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ECOLOGY OF COMMON RACCOON (*Procyon lotor*) IN WESTERN PENNSYLVANIA AS RELATED TO AN ORAL RABIES VACCINATION PROGRAM

A Thesis in

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by

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ABSTRACT

Since the mid-1980s, the common raccoon (*Procyon lotor*) has been responsible for the most intensive rabies outbreak in U.S. history. In response to this outbreak, the United States Department of Agriculture (USDA), Animal and Plant Health Inspection Services (APHIS) developed the Oral Rabies Vaccination (ORV) program. The ORV program was launched with the goal of developing a national control effort that positively impacts human and domestic rabies prevention and control. The multi-year program has the primary goal of creating zones of vaccinated animals along the leading boundaries of the epizootics, thereby halting the spread of the rabies virus.

The ORV program was initiated in Pennsylvania in 2001, with the primary objective of halting the westward expansion of raccoon rabies and secondarily reducing the incidence of rabies and eventually eliminate raccoon rabies throughout the state. The western front of the current rabies outbreak in Pennsylvania provides a unique opportunity to investigate raccoon ecology. An understanding of home ranges of and habitat use by raccoons among different landscapes has become important as rabies developed into an enzootic throughout the mid-Atlantic. The objectives of this study are to (1) identify sizes of home ranges and core areas among 3 landscapes (rural, forested, and suburban), (2) identify landscape differences regarding raccoon habitat use selection at the home-range and core-area scale, and (3) create raccoon resource selection function (RSF) models that are landscape specific.

I monitored radio-collared raccoons from May through early January 2003–2006 in 3 western Pennsylvania counties. I recorded 5,920 locations for 74 (24 female and 50 male) adult radio-collared raccoons, which include 4,703 nocturnal locations (1,223 rural, 1,531 forested, and 1,949 suburban) and 1,217 diurnal locations (339 rural, 397 forested, and 481 suburban). Additional information was recorded from 738 trapped raccoons captured in 6 western Pennsylvania counties (2003–2006) for a secondary study on the public health significance of asymptomatic *Salmonella* serovar infections in raccoons.

A significant 3-way interaction was found for raccoon den type use among sex, den type, and landscape ($G^2 = 391.52$, df = 22, $P \leq 0.0001$), with den type differing by sex ($G^2 = 115.22$, df = 4, $P \leq 0.0001$) and landscape ($G^2 = 270.66$, df = 8, $P \leq 0.0001$). Female raccoons used tree dens more often than males. Males used ground dens and human structures much more frequently than females.

Mean sizes of home ranges and core areas of raccoons did not differ between males and females within the same landscapes (rural: $t = 0.81$, df = 15, $P = 0.433$; forested: $t = 0.12$, df = 17, $P = 0.906$; and suburban: $t = 0.36$, df = 12, $P = 0.72$). As urbanization increased from forested to suburban landscapes, sizes of mean home ranges decreased; however, sizes of core areas did follow a decreasing trend. Male and female raccoons in forested landscapes had significantly larger mean home ranges and core areas than those of male and female raccoons in either rural or suburban landscapes. However, size of core areas for male and female raccoons in rural landscapes did not differ between those of male and female raccoons in suburban landscapes. Differences in seasonal sizes of home ranges were observed only in male raccoons within rural landscapes ($t = 2.45$, df = 20, $P = 0.024$).

Raccoons within rural, forested, and suburban landscapes (home ranges: $\chi^2 \geq 219.5$, df = 5-7, $P \leq 0.001$; and core areas: $\chi^2 \geq 137.8$, df = 5-7, $P \leq 0.001$) used home-range and core-area habitats disproportionately to their availability. Habitat use by raccoons differed among landscapes, with different habitat types being selected within the 3 landscapes.

Accurate predictive models are needed to provide quantitative measures of raccoon distribution on the front of the ORV zone. My research developed landscape specific RSF models that are valuable for quantifying the probability of a raccoon inhabiting an area of interest. Using logistic regression, radiotelemetry locations, geographic information system (GIS) software, and habitat types, I derived study-site probability maps of raccoon occurrence. The RSF models provide the spatial-probability distribution (likelihood of being in an area) of an adult raccoon and can be visualized and made functional within a GIS.

My secondary study isolated *Salmonella enterica* serovars from 6 western Pennsylvania counties examined. Ten serovars were identified, with approximately 7.4% of all raccoon samples being positive. Pulse field gel electrophoresis analysis revealed 13 unique *Salmonella enterica* serovar isolate profiles.

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Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;

Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that, the passing there
Had worn them really about the same,

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept the first for another day!
Yet knowing how way leads on to way,
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I—
I took the one less traveled by,
And that has made all the difference.

-The Road Not Taken
By: Robert Frost

Chapter 1

INTRODUCTION

Zoonotic Diseases

Zoonoses are diseases and infections that are naturally transmitted between vertebrate animals and humans, which have the potential to negatively impact humans (WHO 1957). For example, diseases can have major negative consequences for humans by affecting the food we eat and the income derived from agricultural production. With an ever-increasing human population, interactions between wildlife and people are becoming more commonplace, especially with urban-related species, such as common raccoons (*Procyon lotor*).

