MOVEMENTS, SURVIVAL, AND HABITAT RELATIONSHIPS OF SNOWSHOE HARES FOLLOWING RELEASE IN NORTHEAST OHIO

A Thesis

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By

Kevin Allen Swanson, B.S.

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Master's Examination Committee:

Robert J. Gates, Advisor

Tomas M. Koontz

Roger A. Williams

David P. Scott

Approved by

Robert J. Gates

Advisor
Department of Natural Resources

ABSTRACT

The geographic distribution of snowshoe hares (*Lepus americanus*) is primarily associated with northern boreal forests of North America. Snowshoe hares were once indigenous to the snow-belt region of northeastern Ohio, but were extirpated by the early 1900s. Attempts were made to reintroduce snowshoe hares in northeastern Ohio during the 1950s. However, these releases failed to establish a viable population. Causes of failure are unknown because the releases were poorly documented and monitored. Factors limiting snowshoe hare populations at the southern periphery of their geographic range are poorly understood. Therefore, I monitored an experimental release of 232 snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio during winters 2000-2001. My goals were to; (1) determine the feasibility of establishing a breeding population by releasing hares during winter and, (2) identify the most suitable habitats for snowshoe hares in northeast Ohio. I monitored movements, survival, and habitat use by 160 radio-marked hares during January-June, 2000 and 2001. Hares were released on 8 forest sites that differed in age of dominant trees and wetland coverage. Hares released during 2000 lost more weight before release ($P < 0.001$) and had lower condition ($P = 0.054$) than in 2001. Hares dispersed farther ($P < 0.001$) from release sites in 2001 (937 ± 52 m) than in 2000 (562 ± 41 m). January-June survival was higher ($P = 0.002$) in 2001 (43%) compared to 2000 (21%). Improved pre-release condition and more prolonged snow cover were associated with increased movements and survival in 2001. Predation by coyotes (*Canis latrans*) and red foxes (*Vulpes vulpes*) was the major source of mortality (53-63% of deaths) each year. Mean 95% kernel home ranges were large (55-67 ha) and did not differ between years. Hares used shrub-dominated wetlands, wetland forests (10-20 years old), and early successional forests (<10 years old) in proportions greater than their availability across the study area. Hares used forests >20 years old and non-forested habitats less than their availability in the study area. Dispersal from release sites was lowest in mixed wetland/upland and early regenerating forests during 2000 and 2001. Based on apparent survival during January-March (37-62%), approximately 51 hares survived until the start of the breeding season in 2000, and 58 survived in 2001. Survival was highest among hares released in wetland (37-44%) and regenerating forest stands (22-47%) both years. Reproductive success is the most critical factor that will determine the long-term viability of snowshoe hares after reintroduction into northeast Ohio. Two pregnant females, 8 reproductively active males, and 1 juvenile male were captured during live-trapping in 2000 and 2001. Long-term success of the reintroduction effort will require supplemental releases until a network of local populations is established. Forested landscapes containing ≥11% shrub-scrub wetlands and ≥5% early successional forests are essential to support breeding populations and should be the focus of future releases. Populations should be established in contiguous wetland/forest tracts with connectivity between habitat patches to facilitate inter-population dispersal. Efforts to restore snowshoe hares in northeast Ohio raises awareness of the need to protect native landscapes from development and conserve early successional and forested wetland habitats.

Dedicated to Henry X. Swanson

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VITA

October 9, 1974........................Born - Jacksonville, Florida

1998....................................B.S. Fisheries and Wildlife, Michigan State University

1999-2002.............................Graduate Research Associate,
The Ohio State University

PUBLICATIONS

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CHAPTER 1

INTRODUCTION

Snowshoe hares (*Lepus americanus*) are an abundant indicator species of the northern boreal forests of North America. The geographic range of snowshoe hares encompasses most of Canada and the northeastern United States (Figure 1.1). The snowshoe hare's range also extends south into the Great Lakes region and into higher elevations of the Appalachian and Rocky Mountains (Bittner and Rongstad 1982, Carraker 1985, Flux and Angermann 1990). The species was once indigenous to the snowbelt region of extreme northeastern Ohio, with all known specimens and observations reported from Ashtabula County (Bole and Moulthrop 1942). Human settlement removed much of the native forest habitats that supported snowshoe hare populations in Ohio, and the species was extirpated from the state by the early 1900s (Ohio Division of Wildlife 1992). Several attempts were made to reintroduce snowshoe hares in Ashtabula County during the 1950s. However, these releases did not produce a viable population, and hares remained extirpated in Ohio (Ohio Division of Wildlife, unpubl. data). Causes of failure of earlier restoration attempts are unknown because they were inadequately documented and monitored. No efforts were made to follow live hares using mark-recapture or telemetry techniques. Possible explanations for failure include inadequate quantity or quality of forested habitat, competition with eastern cottontails (*Sylvilagus floridanus*), poor condition or insufficient numbers of released animals, and the numeric and functional responses of the northeastern Ohio predator community (Scott 1999).

Figure 1.1: Geographic range of snowshoe hares in North America, modified from Bittner and Rongstad (1982) (Carraker 1985).

To increase the wildlife diversity of Ohio, the Division of Wildlife decided to undertake another snowshoe hare reintroduction during 2000 and 2001. Restoring snowshoe hares to Ohio focuses attention on the importance of native swamp forests of the boreal region, which is a unique landscape in the state. The attempt to restore an extirpated, area-sensitive forest species also should raise awareness of the need to conserve forest and wetland habitats and manage urban development and other human impacts in northeast Ohio. However, research is needed to better understand factors that limit the geographic distribution of snowshoe hares. Knowledge of critical variables and habitat requirements within the southern geographic range limits of the species in Ohio is lacking. Therefore, the reintroduction effort was preceded by an experimental release designed to determine the feasibility of restoring a viable snowshoe hare population within its former range. Primary goals of the experimental release were to determine if a breeding population could be established by releasing animals during winters of 2000 and 2001 and to identify critical habitats for snowshoe hares in northeast Ohio.

Physical Characteristics

The snowshoe hare is the smallest member of the genus *Lepus* and is similar to the eastern cottontail rabbit in appearance (Flux and Angermann 1990). Physiological characteristics of the snowshoe hare include adaptations for sustained running and survival in northern boreal forests (Carraker 1985, Flux and Angermann 1990). Unlike rabbits, snowshoe hares have a lightly-built skeleton, large ears and hind feet (Bittner and Rongstad 1982, Hall 1981). Snowshoe hare body measurements are: total length, 363-520 mm; hind foot length, 112-150 mm; tail length, 25-55 mm; ear length, 62-70 mm; and average weight, 1,300 g (Bittner and Rongstad 1982). Pelage color varies seasonally with day length. Snowshoe hares molt into a mostly white winter pelage. The autumn molt begins in October and usually lasts until December when hares are white (approximately 70-90 days). The vernal molt begins in March and lasts until May (also approximately 70-90 days). The summer pelage is generally rusty brown with white chin, abdomen, and feet (Bittner and Rongstad 1982).

Population Ecology

Snowshoe hare populations fluctuate with a 10-year cycle throughout much of their range. The hare population cycle is caused by a relationship between hares and their food supply, mediated by hare-predator interactions (Bittner and Rongstad 1982, Carraker 1985, Keith 1974). Snowshoe hare densities that exceed carrying capacity lead to an increase in local predator populations and reduction in natural regeneration of forest strands. Food availability for snowshoe hares eventually falls below that required by the population until survival and reproductive rates decrease. As hare numbers begin to decline, predation rates become significant and decrease the hare population below levels determined by the food supply. Eventually, the abundance of predators falls from the lack of prey, snowshoe hare food resources rebound, and the cycle repeats (Keith 1974). Snowshoe hare population densities have been reported to range from <1 to 39 hares/ha throughout their geographic range, reaching highest densities during years of peak populations (Bittner and Rongstad 1982, Keith 1981). Population peaks normally range from 10-30 times the population low (Keith 1981). The snowshoe hare population cycle appears to be more pronounced in northern populations and within the core of the geographic range. Less fluctuation and lower densities occur in marginal habitats at the periphery of the snowshoe hare range (Adams 1959, Keith et al. 1993). Based on the marginal suitability of habitat in northeast Ohio, preliminary population modeling and experimental releases targeted a density of 1 pair per 20 ha of woody habitat (0.1 hares/ha).

Survival

Extreme winter weather and predation are limiting factors for snowshoe hare populations (Bookhout 1965*b*, Carraker 1985, Litvaitis et al. 1985, Sievert and Keith 1985). Competition with eastern cottontails, sport hunting by humans, parasites, and disease also may influence snowshoe hare survival (Bittner and Rongstad 1982, Sievert and Keith 1985). Common predators in northern areas of snowshoe hare range include lynx (*Lynx canadensis*), goshawk (*Accipiter gentilis*), red fox (*Vulpes vulpes)*, red-tailed hawk (*Buteo jamaicensis*), and pine martin (*Martes americana*) (Carraker 1985). Red fox, coyote (*Canis latrans*), bobcat (*Lynx rufus*), and raptors are important predators in southern portions of the hare range (Wolff 1980). Snowshoe hare mortality rates vary regionally with stage of the population cycle. Keith and Windberg (1978) reported juvenile mortality from birth to winter to be 89-94% during years of extreme population decline and 42-76% during years of population growth. Annual adult mortality rates average 89% in declining and low population years, 64% during increasing population years, and 47% in the peak year (Keith and Windberg 1978). Survival is generally lower among juveniles and during winter and spring seasons when food and cover resources are lacking. Decreased snowshoe hare survival also has been related to factors that increase movements, such as fragmented landscapes, increased activity during breeding seasons, and post-release dispersal of relocated animals (Keith et al. 1993).

Reproduction

Unlike rabbits, snowshoe hares give birth to precocial young and do not build nests. The breeding season varies with latitude, day length, spring weather, and stage of the population cycle (Meslow and Keith 1971). Breeding generally begins between mid-March and early April and lasts through mid-August (Bittner and Rongstad 1982, Bookhout 1965*a*). Breeding starts later in spring for populations located farther north. The species is seasonally polyestrous, producing up to 4 litters per year (Hall 1981). Three to 4 litters are normal in central portions of the range, while 2 litters per year are common farther north (Keith 1981). Litter size also varies with latitude and season. Snowshoe hares produce smaller litters earlier in the breeding season and in southern areas of their range. Litter sizes increase by approximately 1 from the first to last litters of the season, and from 2.2 in southern portions of the range to almost 6 in northern populations (Flux and Angermann 1990, Keith 1981). Total young produced per year per female typically ranges from 6 to 13 (Bittner and Rongstad 1982).

Habitat Requirements

The snowshoe hare uses a variety of woody cover types throughout its range. Snowshoe hares inhabit coniferous, aspen (*Populus* sp.), birch (*Betula* sp.), beech (*Fagus* sp.), maple (*Acer* sp.), and mixed hardwood forests (Carraker 1985, Conroy et al. 1979, Flux and Angermann 1990). Many authors claim that hares prefer coniferous vegetation, but the importance of deciduous cover also has been documented (Bookhout 1965*b*, Buehler and Keith 1982, Scott and Yahner 1989, Wolff 1980). Snowshoe hares typically avoid open areas and prefer dense growth, regenerating forests, and shrub-scrub wetlands. Contiguous or connected forests are necessary for travel and concealment from predators, while habitat interspersion (e.g., swamp edges and other landscape ecotones) provides for optimal distribution of cover and food resources. The snowshoe hare diet varies with food availability, nutritional requirements, and palatability of plant species (Wolff 1980). Spring and summer diets consist of a variety of herbaceous plants, later replaced by a diet of mostly woody vegetation after the first autumn frost (Aldous 1937, Brooks 1955, Carraker 1985). Herbaceous vegetation consumed by snowshoe hares includes grasses (*Gramineae*), legumes (*Leguminosae*), sedges (*Carex* sp.), ferns (*Polypodiaceae*), and the leaves of deciduous trees (Caraker 1985). Snowshoe hares selectively browse twigs ≤3 mm in winter, using rough bark or stem wood only in extreme food shortages (Bittner and rongstad 1982, Carraker 1985). Woody browse preferred by snowshoe hares in the Great Lakes region includes young poplars (*Populus* sp.), willows (*Salix* sp.), and birches.

Availability of sufficient understory cover is the most important component of suitable snowshoe hare habitat (Buehler and Keith 1982, Carraker 1985). Snowshoe hare habitat suitability is determined by cover quality regardless of forest type (Carraker 1985, Litvaitis et al. 1985, Pietz and Tester 1983). Hares require shrub and young forests with high understory stem densities and visual obstruction >40% (Carraker 1985, Grange 1932). Winter is the critical season for snowshoe hares because food and cover resources are less abundant (Carraker 1985, Meslow and Keith 1971). Dense understory vegetation provides protection from predators, shelter from adverse weather, and winter browse. Optimum habitat is sapling and pole-stage forests where fire or clearcutting produces dense woody growth (Bittner and Rongstad 1982, Bookhout 1965*b*). However, snowshoe hares inhabit all successional stages of northern forest except old-growth hardwood stands. Scott and Yahner (1989) and Litvaitis et al. (1985) found that regenerating clearcut stands were important habitat in southern regions. Early successional forests and shrub-scrub wetlands have the greatest potential to support snowshoe hare populations in marginal habitats where conifers are scarce (Carraker 1985, Litvaitis et al. 1985). Forested habitats are not typically managed specifically for snowshoe hare populations and published information on habitat management techniques is limited (Bittner and Rongstad 1982). Thinning of pole-size stands and burning have been suggested to improve forested habitat in marginal landscapes (Adams 1959, Bookhout 1965*b*). Stocking or relocating wild snowshoe hares is possible where suitable habitat exists and on smaller areas where predators can be controlled. However, heavy understory cover is probably essential where predation rates are high (Bittner and Rongstad 1982).

Land use changes severely alter natural landscapes and decrease the potential to support native wildlife populations (Morrison et al. 1998). Habitat loss increases landscape heterogeneity at course scales, affecting ecological patterns and wildlife population dynamics (Wells and Richmond 1995, Wiens 1994). Buehler and Keith (1982) determined that sites containing >160 ha of suitable habitat were most often occupied by snowshoe hares in central Wisconsin. Similarly, Keith et al. (1993) found that snowshoe hares avoided highly fragmented areas and preferred habitat patches ≥23 ha in size. Fragmented forests with low understory stem density tend to increase snowshoe hare movements as dispersing hares search for sufficient cover (Sievert and Keith 1985; Keith et al. 1993). Dispersing snowshoe hares typically have lower survival due to increased predation (Buehler and Keith 1982). Sievert and Keith (1985) found that dispersers experienced higher predation rates than residents, especially where movements were induced by low understory cover and habitat fragmentation. Snowshoe hares establish home ranges based on spatial relationships of cover, food, and predator populations (Carraker 1985, Wolff 1980). The typical active home range is believed to average 3-9 ha (Sievert and Keith 1985). However, home ranges may be as large as 10 to 13 ha when availability of dense cover is low (Bittner and Rongstad 1982, Wolff 1980).

Population Viability in Ohio

Population viability can be defined as "the likelihood of the persistence of well-distributed populations for a specific time, typically a century or longer" (Morrison et al. 1998). The dynamics of a wildlife population are controlled by many physiological, ecological, and environmental relationships. Population viability of a species is affected by geographic distribution patterns, evolutionary adaptations, population demography, metapopulation dynamics, effects of other species, environmental disturbances, and human influences (Johnson 1994, Morrison et al. 1998). Thus, successfully restoring snowshoe hares to the historic range in Ohio will depend on survival and reproduction of animals following release, emigration and immigration between local populations, and adaptation to local environmental conditions (e.g. snow cover and predator populations). The demography of relocated snowshoe hare will be the result of initial release numbers and subsequent population vital rates in existing habitats (Morrison et al. 1998). Diminished survival at the southern limits of the snowshoe hare range is typically the result of higher movements and predation rates associated with less predictable snowfall and insufficient cover in marginal habitats (Keith et al. 1993, Litvaitis et al. 1985, Scott and Yahner 1989, Seivert and Keith 1985). Therefore, the quality and quantity of habitat in Ohio should determine the potential for restoring a self-sustaining population.

Evaluating habitat relationships of relocated animals can provide insight into the suitability of landscapes for a species and should precede any management actions (Litvaitis et al. 1985). However, knowledge from other snowshoe hare populations may not apply well to specific habitat characteristics and environmental conditions in Ohio. The potential to successfully restore the species must be determined by monitoring the response of released hares in the northeast Ohio landscape and associated habitats. Snowshoe hare movements are expected to be greatest immediately following release and in less suitable habitats. Hares should show preference for habitat types containing high understory cover and stem densities. Mortality due to predation is expected to be the primary limiting factor for hares released in Ohio. The quality of habitat and response of local predator communities will determine if survival is sufficiently high to establish a breeding population. If released hares survive through the breeding seasons, reproduction and subsequent juvenile recruitment will be critical to population viability. In addition, the duration of snow cover and competition with eastern cottontails also will affect the success or failure of re-establishing hares in this region. Ultimately, long-term viability of the species in Ohio will require critical food and cover resources associated with the dense understory cover of coniferous forests, shrub wetlands, and early successional habitats.

I monitored an experimental release of snowshoe hares conducted by the Ohio Division of Wildlife in northeast Ohio during 2000 and 2001. My research focused on identifying limiting factors and key population-habitat relationships of hares following release. To assess the potential for restoring a hare population, it was necessary to determine: (1) how movements and habitat use patterns vary with presence/absence of critical habitat characteristics, (2) how survival of released hares varies with presence/absence of critical habitat characteristics, (4) how survival of hares released in northeast Ohio compares with other snowshoe hare populations near the southern periphery of the geographic range, and (3) whether existing habitat conditions are conducive to survival and reproduction of released animals. My approach was to evaluate the releases and habitat suitability of the experimental study area by using radio-telemetry to monitor movements, habitat use, survival, and reproduction following release. I determined dispersal distances, home ranges, habitat preference, survival rates, and causes of mortality of radio-marked hares during January-June, 2000 and 2001. Live-trapping was used to document reproduction and recruitment of young into the local population. Critical variables were analyzed for habitat-specific differences to determine the most suitable habitat types for snowshoe hares in northeast Ohio. Findings also were compared to those of other snowshoe hare population studies to assess future potential of the region to support a viable population.

Results of this study were used to provide recommendations for future releases and to improve the effectiveness of snowshoe hare restoration attempts in northeast Ohio. Monitoring and evaluating the experimental release of snowshoe hares determined critical limiting factors and suitability of existing habitat for the species. The evaluation also identified important natural resources that may be at risk in northeast Ohio and predicted the future potential to support snowshoe hares in the region.

