaa.gov/nsa/ (21 April 2005).

Peragallo, T.A. (1989) *Soil Survey of Norfolk and Suffolk Counties, Massachusetts.* USDA-Soil Conservation Service, United States Department of Agriculture.

Sabine, D.L., Morrison, S.F., Whitlaw, H.A., Ballard, W.B., Forbes, G.J. and Bowman, J. (2002) Migration behavior of white-tailed deer under varying winter climate regimes in New Brunswick. *J. Wildl. Manage.* **66**, 718–728.

Samuel, M.D. and Fuller, M.R. (1994) Wildlife radiotelemetry. In *Research and Management Techniques for Wildlife and Habitats*, Fifth edition (T.A. Bookhout, ed.), pp. 370–418. The Wildlife Society, Bethesda, MD.

Scanu, R.J. (1988) *Soil Survey of Berkshire County Massachusetts.* USDA-Soil Conservation Service, United States Department of Agriculture.

Steel, J. (1999) *Losing Ground: An Analysis of Recent Rates and Patterns of Development and Their Effects on Open Space in Massachusetts.* Masachusetts Audubon Society, Lincoln, MA.

Tierson, W.C., Mattfield, G.F., Sage, R.W., Jr. and Behrend, D.E. (1985) Seasonal movements and home range of white-tailed deer in the Adirondacks. *J. Wildl. Manage.* **49**, 760–769.

Van Deelen, T.R., Campa, H., Hamady, M. and Haufler, J.B. (1998) Migration and seasonal range dynamics of deer using adjacent deeryards in northern Michigan. *J. Wildl. Manage.* **62**, 205–213.

Verme, L.J. (1973) Movements of white-tailed deer in upper Michigan. *J. Wildl. Manage.* **37**, 545–552.

Vogelman, J.E. (1995) Assessment of forest fragmentation in southern New England using remote sensing and geographic information systems technology. *Conserv. Biol.* **9**, 439–449.

White, G.C. and Garrot, R.A. (1990) *Analysis of Wildlife Radio-Tracking Data.* Academic Press, San Diego, CA.

Yahner, R.H. (1988) Changes in wildlife communities near edges. *Conserv. Biol.* **2**, 333.