CHAPTER 2

STUDY AREA AND RELEASE DESIGN

The known historic range of snowshoe hares in Ohio is restricted to the extreme northeastern region of the state, specifically Ashtabula County. Lake effect precipitation in this region results in 190-267 cm (75-105 in.) snow/year (Figure 2.1). Ashtabula County receives 60-85 days with >2.5 cm of snow cover annually (Miller and Weaver 1971, Schmidlin 1989). Historically, the region contained various climax and subclimax forest types (Bole and Moulthrop 1942). Extensive swamp forests associated with poorly- or moderately-drained sites surrounded the Pymatuning Creek and Grand River watersheds. Mixed mesophytic forests with broad-leaved and deciduous species occurred throughout Ashtabula, Lake, and Geauga Counties (Sears 1925). Vegetation of the region mainly consisted of beech-maple forests, dominated by American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red oak (*Quercus rubra*), white ash (*Fraxinus americana*), and white oak (*Quercus alba*) (Transeau and Sampson 1934). Elm-ash swamp forests dominated by American elm (*Ulmus americana*), black ash (*Fraxinus nigra*), white ash, silver maple (*Acer saccharinum*), and red maple (*Acer rubrum*) also were present throughout the landscape. In addition, records indicate that hemlock (*Tsuga* spp.) and white pine (*Pinus strobus*) also were abundant in this region of the state (Sears1925). Forested land was cleared in Ohio beginning in the late 1700s and continuing for the next 150 years. European settlement increasingly fragmented the forest landscape and eliminated nearly all of the virgin forests of northeastern Ohio. The landscape currently contains a patchy mosaic of remnant wetlands and forested tracts within a predominantly agricultural matrix. The encroaching urban edge of Cleveland and associated exurban development further threaten forested habitats the in this region.

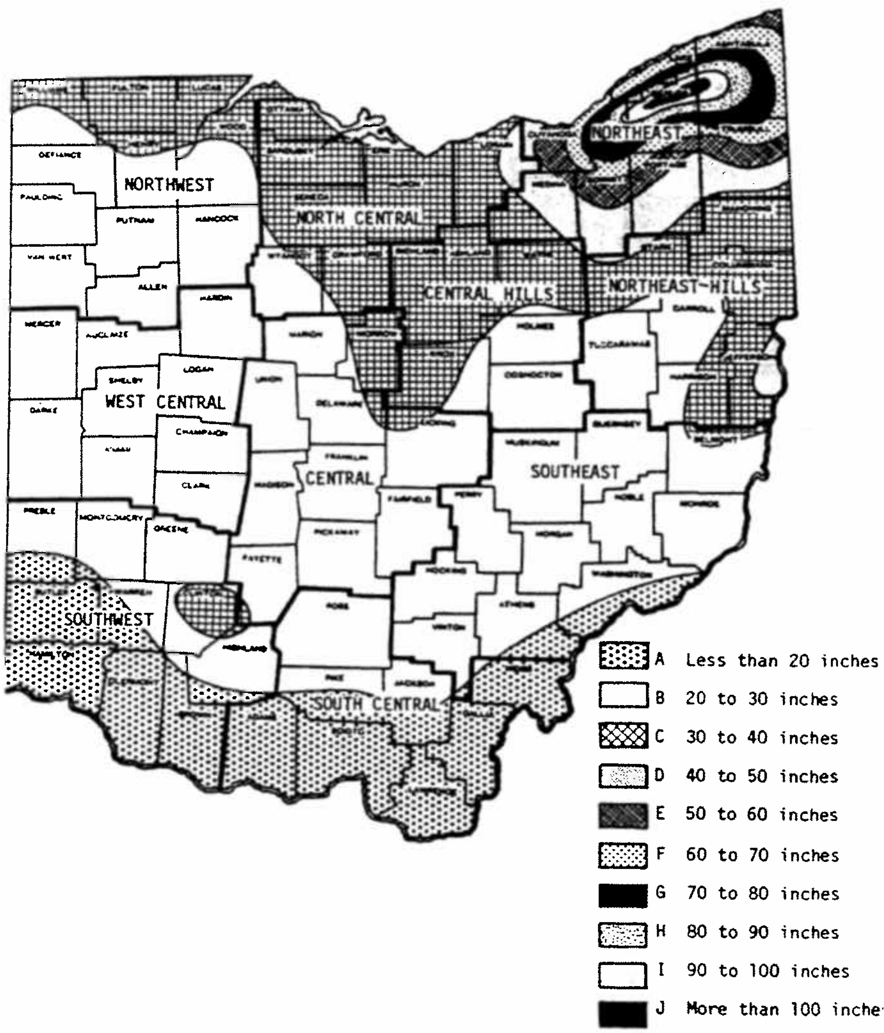

Figure 2.1: Mean annual snowfall (inches) in Ohio (from Miller and Weaver 1971).

The Ohio Division of Wildlife completed an exploratory evaluation of potential snowshoe hare habitat in Ashtabula County, Ohio in 1994. Habitat types considered suitable for snowshoe hares in the region included shrub-scrub wetlands, forested wetlands, deciduous and mixed woodlands with well-developed understory, regenerating clearcuts, and conifer stands (Carraker 1985, Scott 1998). The evaluation revealed a fragmented landscape with a mosaic of wetland habitats and adjoining forest tracts surrounded by a matrix of agricultural, exurban development, and other cover types (Scott 1998). The largest tracts with apparently suitable cover were found in the Pymatuning Creek and Grand River watersheds (Scott 1999). Woody cover types in these areas were similar to marginal habitats that support low densities of hares in north-central Pennsylvania (Scott and Yahner 1989). The Ohio Division of Wildlife mapped the location and distribution of forested areas (>304 ha) and associated shrub-scrub wetlands in Ashtabula County during 1997 (Scott 1998). Twenty-three potentially suitable tracts 413-1,304 ha in size were identified. Each tract included 8-138 ha of shrub-scrub wetlands. As anticipated from preliminary habitat assessments, the landscape contained many open areas that would impede snowshoe hare dispersal among isolated forest fragments (Keith et al. 1993).

The greatest concentration of potential habitat was identified in the west-central portion of Ashtabula County, in the Grand River watershed. Snowshoe hare habitat suitability indices (HSI) were calculated from measurements of vertical obstruction within 3 m of the ground, observed from a distance of 15 m (Carraker 1985). Vertical obstruction was recorded every 25 m along transects located in forested habitat near edges, within interior portions of woody blocks, and in shrub-scrub wetlands. All sampling was conducted during leaf-off in 1999 and 2000. HSI scores of potential release areas ranged from 0.00-0.66. A 2,600 ha tract of habitat in northeastern Geauga and southwestern Ashtabula Counties had the highest overall score and was selected for the initial release of hares in January 2000 and 2001. The experimental release area is located approximately 16 km east of Chardon and 25 km southwest of Jefferson. Universal Transverse Mercator (UTM) coordinates of the experimental release area are within 496,000-502,000 E and 4,598,200-4,604,500 N [Zone 17, North American Datum 1983].

Forested tracts within the study area were delineated by interpreting black and white digital orthophoto quarterquadrangles (DOQQs) acquired from National Aerial Photography Program (NAPP) photography taken between 1993 and 1999 (Ohio Department of Administrative Services 2001). Privately-owned upland and wetland forest tracts within the area differed in size, contiguity, and stand age. The study area was bisected into northern and southern regions by a 2-lane, paved highway (State Route 86). The largest woodland blocks were associated with poorly drained sites that extended across the northern and southwestern portions of the area. Row crop and dairy agriculture was the major land use along roadways and surrounded poorly drained interior forests. Habitats with the greatest potential for snowshoe hares included shrub-dominated wetlands, wetland or upland forests with dense understory, and early successional habitats. The 8 largest tracts of continuous forest cover containing varying amounts of optimum or marginal habitat were selected as release areas (Figure 2.2). Forested tracts containing ≥67% continuous upland, wetland, or early successional forest <10 years old were classified accordingly. Tracts containing 33-67% continuous habitat were classified as mixed stands of upland, wetland, or early successional forest. Four release sites, representing each habitat type, were located north and south of State Route 86. The 8 release areas (sizes = 90-390 ha) were categorized as North or South and according to general habitat characteristics (Table 2.1). Exact locations where snowshoe hares were released at each site during 2000 and 2001 were determined as UTM coordinates, NAD 83.

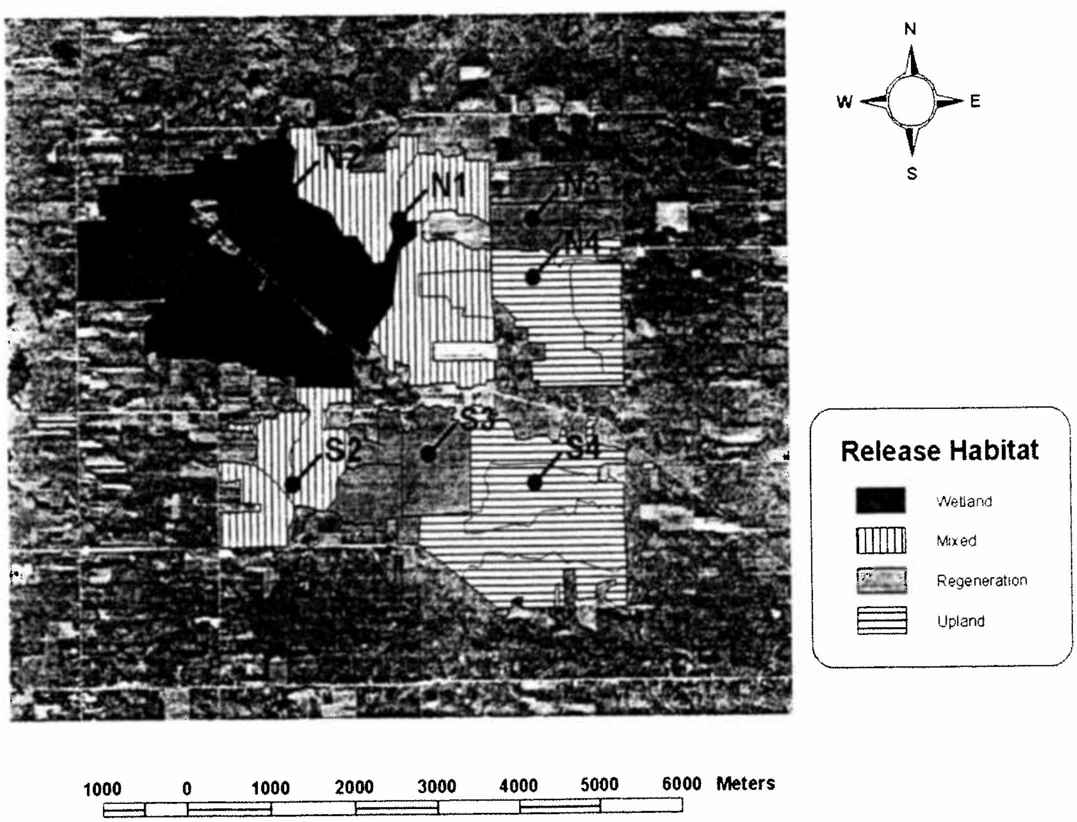

Figure 2.2: Eight release areas and specific release points for snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-February, 2000 and 2001.

Release Area	Habitat Classification	Area (ha)	Release Location (UTM Zone 17, NAD 83)
North 1	Mixed Wetland/Upland Forests	368	499290 E; 4603483 N
North 2	Wetland Forest	280	498273 E; 4603721 N
North 3	Early Successional Forest	89	500852 E; 4603348 N
North 4	Upland Forest	207	501032 E; 4602862 N
South 1	Wetland Forest	387	497452 E; 4602743 N
South 2	Mixed Wetland/Upland Forest	173	497893 E; 4600239 N
South 3	Early Successional Forest	184	500094 E; 4600592 N
South 4	Upland Forest	378	501307 E; 4600400 N
Total		2,066	

Table 2.1: Habitat classification, sizes, and geographic coordinates of 8 sites where snowshoe hares were released in Ashtabula and Geauga Counties, Ohio during January-February, 2000 and 2001.

Published literature was reviewed to determine snowshoe hare survival estimates, reproductive rates, and densities that may be pertinent to hares released in Ohio. Stochastic computer simulations were developed using the software package VORTEX to identify the minimum number of hares needed to maximize the potential for establishing a viable population in northeast Ohio (Scott 1999). Population modeling also assessed the necessity of periodic supplemental releases to sustain population growth. Simulations were performed using a 3,019-ha core release area with 12% shrub-scrub wetland coverage and an average density of 1 pair/8 ha of woody habitat (Scott 2000). The estimated carrying capacity of the core release area was 400 hares. Modeling indicated that release of 100-200 hares in years 1 and 2 supplemented by 100 or more hares every 5-10 years was necessary to establish a viable population. Based on these simulations, the Ohio Division of Wildlife initiated the experimental reintroduction by releasing a minimum total of 200 hares during winters 2000 and 2001.

Snowshoe hares were trapped in the Upper Peninsula of Michigan, mainly in areas surrounding Seney National Wildlife Refuge in Schoolcraft County. Hares were sexed, weighed, externally marked with individually numbered metal ear/foot tags, and held in an outdoor pen for 1-15 days before delivery to Ohio (Keith et al. 1968). To minimize stress due to overcrowding, the outdoor pen at the Seney Wildlife Refuge was enlarged from approximately 77 m^2 to 113 m^2 (47% increase) between the 2000 and 2001 trapping seasons. Maximum hare densities held in captivity at Seney Wildlife Refuge decreased from 1 hare/1.9 m^2 in 2000 (40 hares) to 1 hare/4.5 m^2 in 2001 (25 hares).

Groups of approximately 10-40 animals were transported by fixed-wing aircraft or automobile to the Grand River Wildlife Area in Trumbull County, Ohio during January-February, 2000 and 2001. All hares were weighed and external measurements (ear, body, and hind-foot lengths) were taken after arrival at Grand River. All hares also were marked with external foot or ear tags prior to release. Foot tags had poor retention and caused slight injuries 2000. Thus, hares were marked only with ear tags in 2001. Radio transmitters (164-165 MHz) were attached by external neck collar to the first 50 animals released each year. Functioning radio-transmitters recovered from dead hares were replaced on the next available released animal to maximize the monitored sample size. Hares were held overnight in an outdoor pen before release the following day. The outdoor pen at Grand River Wildlife Area also was enlarged from approximately 37 m^2 to 56 m^2 (50% increase) between the 2000 and 2001 releases. Maximum hare densities held in captivity at Grand River Wildlife Area decreased from 1 hare/1.3 m^2 in 2000 (28 hares) to 1 hare/2.2 m^2 in 2001 (25 hares).

A total of 232 snowshoe hares were released in northeastern Geauga and southwestern Ashtabula Counties during January-February, 2000 and 2001. Seventy-nine hares (39 males, 40 females) were released with radio-collars and 59 (28 males and 31 females) were released without collars in 2000 (Table 2.2). Eighty-one hares (44 males and 37 females) were released with radio-collars and 13 (8 males and 5 females) were released without collars in 2001 (Table 2.3). Individual hares were distributed among the 8 release sites to equalize numbers of radio-collared hares and male:female ratios throughout the study area.

The experimental release was designed to identify limiting factors and determine if survival would be sufficient to establish a breeding population. Comparing movements, survival, and habitat use of hares released in sites with different habitat characteristics would identify the most suitable habitats types for snowshoe hares in northeast Ohio. However, potentially confounding factors (release timing and habitat quality) prevented direct evaluation of survival and movements of hares released in northern versus southern sites. Hares were first released on northern sites in 2000 to control for differences in habitat quality between the northern and southern release sites. In contrast, hares were first released on southern sites in 2001 to separate the effects of release date on movements and survival. Thus, the study was designed to compare movements and survival of hares released on different dates (25 January, 1 February, 8 February, and 21 February) in 2000 and in northern versus southern potions of the study area in 2001.

Release Site	Habitat Type	No. Released With Radio		No. Released Without Radio	
		Males	Females	Males	Females
North 1	Mixed Forest	4	5	4	4
North 2	Wetland Forest	4	5	4	4
North 3	Early Successional	4	5	4	4
North 4	Upland Forest	5	4	1	4
North Total		17	19	13	16
South 1	Wetland Forest	5	6	4	3
South 2	Mixed Forest	5	6	3	5
South 3	Early Successional	6	4	4	4
South 4	Upland Forest	6	5	3	4
South Total		22	21	14	16
Grand Total		39	40	27	32

Table 2.2: Numbers of snowshoe hares released on 8 sites in northeastern Geauga and southwestern Ashtabula Counties, Ohio, during winter 2000.

Release Site	Habitat Type	No. Released With Radio		No. Released Without Radio	
		Males	Females	Males	Females
North 1	Mixed Forest	5	5	0	0
North 2	Wetland Forest	5	5	0	0
North 3	Early Successional	6	3	2	1
North 4	Upland Forest	5	5	0	0
North Total		21	18	2	1
South 1	Wetland Forest	5	5	1	0
South 2	Mixed Forest	6	5	2	1
South 3	Early Successional	6	5	2	2
South 4	Upland Forest	6	4	1	1
South Total		23	19	6	4
Grand Total		44	37	8	5

Table 2.3: Numbers of snowshoe hares released on 8 sites in northeastern Geauga and southwestern Ashtabula Counties, Ohio, during winter 2001.

CHAPTER 3

MOVEMENTS, HOME RANGE, AND HABITAT USE

Habitat composition and structure affect the availability of resources within a landscape, and influence movements, dispersal patterns, and distribution of resident wildlife species (Litvaitis et al. 1985, Morrison et al. 1998). Snowshoe hare movements and habitat use tend to be less predictable in regions with marginal habitat suitability and at the periphery of the hare's range (Keith et al. 1993, Seivert and Keith 1985, Wiens 1994). Protective cover becomes more critical where suitable habitats are more scattered, predator communities are more diverse and stable, and the hare's seasonal pelage is less adapted to unpredictable snow cover (Buehler and Keith 1982). Studies of snowshoe hares at the periphery of their geographic distribution have shown that movements and dispersal play a critical role in range limitation (Buehler and Keith 1982, Sievert and Keith 1985). Predation has been found to be higher on dispersers than residents, as movements through areas of poor cover increased vulnerability (Keith et al. 1993). Extensive movements can be related to fragmented habitats where distances between suitable habitat patches become large (>1 km) (Keith et al. 1993, Sievert and Keith 1985). Extinction of local snowshoe hare populations in central Wisconsin were more likely in landscapes containing <160 ha total forest coverage and in isolated areas containing <20 ha of optimum habitat (Buehler and Keith 1982, Keith et al. 1993).

Analyzing habitat-specific movements and home range characteristics of hares released in northeast Ohio was necessary to determine the quality of habitat and potential of the area to support a viable population. This chapter summarizes movements, dispersal distances, home ranges, and habitat use of radio-collared hares monitored during January-June in 2000 and 2001. Movements, dispersal, and home ranges are compared among releases in different years, among separate regions of the study area, and among different habitat classes. Habitat use also is summarized for all hares that established home ranges. Based on these analyses, I discuss possible reasons for annual differences in movements and assess the potential of habitats within the study area to support snowshoe hares. Specific hypotheses involving movements and habitat use of snowshoe hares released in northeast Ohio include:

1) Movements should be larger than those of resident snowshoe hares within the core of the geographic range and should decrease with time following release.
2) Movements should be similar between 2000 and 2001 in the absence of annual differences in pre-release condition and/or snow cover.
3) Movements should be greater in sites with lower amounts of suitable habitat or where dispersal is less restricted by fragmentation.
4) Home range sizes should be larger than those typical of resident hares within the core of the hare's geographic range.
5) Snowshoe hares should select available habitat types that contain the highest understory cover and stem densities.

FIELD METHODS

Telemetry

Radio-collared hares were located by triangulation approximately 2-5 times per week during January-June, 2000 and 2001. Portable receivers and hand-held yagi antennas were used to determine 2-6 azimuth bearings from 69 fixed telemetry positions located throughout the area (Mech 1983, Samuel and Fuller 1994). Telemetry stations were geo-referenced using a hand-held global positioning system (GPS) and positions were stored as UTM coordinates. Location coordinates (UTM) of live snowshoe hares were determined by triangulation using Locate II software (Nams 1999). Attempts were made to collect bearings for a single location within a 15-min interval and within 45-135° angles of intersection to minimize error associated with animal movements and error ellipse sizes (Samuel and Fuller 1994, Springer 1979). Selected hares were occasionally approached during spring of 2000 and 2001 to determine stage of the pelage molt and identify locations for live-trapping. However, contact was generally avoided to minimize the impacts of monitoring on movements and survival.

Estimates of telemetry error were determined using azimuth bearings to 40 mortality sites from 31 telemetry stations across the study area. Dead hares were found throughout the monitoring period and in the same locations and habitats frequented by live snowshoe hares. Therefore, I considered triangulations taken to dead animals to be most representative of actual field conditions. At least 2 bearings were collected from telemetry stations to radio-collars emitting a mortality signal before carcasses were recovered. Actual locations of carcasses and/or transmitters were then determined using hand-held GPS and stored as UTM coordinates. The estimated and actual bearings were used to estimate mean error (bias) of the bearings and mean error polygon sizes (Lee et al. 1985, Nams 1999, Springer 1979). Mean error (± S.D.) of the bearing estimates (n = 100) was 1.1 ± 5.6°. Mean size (± S.D.) of the error ellipses (n = 40) was 12.9 ± 7.4 ha. Distances between telemetry stations and mortality sites ranged from 22-1,620 m and were representative of distances over which locations of live hares were triangulated. Locations with error polygons >25 ha were excluded from movement and home range analyses (Nams 1999, Samuel and Fuller 1994).

Vegetation Sampling

Vegetation of the study area was measured during January-March, 2001. Winter is the most critical period for snowshoe hares, so I assessed vegetation cover quality by measuring understory woody stem density during the leaf-off season (Carraker 1985, Litvaitis et al. 1985). Forested habitats were sampled with an intensity of 0.5%, using 0.02-ha circular plots spaced at 200-m intervals throughout the area. Transects began with an initial plot positioned at a random distance (0-99 m) south and east from the northwest corner of each forest tract. Sampling points were then established at 200-m intervals along each transect and throughout all forested areas. Understory woody stem density was measured by observing a visual obstruction pole (2-m tall, 0.5-m wide) from 15-m north, south, east, and west of plot center. The obstruction pole was divided into 20 10-cm segments. The number of segments obstructed >25% was recorded from each cardinal direction (Carraker 1985). The number of segments obstructed was averaged over the 4 readings and percent vertical cover (number obstructed/total number) was calculated for each sampling point. Additional habitat variables measured at each sampling point included the number and diameter at breast height (dbh) of overstory trees in a 0.02-ha circular plot and number of woody stems <2-m tall in a 1-m^2 plot centered on each sample point. Overstory trees were classified as woody stems >2-m tall with dbh $\geq$10.2-cm.

DATA ANALYSIS

Movements

Hare locations obtained during 2000 and 2001 were imported into ArcView version 3.1 (Environmental Systems Research Institute). The ArcView *Movements* extension was used to analyze dispersal distances, home ranges, and habitat use (Hooge and Eichenlaub 1997). Straight-line distances between consecutive radio-locations and mean distance moved per day (distance from previous location/no. days between locations) were calculated for all hares with >1 location. Daily movements were plotted against the number of days post-release to determine temporal changes in movement rates. Distances between release sites and all locations collected during dispersal periods (6-9 days post-release) were summarized for 2000 and 2001. Dispersal movements also were determined as the distance from a release site to the centroid of the minimum convex polygon (MCP) home range for each hare. Mean dispersal distances were compared between radio-collared hares released in 2000 and 2001 and hares released at different sites.

Home Ranges

Locations determined during days 1-6 in 2000 and 1-9 in 2001 were removed from home range estimates so that initial post-release dispersal movements were not included in home range estimates. The fixed kernel home range method was used to calculate home range (95% kernel) and core use areas (50% kernel) (Seaman et al. 1998).

Home ranges also were determined using the 100% minimum convex polygon (MCP) method for comparison with other studies. Home range areas of 63 radio-collared hares with ≥10 locations that survived >30 days post-release were plotted against the number of locations to determine minimum sample size needed to estimate home range sizes. Intervals of 5 locations (i.e., 10-14, 15-19, 20-24, 25-29, 30-34, 35-40) were used to create home range-area curves. MCP home range sizes increased with <20 locations (Figure 3.1). Kernel home range (95%) estimates varied with number of locations with a peak at n = 20-24. Although a slight relationship appeared to exist between number of locations and area, removing hare home ranges with <20 locations resulted in minimal change in home range and core use area sizes. Therefore, home range and core use areas were reported for all hares with >10 locations that survived >30 days post-release.

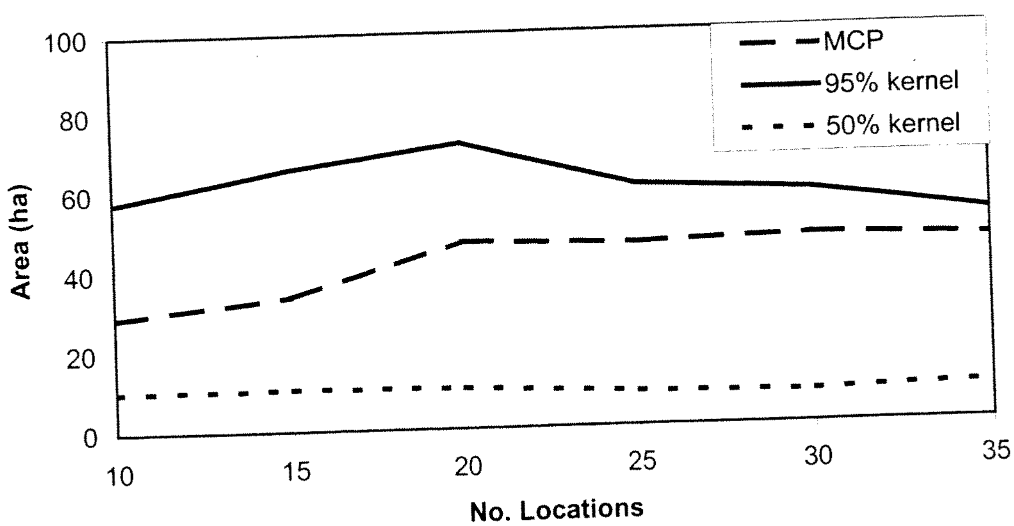

Figure 3.1: Home range-area curves for 60 radio-collared snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2000 and 2001.

Habitat Use

A detailed habitat coverage of the study area was created using recent DOQQs (1993-1999) and ground truthing during 2000 and 2001. Tracts (≥20 ha) containing ≥67% continuous land cover were classified according to general habitat characteristics. Thirty individual forested tracts were grouped into 8 different habitat classes and digitized in ArcView (Figure 3.2). Forested tracts were classified as deciduous or coniferous forest, upland or wetland, and as 1 of 3 age classes (<10 years, 10-20 years, >20 years). Non-forested lands associated with agriculture, residential property, or roadways were classified accordingly. The 2,629-ha study area contained 1,225 ha of upland forests (47%), 842 ha of wetland forests (32%), and 562 ha of non-forested area (21%). The majority of forested area (62%) was >20 years old, with only 7% in the <10-year age-class.

Sample plots were grouped for comparison of understory and overstory vegetation characteristics among habitat classes. Mean understory stem density (stems/ha), percent vertical obstruction, and habitat suitability index (HSI) scores were calculated for each forested habitat class. Snowshoe hare HSI models use vertical obstruction to estimate general habitat quality on a 0-1 scale (1.0 = optimum habitat) (Carraker 1985). Obstruction >40% represents optimal food availability and >90% represents optimal woody cover. Average overstory tree dbh (cm), tree density (stems/ha), basal area (m^2/ha), and percent species composition also were determined. Sample plots in open water were removed from evaluation of overstory vegetation characteristics.

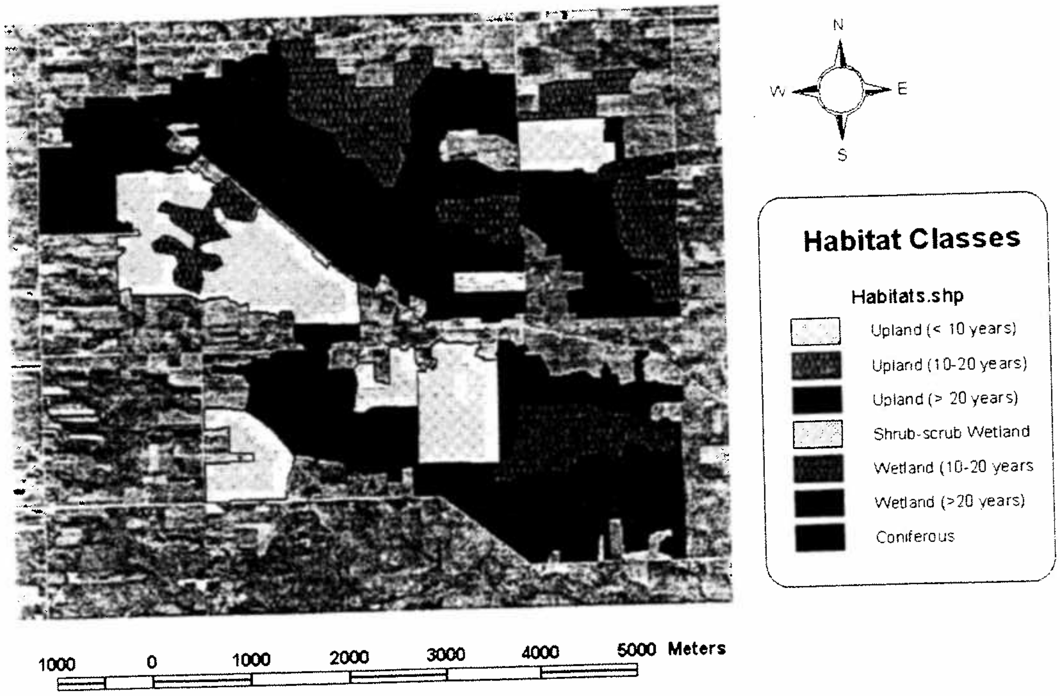

Figure 3.2: Habitat composition of 30 forest tracts available to snowshoe hares in southwestern Ashtabula and northeastern Geauga Counties, Ohio during January-June, 2000 and 2001.

Radio-locations (n = 1,338) and home ranges of 60 hares were overlaid on the habitat coverage in ArcView for comparison of habitat use with availability. These 60 hares survived >30 days, had ≥10 radio locations, and established home ranges within the designated study area. Analysis of habitat use was designed to determine whether proportional use of each habitat type differed from its availability in the study area and within individual home ranges. Second-order habitat selection was determined by comparing habitat composition of 95% kernel home ranges to habitat availability of the study area (Johnson 1980, Samuel and Fuller 1994). Third-order habitat selection also was determined by comparing the habitat surrounding individual radio-locations to composition of the associated home range. Neu et al. (1974) resource preference techniques were used to identify which habitats were used in proportions that differed from availability (Alldredge and Ratti 1986, Alldredge and Ratti 1992, Cherry 1998). A Chi-square goodness-of-fit analysis tested whether habitat use proportions differed from availability (Neu et al. 1974). The amount each habitat type within home ranges was pooled across individual hares and contrasted with the proportion of each habitat type available within the study area (X^2 = observed use – expected use/expected use). In addition, the locations falling in each habitat type were pooled across individuals and contrasted with the proportion of each habitat type available in home ranges. Bonferroni Z-statistics were then used to identify which habitat types differed significantly from availability (*d.f.* = 7, critical *P*-value = 0.05).

RESULS

Movements

Daily Movements. - Distances moved between consecutive radio-locations and distances moved per day were summarized for 61 radio-collared hares monitored in 2000 and for 71 radio-collared hares in 2001. Hares moved similar distances per day ($t = 1.20$, *d.f.* = 917, $P = 0.229$) in 2000 (178 + 7 m/day) and 2001 (190 + 8 m/day). Hares moved greater distances per day ($t = 7.21$, *d.f.* = 132, $P < 0.001$) during 1-6 days post-release (381 + 32 m/day) compared to >7 days post-release (143 + 5 m/day) in 2000 (Figure 3.3). Hares also moved greater distances per day ($t = 9.98$, *d.f.* = 213, $P < 0.001$) during 1-9 days post-release (423 + 28 m/day) compared to >10 days post-release (136 + 5 m) in 2001 (Figure 3.4). Daily movements declined from 600 m/day on day 1 post-release to 123 m/day on day 7, averaging 143 m/day thereafter in 2000. Similar movement patterns were observed in 2001. Daily movements declined from 708 m/day on day 1 post-release to 165 m/day on day 10, averaging 136 m/day thereafter.

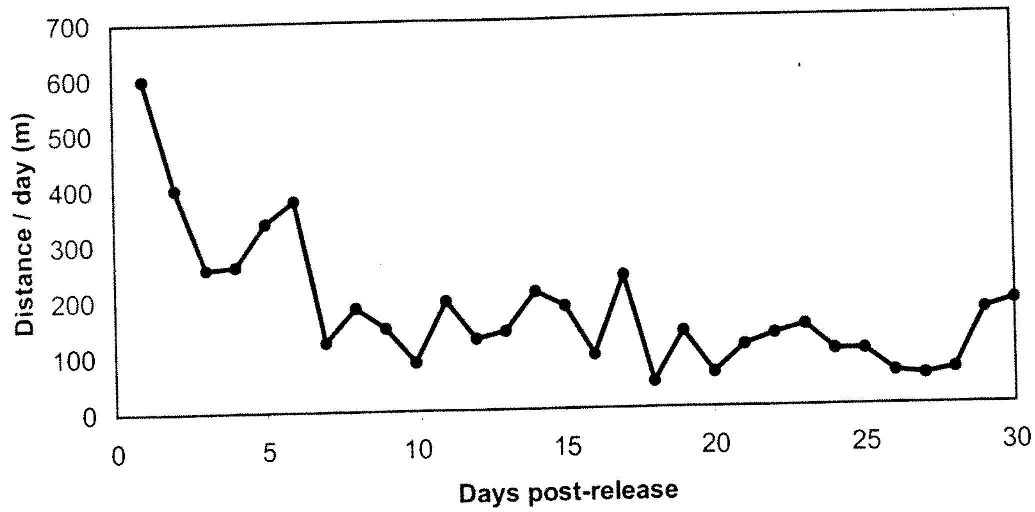

Figure 3.3: Mean daily movements by 61 radio-collared snowshoe hares released in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2000.

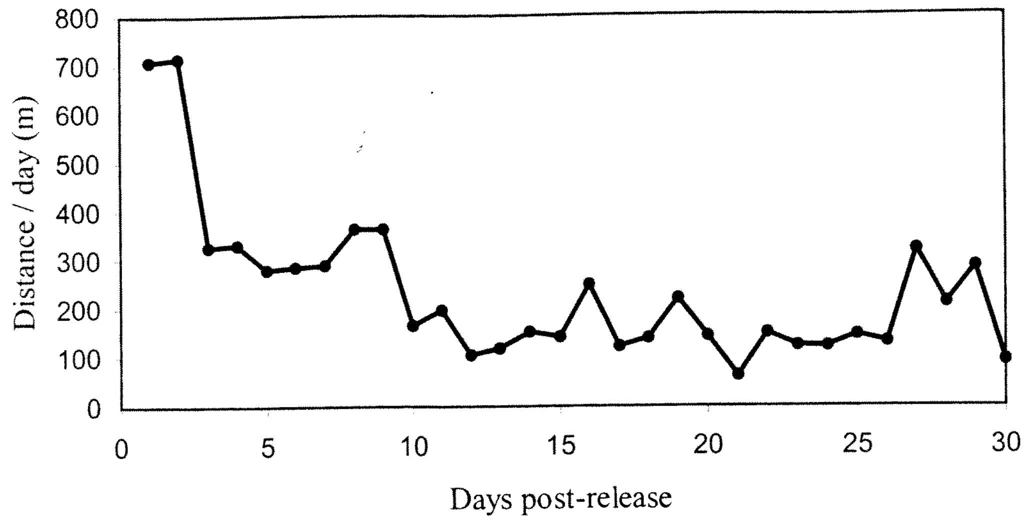

Figure 3.4: Mean daily movements by 71 radio-collared snowshoe hares released in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2001.

Dispersal from Release Sites. - Dispersal distances were summarized for 61 radio-collared hares monitored in 2000 and for 71 radio-collared hares in 2001. Four hares moved >3.0 km from release sites in 2000 and 6 hares moved >4.5 km from release sites in 2001. The greatest distance moved from a release site was 6.0 km for a single hare released in 2001. Hares dispersed ($x \pm$ S.E.) farther ($t = 5.70$, $d.f. = 132$, $P < 0.001$) from release sites in 2001 (937 ± 52 m) than in 2000 (562 ± 41 m). Annual differences in distance from release were consistent with the longer dispersal period in 2001 (9-days) compared to 2000 (6-days). Hares dispersed farther ($t = -1.85$, $d.f. = 51$, $P = 0.035$) from southern release sites (698 ± 88 m) than from northern release sites (515 ± 46 m) in 2000.

Hares also dispersed farther ($t = 0.78$, $d.f. = 177$, $P = 0.035$) from southern release sites (1,067 ± 66 m) than from northern release sites (692 ± 74 m) in 2001.

Dispersal distance from release sites varied among hares released in different habitat types during 2000 and 2001 (Figures 3.5 and 3.6). Hares dispersed greater distances from release sites in wetland forest ($t = 2.19$, $d.f. = 32$, $P = 0.017$) and upland forest ($t = 2.01$, $d.f. = 30$, $P = 0.026$) than from mixed wetland/upland forest in 2000. Hares dispersed greater distances from release sites in wetland ($t = 4.23$, $d.f. = 54$, $P < 0.001$), upland ($t = 1.98$, $d.f. = 47$, $P = 0.020$), and mixed upland/wetland forest ($t = 2.24$, $d.f. = 37$, $P = 0.023$) than from early regenerating forest in 2001. Hares also dispersed greater distances from release sites in wetland forest ($t = 2.59$, $d.f. = 37$, $P = 0.004$) than from mixed upland/wetland forest in 2001. Overall, the shortest dispersal distances were from mixed upland/wetland sites in 2000 and early regeneration sites in 2001.

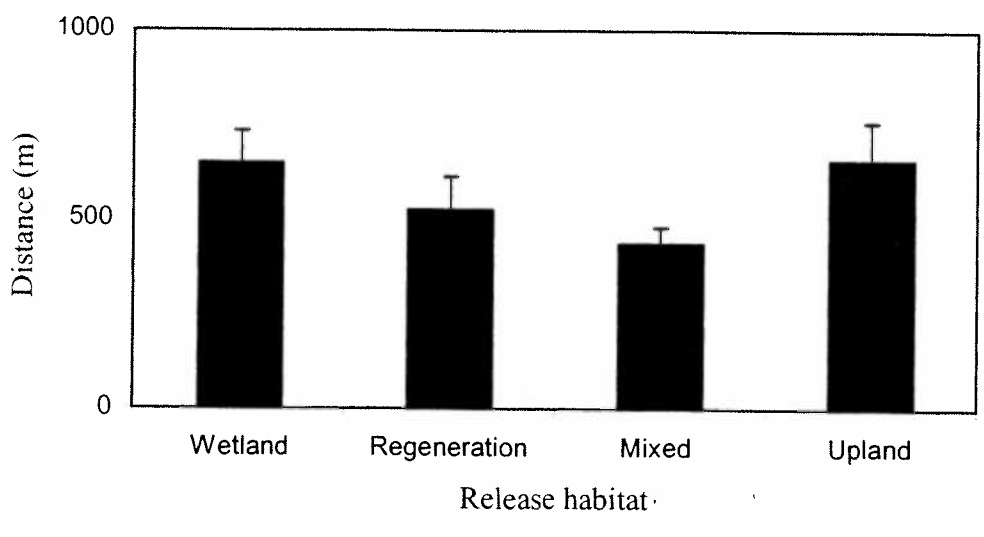

Figure 3.5: Mean dispersal (± S.E.) from release sites by habitat type during 6 days following release for 61 radio-collared snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio, 25 January-28 February, 2000.

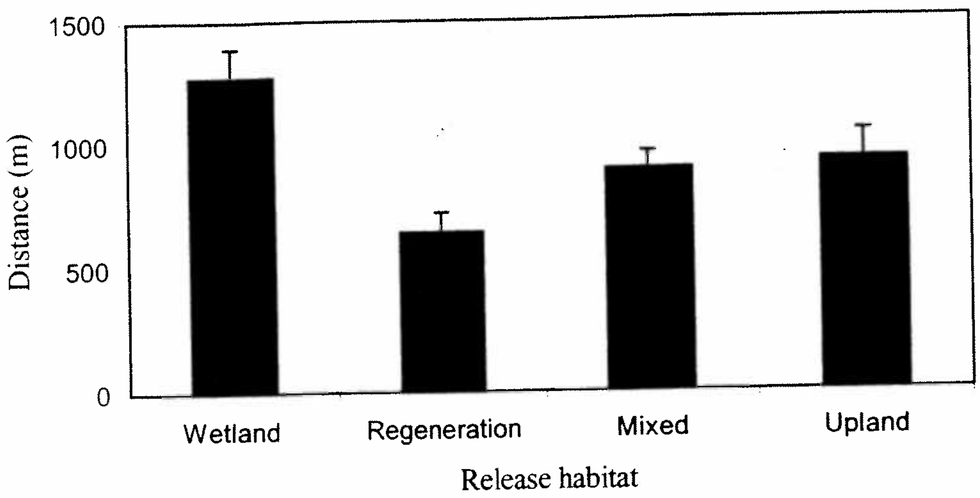

Figure 3.6: Mean dispersal (± S.E.) from release sites by habitat type during 9 days following release for 71 radio-collared snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio, 24 January-8 March, 2001.

Dispersal from Release Sites to Home Ranges. - Dispersal distances from release sites to centroids of MCP home ranges were determined for 25 radio-collared hares monitored in 2000 and for 38 hares monitored in 2001 (Figures 3.7 and 3.8). Hares established home ranges (x ± S.E.) at greater distances (t = 1.84, d.f. = 24, P = 0.036) from release sites in 2001 (1,148 ± 174 m) than in 2000 (758 ± 120 m). Hares established home ranges farther from release sites in wetland (t = 2.54, d.f. = 3, P = 0.016) and early regenerating forests (t = 2.93, d.f. = 3, P = 0.008) than in mixed upland/wetland forests in 2000. Hares also dispersed farther from release sites to home range in wetland (t = 2.38, d.f. = 5, P = 0.020) and early regenerating forests (t = 2.19, d.f. = 5, P = 0.026) than in upland forests during 2000. Dispersal from upland forest release sites was solely based on the northern site (N4) because no hares released in the southern upland forest site (S4) established home ranges in 2000. Hares dispersed greater distances from release sites to home range in wetland (t = 1.88, d.f. = 7, $P = 0.049$) and mixed upland/wetland forests (t = 2.27, d.f. = 9, $P = 0.026$) than in early regenerating forests in 2001. Hares also dispersed farther from release sites to home range in wetland (t = 1.87, d.f. = 7, $P = 0.049$) and mixed upland/wetland forests (t = 2.25, d.f. = 8, $P =$ 0.027) than in upland forests during 2001. Similar to mean dispersal from release sites (Figures 3.5 and 3.6), hares moved the shortest distances to home ranges when released in mixed upland/wetland in 2000 and in early regeneration in 2001. However, dispersal from release sites to home range also was low among hares released in upland forests during 2000 and 2001.

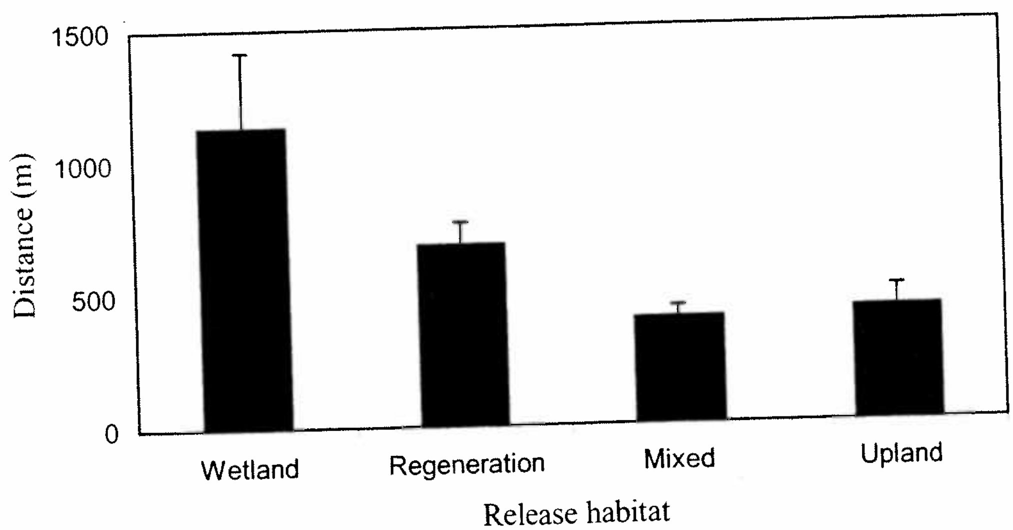

Figure 3.7: Mean dispersal (± S.E.) from release sites to center of MCP home range by habitat type for 25 radio-collared snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio, 26 January-20 June, 2000.

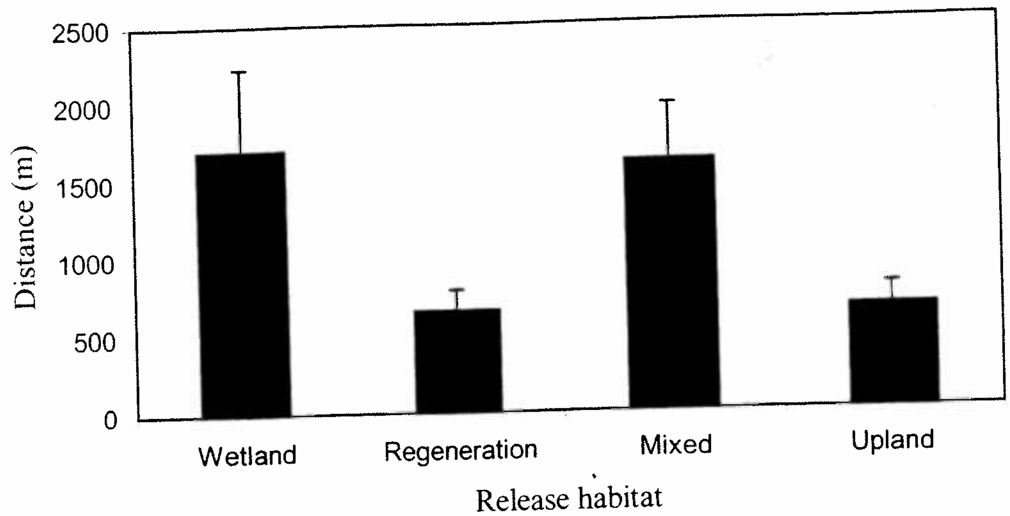

Figure 3.8: Mean dispersal (± S.E.) from release sites to center of MCP home range by habitat type for 38 radio-collared snowshoe hares in northeastern Geauga and southwestern Ashtabula Counties, Ohio, 24 January-18 June, 2001.

Home Range Sizes

Mean 100% MCP home range, 95% kernel home range, and 50% kernel core use areas were determined for 25 hares monitored in 2000 and for 36 hares monitored in 2001 (Table 3.1). Mean 95% kernel home range sizes were similar (t = 1.53, $d.f.$ = 26, P = 0.134) in 2000 and 2001. Mean MCP home range sizes also were similar (t = -0.08, $d.f.$ = 26, P = 0.927) in 2000 and 2001.

Seven radio-collared hares shifted home ranges during 2000 and 2001. Six of the 7 shifts were by males during mid-March through mid-April when hares become reproductively active, suggesting that large home range shifts were related to breeding and attraction to females outside the initial home ranges (Bookhout 1965*a*). These males established their initial home ranges <1 km from release sites where they remained for 30-60 days after release. Males then moved 1-2 km from their first home range to establish a second home range where they remained throughout summer or until death. Only 1 female shifted home ranges during 2000 and 2001. This female dispersed 1 km southwest of release area N2, establishing a home range in forested wetlands of N2 where she remained for 35 days. She then moved 1.2 km east/southeast to release area S1 where she remained throughout 2001.

Year	*n*	100% MCP	95% kernel	50% kernel
2000	25	40.1 ± 3.8	57.1 ± 5.1	8.5 ± 1.0
2001	36	40.5 ± 3.2	66.6 ± 3.2	10.0 ± 0.7

Table 3.1: Mean (± S.E.) home range and core use area estimates (ha) for 61 radio-collared snowshoe hares monitored in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2000 and 2001.

Microhabitat Characteristics

The 2,626-ha study area contained 1,225 ha of upland forest (47%), 842 ha of wetland forest (32%), and 562 ha of non-forested area (21%). Forested habitat of the study area (2,067 ha) consisted of 76% mature forest (>20 yrs), 17% pole-size forest (10-20 yrs), and 7% early successional forest (<10 yrs). A total of 473 sampling points were used to analyze vegetation characteristics of the 7 forested habitat classes (Table 3.2). Based on random placement of sampling points, forested habitat consisted of approximately 4.3% (88 ha) open water and 5.4% (111 ha) herbaceous vegetation.

Habitat Type	Area		No. Plots
	ha	%	
Shrub wetland (>20 yrs)	300	11.4	73
Wetland forest (10-20yrs)	104	4.0	29
Wetland forest (>20 yrs)	437	16.6	98
Upland forest (<10yrs)	144	5.5	31
Upland forest (10-20 yrs)	243	9.3	53
Upland forest (>20 yrs)	796	30.3	178
Coniferous (>20 yrs)	40	1.6	11
Non-forested	562	21.4	-
Totals	2,626		473

Table 3.2: Area, percent availability, and sampling plots in 8 habitat classes available to snowshoe hares in southwestern Ashtabula and northeastern Geauga Counties, Ohio.

Understory vegetation characteristics varied among the 7 forest habitat classes. Total density of woody stems (<2 m tall, <10.2 cm dbh) was greatest in shrub-dominated wetlands and upland forests (<10 yrs) (Table 3.3). The lowest understory stem densities were in wetland (>20 yrs), upland (>20 yrs), and coniferous forests (>20 yrs). Understory vertical obstruction was greatest for coniferous forests, shrub-dominated wetlands, and upland forests (<10 yrs). Habitat suitability index (HSI) values, calculated from vertical obstruction estimates, also were greatest for coniferous forests, shrub-dominated wetlands, and upland forests (<10 yrs). Based on visual obstruction, food availability was optimum (HSI = 1.0) in all habitat types except wetland and upland forests >20 years old. However, woody cover availability was less than optimum (HSI < 1.0) in all habitat classes. Thus, habitat suitability was limited by cover requirements across all habitat types.

Mean dbh, number of trees per ha, and basal area per ha of overstory trees also varied with age class of forested stands (Table 3.4). Mean basal area was greatest in forested stands >20 years old. The greatest density of trees was in coniferous forests and the highest basal area was in upland forests >20 years old. These habitats appeared to have the highest commercial timber harvest value. Thirty-one overstory tree species were identified during vegetation sampling. Species composition of overstory trees was grouped into 5 categories: oak-hickory, red maple, mixed hardwoods, non-commercial, and coniferous (Table 3.5). Tree species composition of shrub-dominated wetlands and forests >20 years old was 43-46% red maple, 39-42% mixed hardwoods, 11-13% oak-hickory, and 1-3% non-commercial. Forested stands 10-20 years old consisted of 53-56% mixed hardwoods, 31-33% red maple, 10-12% oak-hickory, and 2-3% non-commercial species. Forested stands <10 years old contained 39% mixed hardwoods, 35% oak-hickory, 23% red maple, and 3% non-commercial species. Coniferous forest plantings contained 92% conifer, 6% mixed hardwoods, and 2% red maple.

Habitat Type	n	Stems/ha	Visual Obstruction (%)	Habitat Suitability Indices		
				Cover	Food	Total
Shrub Wetland (>20 yrs)	73	34,058 ± 59	66.5 ± 0.6	0.53	1.00	0.53
Wetland Forest (10-20 yrs)	29	26,923 ± 135	51.2 ± 0.7	0.22	1.00	0.22
Wetland Forest (>20 yrs)	98	19,420 ± 31	44.4 ± 0.5	0.09	0.89	0.08
Upland Forest (<10 yrs)	31	35,333 ± 157	68.0 ± 0.7	0.56	1.00	0.56
Upland Forest (10-20 yrs)	53	22,308 ± 69	50.1 ± 0.6	0.20	1.00	0.20
Upland Forest (>20 yrs)	178	18,800 ± 106	32.5 ± 0.3	0.00	0.64	0.00
Coniferous (>20 yrs)	11	7,273 ± 91	71.5 ± 0.9	0.63	1.00	0.63

Table 3.3: Mean (± S.E.) understory characteristics and HSI scores of 7 forested habitat types available to snowshoe hares in southwestern Ashtabula and northeastern Geauga Counties, Ohio during January-June, 2000 and 2001. Snowshoe hare HSI models estimate general habitat quality on a 0-1 scale using vertical obstruction (1.0 = optimum habitat) (Carraker 1985).

Habitat Type	n	Mean dbh (cm)	Trees/ha	Basal Area (m^2/ha)
Shrub Wetland (>20 yrs)	68	20.9 ± 0.3	384.8 ± 4.3	13.3 ± 0.2
Wetland Forest (10-20 yrs)	27	15.8 ± 0.5	532.7 ± 9.1	10.5 ± 0.2
Wetland Forest (>20 yrs)	84	22.5 ± 0.3	423.2 ± 3.3	16.8 ± 0.1
Upland Forest (<10 yrs)	31	14.6 ± 1.0	356.7 ± 8.8	6.0 ± 0.2
Upland Forest (10-20 yrs)	53	16.0 ± 0.2	539.4 ± 3.8	10.9 ± 0.1
Upland Forest (>20 yrs)	178	21.9 ± 0.1	545.7 ± 1.1	20.5 ± 0.1
Coniferous (>20 yrs)	11	17.4 ± 1.1	590.9 ± 10.9	14.0 ± 0.6

Table 3.4: Mean (± S.E.) overstory characteristics of 7 forested habitat classes available to snowshoe hares in southwestern Ashtabula and northeastern Geauga Counties, Ohio during January-June, 2000 and 2001. Overstory species sampled included trees >10.2 cm dbh.

Forest Classification	Tree Species
Red Maple	Red Maple (*Acer rubrum*)
Oak-Hickory	Red Oak (*Quercus rubra*) White Oak (*Quercus alba*) Black Oak (*Quercus velutina*) Chinkapin Oak (*Quercus muehlenbergii*) Shelbark Hickory (*Carya laciniosa*) Shagbark Hickory (*Carya ovata*) Bitternut Hickory (*Carya cordiformis*)
Mixed Hardwoods	Sugar Maple (*Acer saccharum*) Silver Maple (*Acer saccharinum*) Quaking Aspen (*Populus tremuloides*) Big-toothed Aspen (*Populus grandidentata*) Black Cherry (*Prunus serotina*) American Basswood (*Tilia americana*) American Beech (*Fagus grandifolia*) Yellow-poplar (*Liriodendron tulipifera*) Yellow Birch (*Betula alleghaniensis*) American Elm (*Ulmus americana*) Slippery Elm (*Ulmus rubra*) Green Ash (*Fraxinus pennsylvanica*) White Ash (*Fraxinus americana*) Blackgum (*Nyssa sylvatica*) Sweetgum (*Liquidambar styraciflua*) Eastern Cottonwood (*Populus deltoides*)
Coniferous	Norway Spruce (*Picea abies*) Eastern White Pine (*Pinus strobus*) Scotch Pine (*Pinus sylvestris*) Eastern Hemlock (*Tsuga canadensis*)
Non-commercial Hardwoods	Eastern Hophornbeam (*Ostrya virginiana*) Flowering Dogwood (*Cornus florida*) Black Willow (*Salix nigra*)

Table 3.5: List of tree species found in 5 forest classes in northeastern Geauga and southwestern Ashtabula Counties, Ohio.

Habitat Use

Locations and 95% kernel home ranges of 25 radio-collared hares released in 2000 and 35 hares released in 2001 were used to analyze habitat use. These 60 hares survived >30 days, had ≥10 radio locations, and established home ranges within the designated study area. I collected 1,338 hare locations within the study area during January-June, 2000 and 2001. Second-order habitat selection evaluates the selection of a home range and associated resources within the study area (Johnson 1980). Habitat composition of 95% kernel home ranges was compared to the availability of each habitat type in the study area to determine second-order selection (Table 3.2). Third-order habitat selection evaluates the importance of habitat components within the animal's home range. Habitat surrounding hare locations was compared to the availability of each habitat type within individual home ranges to determine third-order selection.

Second-order Selection. – Habitat composition of home ranges differed from proportions of habitat available within the study area ($x^2 = 2{,}499$, d.*f.* = 7; $P < 0.001$). Home ranges contained more shrub-scrub wetlands, wetland forest (10-20 yrs), upland forest (<10 yrs), and coniferous forest than expected based on availability (Table 3.6). Home ranges contained equivalent amounts of upland forest (10-20 yrs) compared to availability in the study area. Home ranges contained less wetland and upland forests (>20 yrs) and non-forested habitats than were available in the study area. Thus, snowshoe hares established home ranges in portions of the study area that contained higher amounts of shrub-scrub wetlands, early successional forests <10 years, wetland forests 10-20 years, and coniferous plantings.

Third-order Selection. - Snowshoe hares did not use the 8 habitat types in proportion to their availability within home ranges ($x^2 = 32$, *d.f.* = 7; $P < 0.001$). Shrub-scrub wetlands and coniferous forest were used in greater proportions than expected based on habitat composition of home ranges (Table 3.7). Use of wetland forests (10-20 yrs), upland forests (<10 yrs), and non-forested habitats were equivalent to availability within home ranges. Wetland and upland forests (>20 yrs) and upland forests (10-20 yrs) were used less than available. Thus, snowshoe hares showed preference for shrub-scrub wetlands and coniferous plantings within 95% kernel home ranges.

Habitat types used greater than available in the study area and in individual home ranges had the highest overall understory cover estimates (51-72%). These habitats also had the greatest mean understory stem densities (27,000-35,000 stems/ha), except coniferous planting, which averaged 7,300 stems/ha. Habitat types that hares avoided or showed no preference for in northeast Ohio had lower understory cover (32-50%) and stem densities (19,000-22,000 stems/ha) than preferred habitats.

	Shrub Wetland	Wetland (10-20 yrs)	Wetland (>20 yrs)	Upland (<10 yrs)	Upland (10-20 yrs)	Upland (>20 yrs)	Conifer (>20 yrs)	Non-forest
Use Prop.	0.2151	0.0608	0.0974	0.1830	0.1008	0.2288	0.0255	0.0162
Upper C.I.	0.2337	0.0716	0.1108	0.2005	0.1145	0.2479	0.0326	0.0219
Lower C.I.	0.1964	0.0500	0.0839	0.1654	0.0871	0.2097	0.0183	0.0105
Availability	0.1142	0.0396	0.1663	0.0548	0.0928	0.3029	0.0156	0.2138
Preference	Prefer	Prefer	Avoid	Prefer	None	Avoid	Prefer	Avoid

Table 3.6: Habitat composition of 95% kernel home ranges in relation to habitat composition of the study area (95% Bonferroni C.I.s) for 60 snowshoe hares monitored in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2000 and 2001. Availability represents the proportion of each habitat type occurring in the study area.

	Shrub Wetland	Wetland (10-20 yrs)	Wetland (>20 yrs)	Upland (<10 yrs)	Upland (10-20 yrs)	Upland (>20 yrs)	Conifer (>20 yrs)	Non-forest
Use Prop.	0.3072	0.0590	0.0830	0.2152	0.0852	0.1861	0.0516	0.0127
Upper C.I.	0.3419	0.0767	0.1037	0.2461	0.1062	0.2154	0.0682	0.0211
Lower C.I.	0.2725	0.0413	0.0622	0.1843	0.0642	0.1568	0.0350	0.0043
Availability	0.2300	0.0655	0.1050	0.1972	0.1086	0.2465	0.0275	0.0175
Preference	Prefer	None	Avoid	None	Avoid	Avoid	Prefer	None

Table 3.7: Habitat surrounding locations of 60 radio-marked hares in relation to habitat composition of 95% kernel home ranges (95% Bonferroni C.I.s) in northeastern Geauga and southwestern Ashtabula Counties, Ohio during January-June, 2000 and 2001. Availability represents the mean proportion of each habitat type occurring in 95% kernel home ranges of 60 hares.

Discussion

Mean distances moved between consecutive locations by hares relocated in northeast Ohio were similar to those observed for transplanted hares in western Virginia (Fies no date). The largest movements from release sites by hares in northeast Ohio (4.5-6.1 km) were similar to those of hares in western Virginia and central Wisconsin (4.7-6.0 km) (Fies no date, Keith et al. 1993). Hares relocated to the geographic range boundary in central Wisconsin moved greater distances than resident hares in the same region. Sievert and Keith (1985) determined that 95% of resident hares in central Wisconsin remained within 1.0 km of their point of release, compared to only 57% of transplants. Movements are often large when animals are relocated into unfamiliar territory or where habitat suitability is marginal. Hare movements in northeast Ohio were greatest immediately following release and decreased with time, similar to dispersal movements observed for hares released in western Virginia and central Wisconsin (Fies no date, Sievert and Keith 1985). Hares had a longer dispersal period and established home ranges farther from release sites in 2001 compared to 2000. This suggests that one or more critical factors limited post-release movements during 2000.

Movements of hares released in northeast Ohio were influenced by habitat characteristics of the study area. Dispersal distances from release sites were greater among hares released in southern sites compared to northern sites in 2000 and 2001. This suggests that hares released in northern sites required less movement to find sufficient resources than hares released in southern sites. However, southern release sites contained more forested area and larger amounts of preferred habitat types (65-232 ha) than northern release sites (0-57 ha). The largest distance between any 2 patches of preferred habitat in the southern region was <1,000 m. In contrast, the largest patch of preferred habitat in the northern region was >1,500 m from other optimum patches. Snowshoe hare movements in the northern region were restricted by limited forest area and habitat fragmentation. Hares dispersing from southern release sites were less vulnerable to predation and capable of moving larger distances. Other studies have found similar relationships between snowshoe hare habitat characteristics and vulnerability to predation. Sievert and Keith (1985) determined that hares avoided large movements and sacrificed food for protective cover in isolated patches of optimum habitat with high predation pressure. Landscapes containing >160 ha of forested coverage and >20 ha of optimum habitat with limited distances (<1 km) between habitat patches were most often occupied by hares in central Wisconsin (Buehler and Keith 1982, Keith et al. 1993).

Dispersal from release sites was lowest in mixed wetland/upland and early regenerating forests during 2000 and 2001. Three of the 4 early regeneration and mixed release sites also were the 3 smallest in total area (89-184 ha). In contrast, wetland and upland forest release sites, which had the largest dispersal movements, also were the largest in total forest area (207-387 ha). Once again, snowshoe hare movements were restricted in smaller forest tracts and where open areas occurred between habitat patches. Dispersal from release sites to home ranges was lowest in mixed wetland/upland and upland forests during 2000 and in early regenerating and upland forests during 2001. Hares released in these habitat types presumably required less movement to locate food and cover resources than hares released in other habitats. Lower dispersal by hares released in early successional forests was expected. Early successional forest release sites contained large patches (57-125 ha) of optimum habitat with high understory cover and woody stem densities. Mixed wetland/upland forest sites were comprised of less optimum habitat (6-65 ha). However, mixed forests had greater habitat interspersion than other habitat types, which is important to accommodate seasonal shifts in food and cover resources. Lower dispersal from release sites to home ranges in upland forests was the result of proximity to optimum habitat. The northern upland forest release site (N4) was <400 m from the early regenerating habitat of release site N3, where the majority of hares from N4 established home ranges. No hares released in the southern upland forest site (S4) established home ranges in 2000 and only 4 did so in 2001. Thus, dispersal distances to home ranges were influenced by suitability of release habitat and proximity to optimum habitat patches.

Home range sizes (100% MCP) of hares released in northeast Ohio (40 ha) were extremely large compared to those from native resident populations of snowshoe hares (3-9 ha, Sievert and Keith 1985). Home ranges are typically large when animals are relocated into unfamiliar territory. Fies (no date) also reported large 95% MCP home range estimates (79 $\pm$ 39 ha) for hares relocated in marginal habitat of western Virginia. However, large home ranges of hares in northeast Ohio also suggest that habitat quality of the study area was marginal compared to other regions within the core of the hare's distribution. Hares apparently required larger use areas to locate food and cover resources in the study area, which contained approximately 22% of optimum habitat. Movements by hares in central Wisconsin implied larger home ranges than the <10 ha typically observed (Sievert and Keith 1985). Behrend (1962) also reported unusually large home ranges (16 ha) at the southern limit of snowshoe hare distribution in Connecticut. Large home ranges among hares released in northeast Ohio also may have been related to the limited number of animals (approximately 51-58) surviving to the breeding seasons during 2000 and 2001. Hares possibly used larger areas to encounter mates under the low population densities.

Hares released in northeast Ohio used habitat types in proportions that differed from their availability in the study area. Hares established home ranges in areas that included more shrub-dominated wetlands, wetland forests (10-20 years old), early successional forests (<10 years old), and isolated conifer stands than represented in the study area. Hares also showed preference for shrub-scrub wetlands and coniferous plantings within 95% kernel home ranges. Understory cover and stem densities were the most important vegetation characteristics determining habitat use. Habitat types preferred by snowshoe hares in northeast Ohio had the highest overall understory cover estimates and understory stem densities. Habitat types that hares avoided or showed no preference for in northeast Ohio had lower understory cover and stem densities than preferred habitats. Other studies suggested similar relationships between understory density, habitat use, and hare abundance (Buehler and Keith 1982, Litvaitis et al. 1985, Sievert and Keith 1985). Sievert and Keith (1985) determined that hares were more abundant in sites with ≥60% understory cover. Similarly, Keith et al. (1993) identified 5-15-year-old aspen stands on poorly drained soils, and willow and alder swales bordering wetlands to be critical for hare persistence in fragmented landscapes. Buehler and Keith (1982) suggested that coniferous cover is the critical factor determining snowshoe hare distribution. However, shrub-scrub wetlands and regenerating clearcuts appear to be important habitats in southern regions of the hare geographic range where coniferous cover is lacking (Scott and Yahner 1989).

Movements and habitat use of snowshoe hares released in northeast Ohio indicate that shrub-dominated wetlands and early successional forests are critical for sustaining snowshoe hare populations in northeast Ohio. Shrub-scrub wetlands were the most abundant of the preferred habitat types, comprising 11% of the total study area. Upland forests <10 years old comprised 6% of the area, followed by wetland forests 10-20 years old (4%), and coniferous plantings (2%). Mature deciduous forests (>20 years) and non-forested habitats were limiting to hares released in northeast Ohio, comprising the majority of the study area (68%). Hares generally avoided these habitats, using forests >10 years old only when associated with lowland areas or when adjacent to optimum habitats. Hares dispersed along riparian corridors and when <1000 m existed between optimum habitat patches. Thus, both size of optimum habitat patches and connectivity between patches are necessary for long-term viability of snowshoe hares in northeast Ohio.

CHAPTER 4

SURVIVAL AND REPRODUCTION

Predation and extreme winter weather are important factors that limit snowshoe hare distribution (Bittner and Rongstad 1982, Carraker 1985, Litvaitis et al. 1985). Dense understory cover provides protection from predators and shelter from adverse weather near the southern periphery of the snowshoe hare range (Buehler and Keith 1982, Carraker 1985). The potential to restore a viable snowshoe hare population in northeast Ohio depends on the amount and quality of food and cover resources required for survival and reproduction. Quality of habitat and response of local predator communities will determine if survival is adequate to support a breeding population. If sufficient numbers of released hares survive to the breeding season, reproduction and subsequent juvenile recruitment will likely be most critical to long-term population viability. Therefore, evaluating survival and reproduction of the experimental releases can provide insight into the potential for establishing a viable snowshoe hare population in northeast Ohio (Litvaitis et al. 1985).

Post-release movements and habitat use of snowshoe hares revealed preferred habitat types in northeast Ohio. Chapter 3 identified habitat types to which hares dispersed and described vegetation characteristics critical to supporting hare populations.

However, to accurately assess the feasibility of a reintroduction it also was necessary to examine post-release survival and reproduction. Comparing survival among release sites should provide further indication of the best habitats for future releases. In addition, comparing survival rates of the experimental release to existing populations at the periphery and core of the hare's range will provide insight into the potential for establishing a viable population in northeast Ohio.

This chapter examines physical condition, survival, and reproduction of snowshoe hares released in 2000 and 2001. Physical characteristics are described for all hares released in winters 2000 and 2001. Sources of mortality, cause-specific mortality rates, and survival estimates are examined for radio-collared hares monitored January-June, 2000 and 2001. Assessment of reproduction and results of live-trapping also are summarized. Survival estimates are compared between 2000 and 2001 releases, north and south regions of the study area, and among different habitat classes. Based on these analyses, I discuss possible reasons for annual and site-specific variations in survival. Specific hypotheses involving survival of snowshoe hares in northeast Ohio include:

1) Mortality due to predation should be the primary limiting factor for snowshoe hares following release.
2) Survival should be lowest during the first 2 weeks after release and among hares that moved the greatest distances.
3) Survival should be highest in areas containing greater amounts of optimum habitat, with high understory cover and stem densities.
4) Condition of release animals, variations in time of release, and duration of snow cover also should influence post-release survival.

FIELD METHODS

Pre-release Condition

All 138 hares (68 males and 70 females) were trapped near Seney National Wildlife Refuge in Schoolcraft County, Michigan and transported to Ohio for release in 2000. Ninety-four hares (52 males and 42 females) were trapped and transported for release in 2001. Captured snowshoe hares were sexed, weighed, tagged, and held in an outdoor pen for 1-15 days before delivery to the release site (Keith et al. 1968). Hares were weighed, external measurements (ear, body, and hind-foot lengths) were taken, and held in an outdoor pen at Grand River Wildlife Area in Trumbull County, Ohio before release the following day. Hares also were examined externally to identify injuries and pelage condition prior to release (Keith et al. 1968). Body and ear length measurements were discontinued in 2001 to minimize handling stress and injuries prior to release.

Telemetry

Survival of radio-collared snowshoe hares was monitored daily during January-June, 2000 and 2001. Radio transmitters (164-165 MHz) were equipped with motion-sensitive mortality sensors that doubled the transmitter pulse if the transmitter remained motionless for ≥8 hours. Radio-transmitters emitting mortality signals were located within 24 hours using a portable receiver and hand-held yagi antenna. Cause of death was determined by examining carcass remains and field signs at recovery sites (Einarsen 1956, Keith et al. 1968). Evidence of predation included tracks, feces, feathers, regurgitated pellets, tooth or talon marks on radio collars, and carcass condition. Lost signals were considered radio failure or dispersal beyond the study area. Dead hares found within 1-5 days of release with head or lower limbs bent backward, trunk arched forward, and exhibiting internal signs of stress at necropsy were categorized as stress deaths (Sievert and Keith 1985). Internal signs of stress included low mesenteric or bone marrow fat and degeneration of the liver (Sievert and Keith 1985).

Live-trapping

I attempted to document reproduction by snowshoe hares released in 2000 and 2001. Efforts to capture live young or adult hares that displayed reproductive activity during the breeding season focused on trapping core-use areas and the most suitable habitat tracts during April-June, 2000 and 2001. Monitoring of radio-collared hares during January-June, 2000 and 2001 revealed locations where extant populations could be live-trapped to assess reproduction. Twenty-five Tomahawk live-traps (90 x 30 x 30 cm) baited with alfalfa pellets and apples were placed at 50-m intervals along 500-m transects or in a 5 x 5 grid matrix, depending on the spatial configuration of suitable habitat. Traps were set for 7-8 days at each site. All captured hares were sexed, weighed, external measurements taken, and examined for reproductive status. Females were visually examined and palpated for signs of pregnancy and/or lactation. Adult males were examined for enlarged testes (Keith et al. 1968). I also trapped during December, 2000-January, 2001 to capture juveniles recruited into the local population. Reconnaissance of the study area and observation of tracks during December 2000 were used to identify areas with substantial hare activity where juveniles may be present. Fifty live-traps were set using similar methods as described above. All captured hares were checked for toe tags, sexed, weighed, external measurements taken, and marked with numbered ear tags.

Snow-cover

Snow depth in the study area was measured every 2-3 days during January-April, 2000 and 2001. Measurements of snow depth (mm) were recorded in forested areas near selected telemetry points. Overall ground snow coverage (%) also was estimated in forested areas at each sampling point. Snow depth and snow coverage were averaged across all measured points (n = 4-8) for each day of sampling. Estimates of snow depth were plotted daily during 23 January-3 April, 2000 and 2001. Trends in snow cover were analyzed for major losses, which may affect vulnerability of snowshoe hares during the spring pelage molt (March-May).

DATA ANALYSIS

Physical Condition

Physical characteristics were analyzed to determine condition of snowshoe hares prior to release. Mean trap weight, release weight, and hind-foot length and body mass were summarized for all hares released in 2000 and 2001. Mean weight loss (between capture and release) and condition index ($\sqrt[3]{\text{total weight}}$/hind-foot length) also were determined to evaluate general condition (Bailey 1968, Brand et al. 1975, Sievert and Keith 1985). Snowshoe hare body measurements and condition indices were compared between 2000 and 2001 to identify annual differences that may have influenced post-release survival and reproduction.

Survival and Causes of Mortality

Lost signals were considered to indicate radio failure or dispersal outside the study area and these hares were censored from survival analyses. Hare deaths due to unnatural causes (stress or handling related) also were censored from survival analyses.

Apparent survival (1- [no. deaths/no. hares released]) was calculated for all hares radio-collared in 2000 and 2001. Apparent survival was compared among hares released in different locations, habitat types, and on separate release dates. Apparent survival was simply the proportion of released animals that survived through the breeding season (January-March) or the entire monitoring period (January-June) during 2000 and 2001. However, apparent survival proportions do not account for the staggered entry of hares into the population or for temporal variation in mortality. Kaplan-Meier survival, modified for the staggered entry of new animals, provides more equitable estimates of weekly and continuous survival rates throughout the monitoring period. Therefore, Kaplan-Meier techniques were used to analyze temporal patterns in survival for all radio-collared hares monitored in 2000 and 2001 (Pollock et al. 1989).

The 2000 and 2001 monitoring periods were divided into 21 weekly time intervals for analysis of survival and cause-specific mortality (Heisey and Fuller 1985). The relative number of transmitter-days and deaths were calculated for each interval and used to determine daily, weekly, and annual survival rates. Annual hare survival rates were the product of all 21 weekly survival rates during 2000 and 2001. Causes of mortality were summarized for all radio-collared hares released each year. Survival and causes of mortality were compared with other studies to evaluate the potential of the study area to support a breeding population. Survival was compared among hares released at different sites to identify the most suitable habitats for snowshoe hares in northeast Ohio.

RESULTS

Physical Condition

Body mass and condition indices were determined for 138 hares (68 males, 70 females) released in 2000 and for 94 hares (52 males, 42 females) released in 2001 (Table 4.1 and 4.2). Physical attributes were not reported for all individuals in 2000 due to loss of toe tags and measurement errors. Hind-foot length was used as an index of body size in 2000 and 2001. Mean hind-foot length of hares was similar ($t = 0.91$, $d.f. = 227$, $P = 0.182$) in both years. Hares lost more weight before release during 2000 ($t = -8.65$, $d.f. = 210$, $P < 0.001$) than during 2001. Mean condition index of hares released in 2000 also was lower ($t = -1.61$, $d.f. = 217$, $P = 0.054$) than in 2001.

Parameter	*n*	Mean	S.E.
Trap weight (g)	121	1,448.3	13.9
Release weight (g)	136	1,347.5	13.4
Weight change (g)[a]	120	- 103.5	8.6
Hind-foot length (mm)	136	134.5	0.6
Condition index[b]	133	0.082	0.004
No. days elapsed[c]	126	5.6	0.2

[a] Weight loss between trap and release dates was used to evaluate pre-release physical condition of snowshoe hares.
[b] Condition index ($\sqrt[3]{\text{total weight}}$/hind-foot length) prior to release also was used to evaluate physical condition of snowshoe hares (Brand et al. 1975).
[c] Number of days elapsed between capture and release.

Table 4.1: Physical condition of 138 snowshoe hares before release in Geauga and Ashtabula Counties, Ohio, 25 January-21 February, 2000.

Parameter	*n*	Mean	S.E.
Trap weight (g)	94	1,366.7	14.1
Release weight (g)	94	1,366.0	15.3
Weight change (g)[a]	94	- 0.7	8.2
Hind-foot length (mm)	94	133.8	0.5
Condition index[b]	94	0.083	0.002
No. days elapsed[c]	94	8.4	0.4

[a] Weight loss between trap and release dates was used to evaluate pre-release physical condition of snowshoe hares.
[b] Condition index ($\sqrt[3]{\text{total weight}}$/hind-foot length) prior to release also was used to evaluate physical condition of snowshoe hares (Brand et al. 1975).
[c] Number of days elapsed between capture and release.

Table 4.2: Physical condition of 94 snowshoe hares before release in Geauga and Ashtabula Counties, Ohio, 23 January-27 February, 2001.

Post-release Survival

Causes of Mortality. - Fourteen intact carcasses were recovered during January 26-May 2, 2000. Apparent causes of mortality were initially either unknown or assumed to be stress-related for 12 carcasses. Only 2 of these hares survived >10 days post-release and 11 had condition indexes (0.077-0.082) below the mean (0.082) for the 2000 release, suggesting they were in relatively poor condition. Necropsy examinations revealed that 6 of the unknown deaths were caused by handling injuries. These animals suffered severe trauma (internal hemorrhage, bone breakage, and organ damage) in the thoracic area, probably the result of excessive force applied during handling. Three of the remaining unknown sources of mortality were classified as stress, and 3 remained unknown after necropsy. Eight whole carcasses were collected during January 28-March 28, 2001. Apparent causes of mortality for these hares were either unknown or assumed to be stress-related. Only 3 of these hares survived >10 days post-release, although only 1 hare had a condition index (0.079) below the mean (0.083) for the 2001 release. Necropsy observations showed that 7 of the unknown deaths were caused by predation (6 *Canidae*, 1 domestic dog). These animals suffered severe trauma (internal hemorrhage, bone breakage, and organ damage) and puncture wounds in the thoracic or hind-quarter areas. The remaining hare had no internal injuries but showed signs of stress (low condition index, no subcutaneous fat, and liver degeneration) at necropsy.

Causes of mortality were determined for 55 of 62 (89%) hare deaths during 2000 and for 38 of 40 (95%) deaths during 2001. Coyote, foxes, and unknown canids were responsible for the majority of deaths in 2000, followed by raptors, unknown, and handling (Figure 4.1). *Canidae* were again the major source of mortality in 2001, followed by raptors (Figure 4.2). Sixteen of 62 mortalities (26%) were classified as unknown, handling, or stress in 2000 compared to only 3 of 40 (8%) mortalities that were similarly classified in 2001. One snowshoe hare with a severe lesion on the hind-quarters was euthanized before release in 2000. Two other hares were transferred to a veterinary clinic in 2000 for treatment of external wounds. Both died within 5 days, apparently due to handling stress. Two hares were euthanized prior to release in 2001 due to severe lesions on the back and hind-quarters. Most of the visible wounds were small abrasions that occurred during trapping, transport, or captivity.

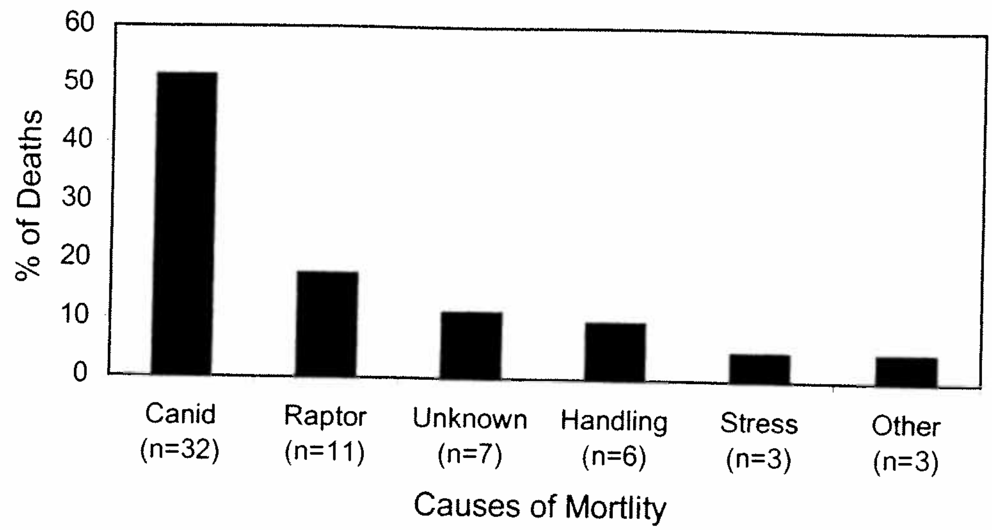

Figure 4.1: Sources of mortality for 62 snowshoe hares recovered from Geauga and Ashtabula Counties, Ohio, January 26-June 20, 2000. Canid includes coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and unknown canid mortalities. Other includes mortalities causes by domestic animal, *Mustelidae*, or automibile.

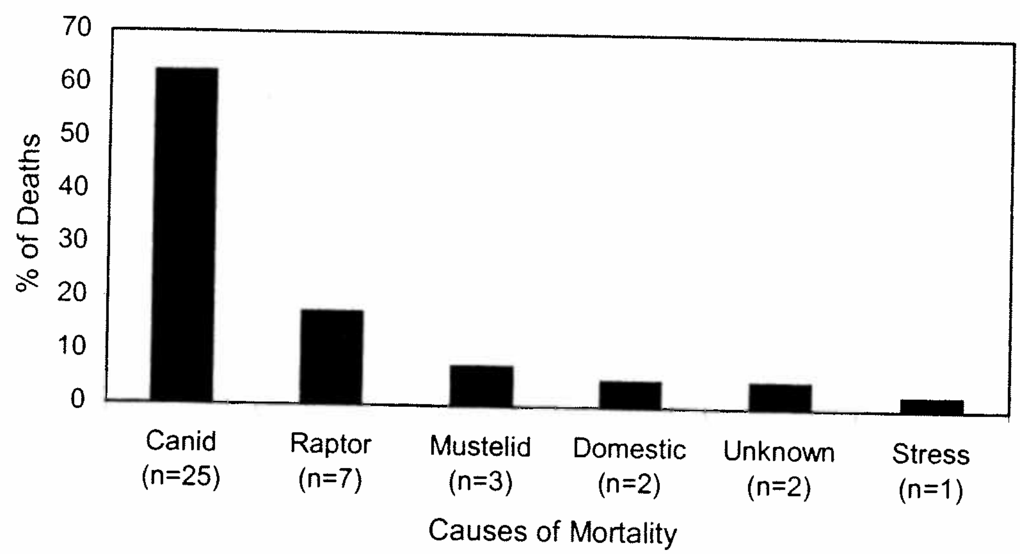

Figure 4.2: Sources of mortality for 40 snowshoe hares recovered from Geauga and Ashtabula Counties, Ohio, January 24-June 18, 2001. Canidae includes coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and unknown canid mortalities. Domestic includes mortalities causes by domestic animal.

Cause-specific Mortality. - Nine hares were censored from survival analysis due to handling or stress mortality and 3 were censored due to lost signals in 2000. Eleven hares were censored due to lost signals and 1 due to stress mortality in 2001. More signals were lost in 2001 because I re-used collars (n = 24) that were recovered from hares released in 2000. Specific causes of mortality were separated into 3 categories (*Canidae*, raptor, and other) for analysis of cause-specific mortality rates (Table 4.3). Other causes of mortality included those attributed to domestic animals, *Mustelidae*, automobile, and unknown. Predation by *Canidae* was the most likely source of mortality each year (46-50%). Raptors were a more important source of mortality in 2000 compared to 2001. The importance of other sources of mortality did not differ between years.

		Cause-specific mortality rate		
Year	147-day survival rate	*Canidae*	Raptor	Other
2000	0.1853	0.4964	0.1613	0.1569
2001	0.2992	0.4644	0.0642	0.1625

Table 4.3: Survival and cause-specific mortality rate estimates for 160 radio-collared snowshoe hares released in Geauga and Ashtabula Counties, Ohio during 26 January-20 June, 2000 and 24 January-18 June, 2001 (Heisey and Fuller 1985).

Kaplan-Meier Survival. - Temporal trends in survival varied between hares released each year (Tables A.1 and A.2). Kaplan-Meier survival through 21 weeks of monitoring was higher in 2001 (31%) compared to 2000 (17%) (Figure 4.3). These annual survival rates were similar to those calculated using the Heisey and Fuller (1985) technique. Weeks 1-5 represented periods when newly released hares were most at risk and mortality rates were highest. Hares released in 2000 experienced 62% of mortalities during the first 5 weeks of monitoring (Table A.1). Cumulative survival was 40% in weeks 1-5 and 41% in weeks 6-21 during 2000. Hares released in 2001 experienced 33% of mortalities during the first 2 weeks of monitoring (Table A.2). Cumulative survival was 58% in weeks 1-2 and 54% in weeks 3-21 during 2001. Following the periods of high mortality associated with newly relocated animals, trends in weekly survival were similar each year. Survival during weeks 6-21 in 2000 and weeks 3-21 in 2001 are more representative of resident hares in available habitat of northeast Ohio.

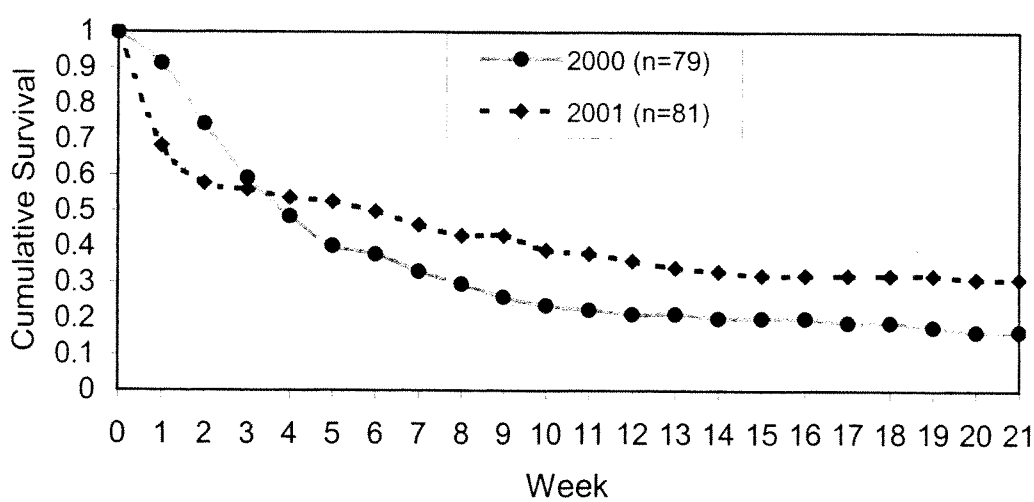

Figure 4.3: Kaplan-Meier survival functions, modified for staggered entry of 160 snowshoe hares released in Geauga and Ashtabula Counties, Ohio during 26 January-20 June, 2000 and 24 January-18 June, 2001.

Apparent Survival. - Apparent survival was calculated for each release site and for all radio-collared hares monitored during January-June, 2000 and 2001 (Tables A.3 and A.4). Apparent survival was higher ($z = 2.81$, $P = 0.002$) in 2001 (43%) than in 2000 (21%). Survival rates did not differ between males and females in 2000 ($z = 0.66$, $P = 0.237$) or in 2001 ($z = 0.23$, $P = 0.389$). Lower survival was associated with differences in post-release movement during 2000 and 2001. Hares that survived <14 days post-release moved larger distances ($x \pm$ S.E.) ($t = 2.16$, $d.f. = 18$, $P = 0.021$) between radio locations (829 ± 155 m) than hares that survived >2 weeks (485 ± 35 m) in 2000. Hares that survived <14 days post-release also moved larger distances ($t = 1.86$, $d.f. = 17$, $P = 0.044$) between radio locations (823 ± 141 m) than hares surviving >2 weeks (562 ± 33 m) in 2001.

Hares released on later dates generally experienced lower survival during 2000 and 2001. Apparent survival during January-June, 2000 was highest for hares released on 25 January (36%), followed by 1 February (32%), 8 February (14%), and 21 February (0%). Weekly survival of hares released on 25 January was relatively consistent during 2000, while survival of hares released on later dates had lower survival during weeks 1-5 post-release. Hares released on 25 January also had smaller weight changes ($t = 3.69$, $d.f. = 26$, $P = 0.001$) and were in better pre-release condition than hares released on later dates. Apparent survival during January-June, 2001 was highest for hares released on 13 February (59%), followed by 23 January (43%), 2 February (40%), and 27 February (22%). Contrary to 2000, hares released later in winter 2001 did not have lower survival during the first few weeks post-release. There also was no difference in pre-release physical condition for hares released on different dates in 2001.

I compared apparent survival estimates between northern and southern release sites in 2000 and 2001. Survival was similar ($z = 0.19$, $P = 0.405$) for hares released on northern sites (22%) and southern sites (20%) in 2000. Most animals (67%) were released on 25 January, 2000 in the north region. Hares released on 25 January had higher survival and were in better condition compared to hares released on later dates. Weekly survival of hares released on northern sites was relatively consistent during 2000, while survival of hares released on southern sites was lower during weeks 1-5 post-release. Survival also was not statistically different for hares released on southern sites (47%) and northern sites (39%) in 2001 ($z = 0.66$, $P = 0.242$). Weekly survival was relatively consistent in both regions during January-June, 2001. Most hares (55%) released in the south region were released on 23 January, 2001. Once again, hares released earlier generally had higher survival compared to later releases. Apparently, slight differences in survival between northern and southern release sites were related to timing of releases and quality of release animals.

Survival varied among different release habitats during 2000 and 2001. Apparent survival in 2000 was highest for hares released in wetland forest sites, followed by early regeneration, mixed wetland/upland forest, and upland forest (Figure 4.4). Survival of hares released in wetland forest and early regenerating sites was higher ($z = 1.98$, $P = 0.022$) than for hares released in mixed and upland forest sites. Apparent survival in 2001 also was highest for hares released in wetland forest sites, followed by early regeneration, mixed wetland/upland forest, and upland forest (Figure 4.5). Similar relative differences in apparent survival were observed among release habitats during 2001. However, there were no significant differences ($z = 0.86$, $P = 0.180$) between survival of hares released in wetland and early regenerating sites compared to mixed and upland forest sites. Trends in survival were not as distinct in 2001 as snowshoe hares had higher survival in all habitat types.

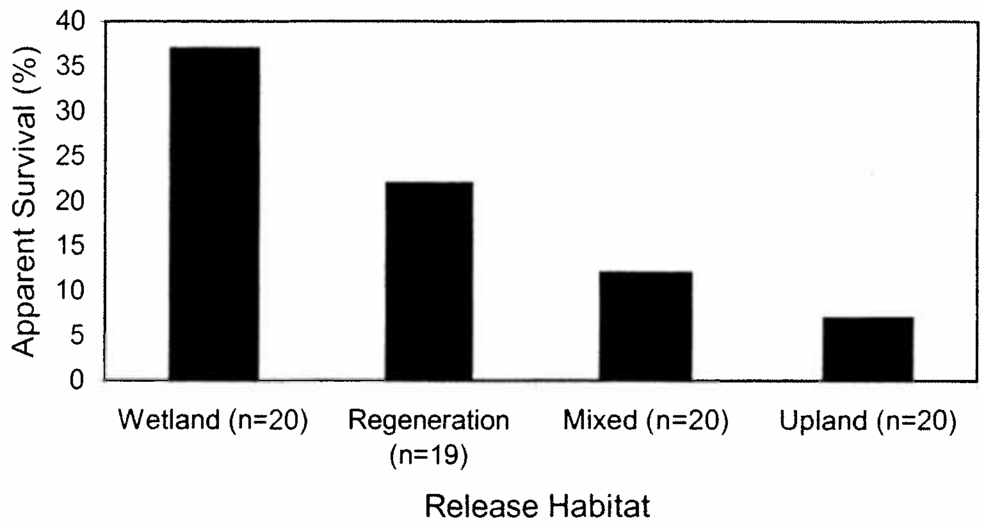

Figure 4.4: Apparent survival by release habitat of 79 snowshoe hares monitored in Geauga and Ashtabula Counties, Ohio during 26 January-20 June, 2000.

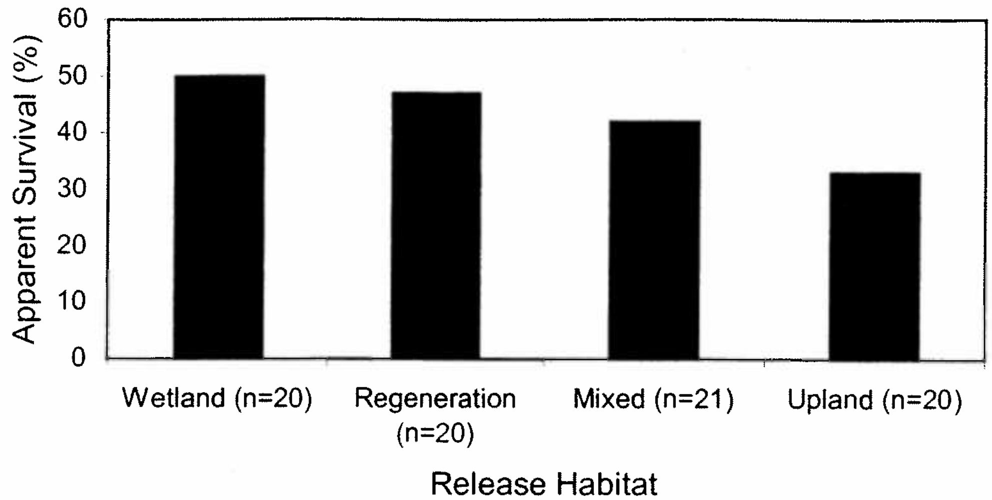

Figure 4.5: Apparent survival by release habitat of 81 snowshoe hares monitored in Geauga and Ashtabula Counties, Ohio during 24 January-18 June, 2001.

Snow Cover. - Snow conditions may have contributed to lower survival of hares released on later dates during winters 2000 and 2001. The latest snowshoe hare releases occurred on 21 February in 2000, and on 27 February in 2001. Apparent survival of hares released on these dates was lower than for hares released on earlier dates. The last releases coincided with sharply declining or low snow cover each year (Figure 4.6). Snow cover in forested portions of the study area was <25% by late-February in 2000 and 2001. The major spring snow-melt occurred earlier in 2001 (5-10 February) compared to 2000 (22-27 February). However, periodic snowfalls after the initial spring melt provided approximately 20 more days with ≥25% snow-cover during late-January through late-March, 2001 compared to 2000. Thus, the longer duration of snow cover may have contributed to overall higher survival in 2001.

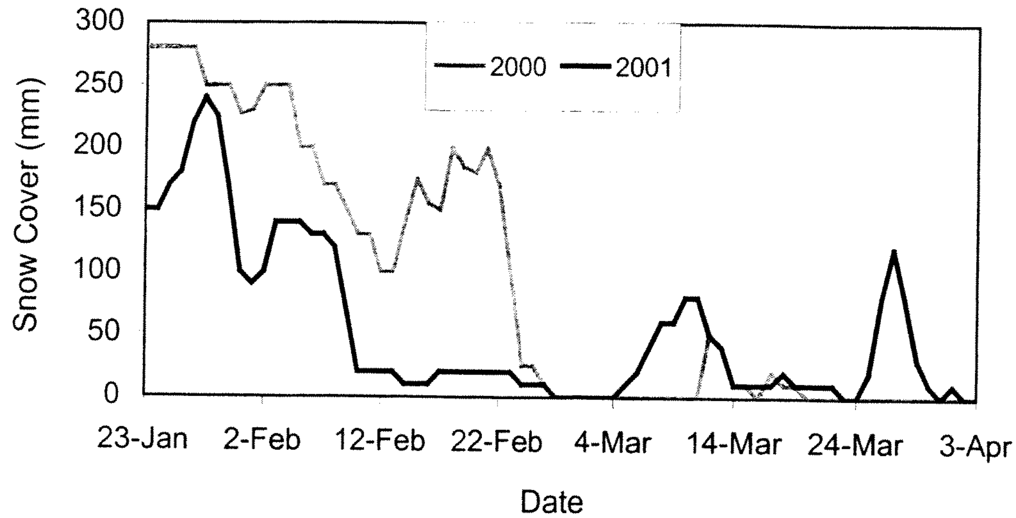

Figure 4.6: Estimated snow depth under forest canopy of the snowshoe hare release area in northeastern Geauga and southwestern Ashtabula Counties, Ohio during 23 January-3 April, 2000 and 2001.

Reproduction and Recruitment

Six hares (5 males, 1 female) were captured during the 2000 breeding season (Table B.1). Female 086 did not show signs of reproduction when palpated for pregnancy or inspected for lactation. Female 086 frequented the home range of male 046 for >3 months and could have been between litters when captured. Five males (046, 035, 133, 673, and 026) were captured during the 2000 breeding season (035 and 133 were captured twice). All had fully descended and enlarged testes (30-40 mm). Six hares (3 males, 3 females) also were captured during the 2001 breeding season (Table C.1). Two females (417, 435) were pregnant at time of capture. Palpating to count embryos was inconclusive, but both hares had enlarged abdomens and were >385 g heavier than at release. The 3 males (439, 449, 469) had fully descended and enlarged testes (30-40 mm). Trapping success was limited during the 2000 and 2001 breeding seasons with few individuals widely distributed over a large area. In addition, growth of natural vegetation with the advance of spring season probably inhibited effectiveness of baited traps. Trapping success was 0.03 hares/trap night during May-June, 2000 and 0.02 hares/trap night during May-June, 2001.

Winter trapping efforts focused on areas surrounding release site N3 where 6 radio-collared hares survived through the breeding season and substantial track sign was observed in December 2000. Four hares (3 males, 1 female) were captured during winter 2000-01 (Table B.1). Trapping success during December, 2000 and January, 2001 was 0.03 hares/ trap night. Three of these hares were released in 2000, 2 wore radio-collars, and one had badly worn toe tags. The final snowshoe hare captured was a juvenile, obviously recruited from the 2000 breeding season. The juvenile was captured only once, while other hares were captured 5-6 times each. Hare 001/002 lost 330 g through the 6 captures over 8 days and died from apparent malnutrition on 10 January, 2000 when trapping ceased. Hares 005/006 and 007/008 did not lose weight with successive recaptures.

DISCUSSION

Weight loss, stress-related deaths, and handling injuries were reduced during captivity, transport, and release in 2001. Outdoor pens were enlarged approximately 50% between 2000 and 2001 releases. Although hares were held for longer periods during 2001 compared to 2000, pre-release condition was better among hares released in 2001. Thus, extended captivity in outdoor pens may not affect physical condition unless hares are overcrowded. Extended confinement during transport also may affect physical condition of snowshoe hares. Most hares were held individually in cardboard boxes for only 6-10 hours during transport by aircraft to Ohio. However, a single group of animals (n = 40) was transported by automobile to Ohio due to poor weather. These animals were confined for >24 hours and had poor physical condition compared to other hares released in 2000. Body and ear length measurements were discontinued to minimize handling time in 2001. Marking with foot tags also was discontinued due to poor retention and injuries to toe webbing. Nylon bags were used during the majority of handling and cloth nets were used to capture hares in outdoor pens prior to 2001 releases. Hares also were supplied with increased amounts of apples, alfalfa, and willow browse while held overnight at Grand River Wildlife Area during 2001.

Predation by *Canidae* was the major source of mortality each year. Mammals are typically the most important predators of snowshoe hares. Predator pressure also is more sustained at southern boundaries of the hare's range (Buehler and Keith 1982, Sievert and Keith 1985). Mortality rates were highest during the first 1-5 weeks of monitoring in 2000 and 1-2 weeks in 2001. The chance of death is typically greatest within the first 2 weeks after release as animals became familiar with their surroundings and search for sufficient cover (Fies no date, Sievert and Keith 1985). Hares that survived >2 weeks following release moved shorter distances compared to hares that survived <2 weeks during each year. Large movements are often associated with higher mortality at the southern periphery of the hare's range (Keith et al. 1993). Although snowshoe hares moved larger distances from release in 2001 compared to 2000, survival during January-June was higher in the second year.

Annual differences in survival were almost entirely associated with improved pre-release condition and timing of releases relative to snow cover. Other long-term studies in central Wisconsin have identified unpredictable snow cover to be critical near the southern periphery of the snowshoe hare's range (Buehler and Keith 1982). Population changes of the local predator communities and availability of alternative prey species also may have contributed to increased survival in 2001. Overall, after the periods of high mortality associated with new releases, survival rates were similar between March-June, 2000 (0.43) and February-June, 2001 (0.54). Survival during these periods is probably more representative of resident hares in available habitat of northeast Ohio.

Southern release sites contained larger amounts of preferred habitat types (65-232 ha) than northern release sites (0-57 ha) and were expected to have higher survival during 2000 and 2001. However, anticipated relationships between habitat suitability and survival were affected by variations in release date and pre-release condition. Survival was slightly higher in northern sites where hares were released first in 2000. In contrast, survival was slightly higher in the southern release sites where hares were released first in 2001. Hares released later in winter apparently had less time to establish home ranges prior to spring snow-melt and were more vulnerable during 1-2 weeks post-release. Poor physical condition also may have contributed to lower survival in later releases. Hares released on 25 January probably survived better than hares released later in 2000 because they were in better condition prior to release. These observations indicate that the timing of release and quality of release animals was more critical to survival than differences in habitat quality between the northern and southern regions of the study area.

Snowshoe hare survival varied with habitat characteristics of release sites. Survival was highest for hares released in areas containing high amounts of shrub-scrub wetland and early successional forest each year. Shrub-dominated wetlands and regenerating clearcuts are important habitats in southern regions of the snowshoe hare geographic range where coniferous cover is lacking (Scott and Yahner 1989). Quality habitat types selected by snowshoe hares contained high understory cover and stem densities. Overall, survival was higher in areas containing larger amounts of prime habitat (early successional forests, shrub-scrub wetlands, wetland forests 10-20 years old, and conifer plantings) during 2000 and 2001. Release areas containing >100 ha of preferred habitat had the highest survival (0.24-0.47), followed by those containing 20-100 ha (0.25-0.35), and <20 ha (0.12-0.16). Hares in central Wisconsin survived best during March-August in areas containing 27.7 ha of prime habitat (0.45), followed by 23.2 ha (0.27), and 7 ha (0.08). Similar to northeast Ohio, prime habitats in central Wisconsin were identified as coniferous forests, 5-15-year-old hardwood stands, and shrub-scrub wetlands with >60% understory cover (Keith et al. 1993, Sievert and Keith 1985).

Survival of hares monitored in northeast Ohio during January-June, 2000 (0.18) and 2001 (0.30) was greater than the 202-day survival rate (0.09) for hares relocated and monitored in western Virginia during January-August, 1989 and 1990 (Fies no date). The snowshoe hare relocation attempt in western Virginia was deemed impractical due to poor trapping success, high predation rates, and insufficient habitat. Seasonal (180-day) survival of hares monitored in central Wisconsin during March-August, 1989-90 (0.34) was higher than 147-day survival rates of hares in northeast Ohio during 2000 (0.18), but similar to survival during 2001 (0.31) (Keith et al. 1993). In addition, mean 30-day survival of hares transplanted to good cover in central Wisconsin during 1982 and 1983 (0.73; Sievert and Keith 1985) was similar to that of hares monitored in northeast Ohio during 2000 (0.72) and 2001 (0.82). Survival of hares released in Ohio was comparable to other extant populations at the southern boundary of the geographic distribution and should be sufficient to support a population through the breeding season.

Survival and reproduction are critical parameters that affect viability of hare populations in marginal habitat (Keith et al. 1993). However, above average reproductive rates have been observed among hares in central Wisconsin and are believed to compensate for low survival rates that characterize otherwise declining populations (Kuvlesky and Keith 1983, Sievert and Keith 1985). Limited evidence of breeding and recruitment of hares released in northeast Ohio was detected in 2000 and 2001. However, reproductively active hares were observed within early regeneration and shrub-scrub habitats in northern and southern regions of the study area. Shrub-scrub wetlands were the most abundant high quality habitat, followed by upland forests <10 years old, wetland forests 10-20 years old, and conifer plantings. Mature deciduous forests (>20 years old) and non-forested habitats were limiting to hares released in northeast Ohio and comprised the majority of the study area. Large patches of optimum habitat have potential to support breeding populations and recruitment of young hares. Thus, conserving a landscape mosaic of shrub-scrub wetlands and early successional forests is essential to viability of a self-sustaining hare population in northeast Ohio.

CHAPTER 5

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The significance and social value of the snowshoe hare depends primarily on the geographic region and attitudes of people involved (Bittner and Rongstad 1982). Snowshoe hares are an important indicator species of northern boreal and sub-boreal forests and represent a valuable native wildlife resource of northeast Ohio. The attempt to reintroduce snowshoe hares in Ohio is consistent with goals of the Ohio Division of Wildlife's tactical plan for population recovery of state-listed terrestrial wildlife species. Because snowshoe hares were once indigenous to northeast Ohio, this project provides a better understanding of the importance of native swamp forest habitats for terrestrial wildlife species. The snowshoe hare reintroduction focuses attention on the need to conserve wetland, early successional, and coniferous forests. Managing habitat for an area-sensitive forest species raises awareness for protection of forested landscapes from increased development and fragmentation. Given that the loss of native habitat probably contributed to extirpation of snowshoe hares from Ohio, current trends and future outlook for the region should be considered in reintroducing this species.

Success rates of animal relocations are typically over-estimated, which creates difficulty in accurately predicting the value of such projects for conservation. However, specific improvements in release design and management efforts may enhance the effectiveness of animal relocations (Fischer and Lindenmayer 2000, Griffith et al. 1989, Wolf et al. 1996). Detailed information on species biology and relocation potential should be analyzed prior to any management effort. A better understanding of limiting factors and critical habitat requirements of hares released at the southern geographic range limit of snowshoe hares in Ohio was needed. Thus, the experimental snowshoe hare releases were conducted during 2000 and 2001 to maximize the potential for successfully restoring a long-term viable population in northeast Ohio. The Ohio Division of Wildlife reviewed pertinent literature, identified potential habitat types, and selected the most suitable sites for the experimental snowshoe hare releases. The study area was selected to represent available habitats and conditions within the known historic range of hares in northeast Ohio. Efforts were made to release a sufficient number of high quality animals from wild source populations.

This chapter summarizes outcomes and findings of the experimental snowshoe hare releases during 2000 and 2001. The evaluation determined critical limiting factors and the most suitable habitats for snowshoe hares in northeast Ohio. Herein, I identify important natural resources that may be at risk in northeast Ohio and assess the future potential of the region to support snowshoe hares. Results of the study were used to provide recommendations for future releases and to improve the effectiveness of restoration attempts in northeast Ohio. The Ohio Division of Wildlife can use this evaluation to identify areas with the greatest potential for supporting a viable population, further define reintroduction success, and develop a long-term monitoring program to collect information on population status.

LIMITING FACTORS AND HABITAT POTENTIAL

The most important factor affecting survival of hares during 2000 and 2001 was mammalian predation, specifically by *Canidae*. Predator control methods could be used to increase snowshoe hare abundance in areas that experience high losses due to localized predator communities. Success of animal reintroductions is typically greater when the major source of mortality is effectively removed (Fischer and Lindenmayer 2000). However, heavy understory cover is probably critical for snowshoe hares where predation rates are high (Bittner and Rongstad 1982). In addition to predation, condition of release animals, variations in time of release, and adverse weather conditions also affected survival of reintroduced snowshoe hares. Poor condition of release animals lowered post-release survival during 2000. Pre-release condition was improved during 2001 by minimizing overcrowding of captive animals, duration of confinement during transport, and excessive handling. Snowshoe hares also may have been more vulnerable to predation if the pelage-molt did not coincide with loss of snow cover in spring 2000. Releasing hares earlier in winter seasons can minimize losses due to unpredictable snow cover. Ultimately, mortalities associated with extremely low snowfall amounts and unusually early snowmelt in northeast Ohio may be inevitable.

Applying apparent survival during January through mid-March (0.37-0.62), approximately 51 of 138 hares survived until the start of the breeding season in 2000; 58 of 94 survived in 2001. Based on apparent survival during January-June (0.21-0.43), approximately 29 hares released in 2000 and 40 hares released in 2001 may have been available to breed in the following seasons. Comparing survival rates of hares released in northeast Ohio to that of other studies near the southern periphery of the geographic range suggests that survival was sufficient to establish a breeding population in the experimental study area. Survival rates during January-June, 2000 and 2001 (0.18-0.30) was greater than 202-day survival (0.09) for hares relocated and monitored in western Virginia (Fies no date). Mean 30-day survival of resident (0.86) and transplanted hares (0.73) in good cover of central Wisconsin were similar to that of hares monitored in northeast Ohio during 2000 and 2001 (0.72-0.82) (Sievert and Keith 1985). However, limited evidence of reproduction was detected among hares released in northeast Ohio due to minimal success of live-trapping. Two pregnant females, 8 reproductively active males, and 1 juvenile male were captured during 2000 and 2001. Ultimately, reproductive success is the most critical factor that will determine the long-term viability of snowshoe hares after reintroduction into northeast Ohio.

Snowshoe hares in northeast Ohio survived best when released in shrub-scrub wetland and early successional forests each year. Survival during January-June, 2000 and 2001 was highest in sites containing >100 ha of preferred habitat types (0.24-0.47), followed by those containing 21-100 ha (0.25-0.35), and ≤20 ha (0.12-0.16). Therefore, higher survival rates may be attained by releasing hares into areas with greater amounts of preferred habitat. After the periods of high mortality associated with newly relocated animals, survival rates were 0.43 during March-June, 2000 and 0.54 during February-June, 2001. These survival rates are more representative of resident hares in available habitat of northeast Ohio. Seasonal survival of hares monitored in central Wisconsin during March-August (0.34) and September-February (0.43) was similar to that of hares in northeast Ohio following the periods of high risk (Keith et al. 1993). Based on survival of the experimental hare releases during 2000 and 2001, relocating wild snowshoe hares in northeast Ohio appears feasible where suitable habitat exists.

The 232 snowshoe hares released in 2,066 ha of forested habitat during 2000 and 2001 corresponded to an overall density of 1 hare/9 ha of woody habitat. Based on survival rates during January through mid-March, breeding densities of approximately 1 hare/41 ha of woody habitat were established in 2000 and 1 hare/36 ha of woody habitat in 2001. These breeding densities were similar to mean 100% MCP home range sizes during 2000 and 2001 (40 ha). Hares preferred shrub-dominated wetlands, early successional forests (<10 years old), wetland forests (10-20 years old), and conifer plantings. These high quality habitats comprised 589 of the 2,066 ha (28%) of forested habitat in the study area. Based on survival rates during January through mid-March, breeding densities of approximately 1 hare/12 ha of optimum habitat were established in 2000 and 1 hare/10 ha of optimum habitat in 2001. Shrub-scrub wetlands comprised 14.5% of the available forested area in large patches (31-207 ha). Early successional forests (<10 years old), wetland forests (10-20 years old), and coniferous plantings were less abundant in the study area. Early successional growth comprised 7% of the forested area in continuous patches 50-94 ha in size. Wetland forests (10-20 years) comprised 5% and coniferous plantings only 2% of the forested area. In contrast, mature deciduous forests (>20 years) and non-forested habitats were over-abundant and limiting to snowshoe hares, comprising the majority of the study area (68%).

Large home ranges of snowshoe hares suggest that habitat suitability of the study area was marginal. However, movements and home ranges are often large when animals are relocated into unfamiliar territory. Movements were similar to those observed in other hare relocation efforts (Fies no date, Keith et al. 1993, Sievert and Keith 1985). Snowshoe hares dispersed greater distances from southern release sites compared to northern sites. The southern region of the study area had more total forested area, more high quality habitat, and smaller distances between optimum habitat patches than the northern region. Hares dispersing from southern release sites were less vulnerable to predation and capable of moving longer distances. Snowshoe hares also dispersed larger distances when released in wetland and upland forest sites. These release habitats generally contained more total forested area and more dispersed resources compared to mixed and early regenerating forest sites. Overall, movements were restricted in smaller forest tracts (<100 ha) and where large distances (>1,000 m) separated optimum habitat patches.

Shrub-scrub wetlands were the most abundant high quality habitat type and appeared to have the greatest potential for supporting snowshoe hares in northeast Ohio. Shrub habitats are associated with permanent wetland basins that are less vulnerable to human impacts. These habitat types are more likely to remain suitable for snowshoe hares, unlike forested stands that must be continually renewed. Snowshoe hare populations tend to decline when forests mature in the absence of fire or cutting (Carraker 1985, Conroy et al. 1979). Small isolated hare populations are usually associated with bog edges or other natural openings that may support patches of willow, alder, hazel, and other low-growing woody vegetation in areas dominated by old growth (Bittner and Rongstad 1982, Keith et al. 1993). Clear-cutting, thinning, and selective cutting create early successional forests and have been suggested as habitat management techniques in marginal landscapes (Conroy et al. 1979). These forestry practices could be used to restore early successional forests in northeast Ohio. However, such management would be most productive when associated with large wetland basins containing ≥15% shrub-scrub habitats. Ultimately, maintaining quality hare habitat in Ohio will require conservation of contiguous shrub-dominated wetlands and management of early successional habitats surrounding these permanent wetland basins.

LAND-USE

Unique land-use issues exist in northeast Ohio and deserve consideration in restoring viable snowshoe hare populations to the region. The landscape of northeast Ohio has qualities that may positively and negatively influence long-term success of the reintroduction. The extensive lowland areas of Ashtabula and Geauga counties have the greatest potential to support viable snowshoe hare populations. Northeast Ohio contains the majority of Ohio's wetland area (Ohio Wetland Restoration and Mitigation Strategy Blueprint 1999). Land cover of Ashtabula County currently consists of 24% wetlands (49% of its original wetland area). Major wetland types of Ashtabula County include woods on hydric soils (68%) and shrub-scrub wetlands (18%), that offer the greatest potential to support snowshoe hare populations. Geauga County contains less total wetland area (11%), but wetlands include a greater proportion of shrub-scrub types (23%). The largest wetland tracts in northeast Ohio are generally publicly owned by state or federal agencies and have some degree of conservation.

Early successional forests (seedling and sapling age classes) also have potential to support snowshoe hares in northeast Ohio. However, these habitats must be regenerated as forests mature if snowshoe hare populations are to persist. Ohio's forests have been maturing in recent years (Ervin et al. 1994). Forest inventories determined that

Ashtabula County's timberland consisted of 44% sapling and seedling size classes and 14% poletimber in 1979 (Griffith et al. 1993). Based on forest inventories during 1990-1991, timberland of Ashtabula County consisted of less sapling and seedling classes (31%) and greater amounts of poletimber (46%). Forest inventories determined that timberland of Geauga and Lake counties consisted of 38% sapling and seedling and 9% poletimber in 1979 (Griffith et al. 1993). Similar to forest trends in Ashtabula County, timberland of Geauga and Lake counties consisted of less sapling and seedling classes (16%) and greater amounts of poletimber (26%) during the 1990-1991 inventories. The 1990-1991 forest inventory also determined that average annual net growth of growing-stock and sawtimber on timberlands of Ashtabula, Geauga, and Lake counties greatly exceeded average annual removals (Griffith et al. 1993). Awareness already has been raised of the importance of early successional forests in Ohio for ruffed grouse (*Bonasa umbellus*), American woodcock (*Scolopax minor*), and several songbird species (Rodewald 2001). Greater emphasis should be placed on the necessity for maintaining forests of various ages for all wildlife species in Ohio.

The majority of forested habitat in northeast Ohio is in private ownership, primarily remnant blocks and wetland basins in a landscape dominated by agriculture (Ervin et al. 1994, Griffith et al. 1993). Timberland of Ashtabula County is mostly owned by non-farming private individuals (87%), followed by farmers (9%), and corporations (3%). Timberland of Geauga and Lake counties also is primarily owned by non-farming private individuals (76%), followed by corporations (15%), and farmers (2%). Although northeast Ohio contains large wetland areas and is primarily in non-industrial private ownership, there is serious threat from urban sprawl and increased habitat fragmentation. Substantial losses of forest threaten the future of northeast Ohio's natural habitats (Ohio Wetland Restoration and Mitigation Strategy Blueprint 1999). Based in the 1990-1991 forest inventory, forested lands comprised 51% of Ashtabula County (Griffith et al. 1993). Geauga and Lake counties, immediately west of Ashtabula County, were comprised of 46% forested lands. However, Cuyahoga County, which contains the greater Cleveland metropolitan area, has substantial residential development and was comprised of only 18% forested lands. Approximately 43% of Ohio's population is located in northeast Ohio with over 3 million people living within 35 miles of the Grand River lowlands (Ohio Wetland Restoration and Mitigation Strategy Blueprint 1999). Because the snowshoe hare is an exclusively forest-dwelling species with limited dispersal capabilities, fragmentation can severely limit emigration and immigration between populations. Therefore, the encroaching urban edge of Cleveland and associated residential development threaten the future of snowshoe hare habitat in this region. Maximizing connectivity between suitable habitat blocks is critical for long-term viability of any wildlife population in northeast Ohio.

There is a need to inform landowners of critical wildlife habitats in Ohio and increase awareness of forest conservation. Private landowners have the unique opportunity to become involved with conservation and restoration of habitat for species like snowshoe hares. Many long-term residents are focused on preserving land in its existing use or passing lands on to family members with similar values (Polson et al. 2001). For example, the Amish community owns a substantial amount of property in western and northeastern Ohio. Amish families are less likely to sell property or alter forested lands for reasons other than agriculture, livestock, or small-scale forestry practices (Strouse and James 2001). Periodic cutting of private Amish forests can continually regenerate early successional forest habitats that are important for supporting viable populations of snowshoe hares in northeast Ohio. There are many federal, state, and private programs for landowners interested in protecting habitat from development. Purchase of conservation easements and development rights by environmental organizations can be used to protect lands from development (Daubenmire and Blaine 1998, Schear and Blaine 1998). Incentives, educational outreach, and assistance programs provide the means and encouragement for landowners to improve wildlife habitat (Heiligmann 2002, Rausch and Sohongen 1997). Thus, awareness of private landowner environmental programs and wildlife habitats of northeast Ohio must increase.

Although there are threats of development and increased forest fragmentation in this region of Ohio, family-owned properties and the large watersheds could protect much of the forested landscape from change. The Grand River watershed is of particular interest for snowshoe hares and may be the primary focus of future releases. A significant partnership has been established between northeastern Ohio residents, landowners, businesses and communities to protect pristine wetland habitat of the Grand River lowlands. Grand River Partners, Inc. works to protect the Grand River and its tributaries and wetlands through natural resources stewardship (Delong 1999). As previously mentioned, changing land use (especially increasing residential development) is the greatest threat facing the Grand River region (Delong 1999). However, approximately 32% of the lowland area in this watershed already has been acquired by conservation groups. Many conservation easements in the area also protect riparian corridor habitat. Spearheading these conservation efforts, the goal of the Ohio Division of Wildlife's tactical plan for the Grand River lowlands is "to conserve and enhance wildlife diversity, wetland and riverine habitats, and increase recreational opportunities, utilizing a watershed approach" (Ohio Wetland Restoration and Mitigation Strategy Blueprint 1999). Major objectives of the project are to raise public awareness of issues and opportunities, protect additional habitat, and increase the number of partners. Specifically, the Ohio Division of Wildlife hopes to increase the amounts of protected habitat and riparian corridor 50% by 2005.

The potential for restoring a snowshoe hare population in northeast Ohio is promising. Experimental releases appeared successful in establishing an isolated breeding population. Survival of hares released in northeast Ohio during 2000 and 2001 was comparable to that of other extant hare populations near the southern periphery of their geographic range. Limiting factors and suitable habitats for snowshoe hares in northeast Ohio were identified during the experimental releases. Such information can be used to maximize success of future releases and the potential for establishing a long-term viable population. Although there are impending threats to the landscape, snowshoe hares adapted surprisingly well to available habitats of northeast Ohio. However, there is a need for increased conservation of native sub-boreal habitats and protection of forested landscapes from development. Long-term success of the snowshoe hare reintroduction will probably depend on land owner cooperation and future land-use trends in this region of the state.

MANAGEMENT RECOMMENDATIONS

Research exploring factors that influence success of animal reintroductions is limited. Fischer and Lindenmayer (2000) reviewed 180 case studies published in 12 major scientific journals to identify important issues common to such projects (Griffith et al. 1989, Wolf et al. 1996). Twenty-six percent of reintroductions reviewed by Fischer and Lindenmayer (2000) were successful, 27% failed, and the outcomes of 47% were unknown at the time of publication. Reintroductions that originated from a wild source population had higher success (31%) than those originating from captive populations (13%). Success was greater when >100 animals were released (50%) compared to reintroductions involving <100 animals (18%). Success also was greater when the major cause of decline was identified and effectively removed (22%) than when no efforts were taken to eliminate the major cause of decline (0%). Finally, failure of mammal reintroductions decreased from 42% to 12% when the initial populations were supplemented by additional releases.

It will be necessary to continue monitoring the experimental hare population in northeastern Geauga and southwestern Ashtabula counties, Ohio. Additional populations also must be established near the experimental release area if that population is to persist. Specific improvements in release design and management efforts may enhance the effectiveness of restoring snowshoe hares in northeast Ohio. In combination with general suggestions such as those proposed by Fischer and Lindenmayer (2000), findings from the experimental snowshoe hare releases during 2000 and 2001 were used to guide management recommendations. Pertinent recommendations for future releases and monitoring are listed below:

- Continued attempts should be made to minimize mortality caused by stress or injuries prior to release. Larger pens and/or smaller numbers of captive animals can minimize overcrowding during captivity. No more than 1 hare/2 m^2 should be held in outdoor pens to minimize overcrowding.
- Extended confinement during transport and excessive handling also can affect physical condition. Efforts should be made to minimize confinement to <10 hours. Thus, air transport appears critical for reducing stress-related deaths. In addition, unnecessary handling of animals should be avoided and is only recommended for experienced biologists.
- Snowshoe hare releases in northeast Ohio should occur at least 1-2 weeks before the major spring snowmelt. Based on snow cover observations during 2000 and 2001, snowshoe hares should be released no later than mid-February. Preferably, releases in northeast Ohio should occur before the first week of February.
- Future release areas should be identified based on suitability of available habitat in the experimental study area in northeast Ohio. Potential sites should consist of ≥80% contiguous forest coverage and ideally should contain ≥20% of shrub-dominated wetlands, early successional forests, and/or conifer plantings with understory cover ≥60%. Priority should be given to forested blocks with ≥15% shrub wetlands, surrounded by early successional growth and/or coniferous plantings.
- Special consideration should be given to the largest blocks of suitable habitat that are connected to additional sites by forested riparian corridors. Based on the largest movements by snowshoe hares in northeast Ohio and other regions of the

hare's range, release habitat should be within 6 km of other contiguous forested habitat to facilitate inter-population dispersal.

- Local release sites within larger tracts should occur in forested blocks at least 100-200 ha in size, which contain >20 ha patches of shrub-scrub wetlands, early successional forests, and/or coniferous plantings. Landscapes with <1,000 m between optimum habitat patches will maximize movements during the breeding seasons and promote dispersal of young hares throughout the population.
- Local release densities should depend on total forested area and composition of prime habitats. Given survival rates of the experimental releases during January-March, release numbers should be sufficient to establish breeding densities of ≥1 hare/40 ha of woody habitat or ≥1 hare/10 ha of optimum habitat. Generally, local releases should consist of ≥100 animals to maximize potential for success.
- Stochastic population models should be revised based on results of the experimental releases to establish criteria for a "viable" snowshoe hare population in northeast Ohio. Survival rates and breeding densities should be derived from the experimental population released during 2000 and 2001. Given the limited success of live-trapping to assess reproduction in northeast Ohio, reproductive rates should be derived from relevant studies at the periphery of the hare's range.
- Local snowshoe hare populations should be monitored annually (track counts) following releases to identify population status. Live-trapping also can be used to estimate population densities and document reproduction. The necessity for supplemental releases should be identified based on annual population status, results of stochastic modeling, and definitions of long-term population viability.

- Land owner outreach programs should become a major focus of the snowshoe hare re-introduction in northeast Ohio. Land owner interest and cooperation is critical in northeast Ohio due to specific habitat requirements and the general lack of awareness of snowshoe hare biology. Educational outreach efforts should focus on the importance of wetland and early successional habitats and the potential threats of development and habitat fragmentation.

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APPENDIX A

Survival Tables

Week	Dates	No. at Risk	No. Deaths	No. Censored	No. Added	Weekly Survival	Cumulative Survival
1	26 Jan-1 Feb	24	2	1	29	0.9130	0.9130
2	2 Feb-8 Feb	50	8	7	11	0.8140	0.7432
3	9 Feb-15 Feb	46	9	2	4	0.7955	0.5912
4	16 Feb-22 Feb	39	7	0	11	0.8205	0.4851
5	23 Feb-29 Feb	43	7	2	0	0.8293	0.4022
6	1 Mar-7 Mar	34	2	0	0	0.9412	0.3786
7	8 Mar-14 Mar	32	4	0	0	0.8750	0.3313
8	15 Mar-21 Mar	28	3	0	0	0.8929	0.2958
9	22 Mar-28 Mar	25	3	0	0	0.8800	0.2603
10	29 Mar-4 April	22	2	0	0	0.9091	0.2366
11	5 April-11 April	20	1	0	0	0.9500	0.2248
12	12 April-18 April	19	1	0	0	0.9474	0.2130
13	19 April-25 April	18	0	0	0	1.0000	0.2130
14	26 April-2 May	18	1	0	0	0.9444	0.2011
15	3 May-9 May	17	0	0	0	1.0000	0.2011
16	10 May-16 May	17	0	0	0	1.0000	0.2011
17	17 May-23 May	17	1	0	0	0.9412	0.1893
18	24 May-30 May	16	0	0	0	1.0000	0.1893
19	31 May- 6 June	16	1	0	0	0.9375	0.1775
20	7 June-13 June	15	1	0	0	0.9333	0.1656
21	14 June-20 June	14	0	0	0	1.0000	0.1656
Totals			53	12	55		0.1656

Table A.1: Kaplan-Meier survival estimates, modified for staggered entry of 79 radio-collared snowshoe hares released in Geauga and Ashtabula Counties, Ohio during 26 January-20 June, 2000.

Week	Dates	No. at Risk	No. Deaths	No. Censored	No. Added	Weekly Survival	Cumulative Survival
1	24 Jan-30 Jan	23	7	1	25	0.6818	0.6818
2	31 Jan-6 Feb	40	6	1	0	0.8462	0.5769
3	7 Feb-13 Feb	33	1	0	19	0.9697	0.5594
4	14 Feb-20 Feb	51	2	1	0	0.9600	0.5371
5	21 Feb-27 Feb	48	1	1	14	0.9787	0.5256
6	28 Feb-6 Mar	60	3	3	0	0.9474	0.4980
7	7 Mar-13 Mar	54	4	1	0	0.9245	0.4604
8	14 Mar-20 Mar	49	3	2	0	0.9362	0.4310
9	21 Mar-27 Mar	44	0	1	0	1.0000	0.4310
10	28 Mar-3 April	43	4	0	0	0.9070	0.3909
11	4 April-10 April	39	1	0	0	0.9744	0.3809
12	11 April-17 April	38	2	0	0	0.9474	0.3608
13	18 April-24 April	36	2	0	0	0.9444	0.3408
14	25 April-1 May	34	1	0	0	0.9706	0.3308
15	2 May-8 May	33	1	0	0	0.9697	0.3207
16	9 May-15 May	32	0	0	0	1.0000	0.3207
17	16 May-22 May	32	0	1	0	1.0000	0.3207
18	23 May-29 May	31	0	0	0	1.0000	0.3207
19	30 May-5 June	31	0	0	0	1.0000	0.3207
20	6 June-12 June	31	1	0	0	0.9677	0.3104
21	13 June-19 June	30	0	0	0	1.0000	0.3104
			39	12	58		0.3104

Table A.2: Kaplan-Meier survival estimates, modified for staggered entry of 81 radio-collared snowshoe hares released in Geauga and Ashtabula Counties, Ohio during 24 January-19 June, 2001.

Release Site	Habitat Type	No. Released Without Radios		No. Released With Radios		Radioed Hare Mortalities		Censored Radios	Apparent Survival
		Males	Females	Males	Females	Males	Females		
North 1	Mixed Forest	4	4	4	5	4	3	2	0.00
North 2	Wetland Forest	4	4	4	5	1	5	0	0.40
North 3	Regeneration	4	4	4	5	2	4	0	0.33
North 4	Upland Forest	1	4	5	4	3	3	2	0.14
South 1	Wetland Forest	4	3	5	6	3	3	1	0.40
South 2	Mixed Forest	3	5	5	6	3	4	2	0.22
South 3	Regeneration	4	4	6	4	5	3	1	0.11
South 4	Upland Forest	3	4	6	5	4	3	4	0.00
2000 Totals		27	32	39	40	25	28	12	0.21

Table A.3: Numbers and fates of snowshoe hares released on 8 sites in northeastern Geauga and southwestern Ashtabula Counties, Ohio, during winter 2000. Apparent survival was determined after each release during 26 January-20 June, 2000.

Release Site	Habitat Type	No. Released Without Radios		No. Released With Radios		Radioed Hare Mortalities		Censored Radios	Apparent Survival
		Males	Females	Males	Females	Males	Females		
North 1	Mixed Forest	0	0	5	5	3	2	2	0.38
North 2	Wetland Forest	0	0	5	5	3	2	2	0.38
North 3	Regeneration	2	1	6	3	2	2	1	0.50
North 4	Upland Forest	0	0	5	5	3	3	1	0.33
South 1	Wetland Forest	1	0	5	5	0	3	2	0.62
South 2	Mixed Forest	2	1	6	5	5	1	0	0.45
South 3	Regeneration	2	2	6	5	4	2	0	0.45
South 4	Upland Forest	1	1	6	4	1	3	4	0.33
2001 Totals		8	5	44	37	21	18	12	0.43

Table A.4: Numbers and fates of snowshoe hares released on 8 sites in northeastern Geauga and southwestern Ashtabula Counties, Ohio, during winter 2001. Apparent survival was determined after each release during 24 January-19 June, 2001.

APPENDIX B

Live-trapping Table

Season	Date	Tag No.	Sex	Location	Weight (g)	Condition[a] Index	Breeding[b] Status
spring 2000	5/6/00	035/035	M	N3/N4	1,840	0.0888	None
spring 2000	5/13/00	035/035	M	N3/N4	2,060	0.0909	Active
spring 2000	5/24/00	133/133	M	N3/N4	1,120	0.0781	Active
spring 2000	5/30/00	133/133	M	N3/N4	1,130	0.0783	Active
spring 2000	6/2/00	046/046	M	S2	1,370	0.0854	Active
spring 2000	6/5/00	673/673	M	N3	1,250	0.081	Active
spring 2000	6/7/00	086/086	F	S2	1,710	0.0906	None
spring 2000	6/7/00	026/026	M	N3	1,790	0.0861	Active
winter 2000	12/27/00	001/002	M	N3/N3b	1,430	0.0854	None
winter 2000	12/30/00	001/002	M	N3/N3b	1,400	0.0847	None
winter 2000	1/4/00	001/002	M	N3/N3b	1,380	0.0843	None
winter 2000	1/8/00	001/002	M	N3/N3b	1,340	0.0835	None
winter 2000	1/9/00	001/002	M	N3/N3b	1,270	0.082	None
winter 2000	1/10/00	001/002	M	N3/N3b	1,100	0.0782	None
winter 2000	12/28/00	003/004	M	N3/N3b	1,560	0.084	Juvenile
winter 2000	12/29/00	005/006	M	N3/N3b	1,680	0.0826	None
winter 2000	12/30/00	005/006	M	N3/N3b	1,670	0.0824	None
winter 2000	1/3/00	005/006	M	N3/N3b	1,680	0.0826	None
winter 2000	1/4/00	005/006	M	N3/N3b	1,640	0.0819	None
winter 2000	1/5/00	005/006	M	N3/N3b	1,620	0.0816	None
winter 2000	1/10/00	005/006	M	N3/N3b	1,630	0.0817	None
winter 2000	12/30/00	007/008	F	N3/N3b	1,590	0.0834	None
winter 2000	1/3/00	007/008	F	N3/N3b	1,600	0.0835	None
winter 2000	1/4/00	007/008	F	N3/N3b	1,580	0.0832	None
winter 2000	1/5/00	007/008	F	N3/N3b	1,570	0.083	None
winter 2000	1/8/00	007/008	F	N3/N3b	1,580	0.0832	None

Table B.1: Physical characteristics and breeding status of 16 snowshoe hares captured in Geauga and Ashtabula Counties, Ohio during 2000 and 2001.

(Continued)

Table B.1: Continued

Season	Date	Tag No.	Sex	Location	Weight (g)	Condition[a] Index	Breeding[b] Status
spring 2001	5/2/01	417/418	F	S1	1,685	0.0901	Pregnant
spring 2001	5/8/01	449/450	M	S1	1,315	0.0829	None
spring 2001	6/7/01	449/450	M	S1	1,300	0.0827	Active
spring 2001	6/13/01	449/450	M	S1	1,310	0.0829	Active
spring 2001	5/18/01	435/436	F	S3	1,965	0.0928	Pregnant
spring 2001	5/19/01	435/436	F	S3	1,970	0.0928	Pregnant
spring 2001	5/18/01	439/440	M	S3	1,370	0.0888	Active
spring 2001	5/19/01	2016/2309	F	S3	1,630	0.0885	None
spring 2001	5/31/01	469/470	M	N3	1,300	0.0839	Active

[a] Condition index ($\sqrt[3]{\text{total weight}}$/hind-foot length) used to evaluate physical condition of snowshoe hares (Brand et al. 1975).

[b] Testicular activity indicated by fully descended testes swollen >20 mm in length (Bookhout 1965*a*).