Of the 1,415 known catalogued diseases of humans, more than 62% have a zoonotic (vertebrate) origin (Cleaveland et al. 2001). Outbreaks of zoonotic diseases emerge when new or known microorganisms occur in areas in which the disease previously was unknown (Burroughs et al. 2002). Additional factors, such as climate, technology, land use, and human behavior, can converge in a manner favorable to the emergence of zoonotic diseases.

Raccoon Rabies

Rabies is an acute, fatal, viral zoonotic disease that can be found in all mammals (Krebs et al. 2000) and is transmitted most often by the bite of an infected animal. Rabies in raccoons virtually was unknown before the 1950s (CDC 2001). Raccoon rabies was first described in Florida in 1954 and spread slowly during the next 3 decades into Georgia, Alabama, and South Carolina. In Virginia, during the late 1970s, raccoon rabies, a previously geographically unknown disease in the mid-Atlantic, emerged as rabid raccoons were translocated from Florida to Virginia, initiating an outbreak in the mid-Atlantic states (Winkler and Jenkins 1991, Childs et al. 2001). By the late 1980s, reports of raccoon rabies surpassed all other rabies wildlife vectors in the mid-Atlantic states (Rupprecht and Smith 1994). Since then, raccoon rabies developed to form the most intensive rabies outbreak (a sudden rise in the incidence of a disease) in U.S. history.

The virus moved along the eastern side of the Appalachian Mountains into Pennsylvania, Maryland, and West Virginia until it breached the Appalachian front in the late 1980s and spread throughout Pennsylvania in eastward and northward directions (Moore 1999). In the past 21 years, all mid-Atlantic and New England states have experienced at least 1 outbreak of raccoon strain rabies (Winkler and Jenkins 1991). In 1999, the initial 3 cases of raccoon rabies were confirmed in southern Ontario; in 2000, 13 positive cases were reported in Charlotte County of New Brunswick (Rosattee et al. 2001). Raccoon rabies currently has a continuous distribution east of the Appalachian Mountains, from Maine to Florida, and it is beginning to spread west into eastern Ohio (Moore 1999). The rabies epizootic (epidemic in animals) has the potential to spread throughout the United States (CDC 2001, Childs et al. 2001).

Rabies has been preventable and treatable in humans since Pasteur developed a prophylaxis vaccination in the late 1880s (Baer 1991). Domestic pet vaccination, stray animal control, and public health education greatly reduced the occurrence of rabies in domestic animals by the early 1960s in the United States (Hoffman and Gottschang 1977). In particular, pet vaccinations have been effective in breaking the chain of rabies transmission from domestic animal species to humans; however, abundant and widely distributed wildlife make it difficult to control the rabies virus.

Rabies Public Health Impacts

Estimates of the costs of rabies prevention in the United States are from $230 million to $1 billion per year (Fishbein and Arcangeli 1987, Uhaa et al. 1992, Rupprecht et al. 1995). Prevention-related costs are vaccination of companion animals and public funding of animal control programs, such as the Oral Rabies Vaccination (ORV) program, rabies diagnostic laboratories, and rabies postexposure treatment (Rupprecht et al. 1995). Approximately 20,000 people per year in the United States receive postexposure treatment for contact with wildlife, which exceeds $1,000 per person (Rupprecht et al. 1995).

Oral Rabies Vaccination Program

The ORV program was established in the United States in 1995 by the United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS), and the Centers for Disease Control and Prevention (CDC). Texas was the first state to initiate an active program in 1995; 15 other state (Alabama, Arizona, Florida, Maine, Maryland, Massachusetts, New Hampshire, New York, Ohio, Pennsylvania, Tennessee, Vermont, Virginia, West Virginia, and Wyoming) authorities and health officials have since established programs since 1995. The ORV effort was launched with the goal of developing a national control strategy that positively impacts human and domestic rabies prevention and control. The multi-year program has the primary goal of creating zones of vaccinated animals along the leading boundaries of the epizootics, thereby halting the spread of the rabies virus.

The Pennsylvania Department of Health, USDA, APHIS, and WS initiated the ORV program in Pennsylvania in 2001 (Fig. 1). Wildlife Services provided wildlife management leadership and the major source of cooperative funding. The Pennsylvania Game Commission, Pennsylvania Department of Agriculture, Allegheny County Health Department, Erie County Department of Health, The Pennsylvania State University, and the CDC provided additional logistical support. The primary objective of the ORV program in Pennsylvania is to halt the westward expansion of raccoon rabies and secondarily to reduce the incidence of rabies and eliminate raccoon rabies throughout the state (USDA WS 2001).

Raccoon Rabies in Pennsylvania

Raccoon rabies was documented in Bedford, Fulton, and Franklin Counties in 1982 (Wampler 2002). The virus then spread eastward and northward, with the greatest density of cases in the south central part of Pennsylvania (Moore 1999). It became enzootic (prevalent among animals of a specific geographic area) throughout the Commonwealth by 1994 (Wampler 2002). Four years later, 488 raccoons in Pennsylvania tested positive for rabies. Currently, more than 58% of the positive annual rabies cases in Pennsylvania are raccoons, with the other 42% of the cases of rabies being in striped skunk (*Mephitis mephitis*), bats (Vespertilionidae species), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), and feral cats (*Felis catus*).

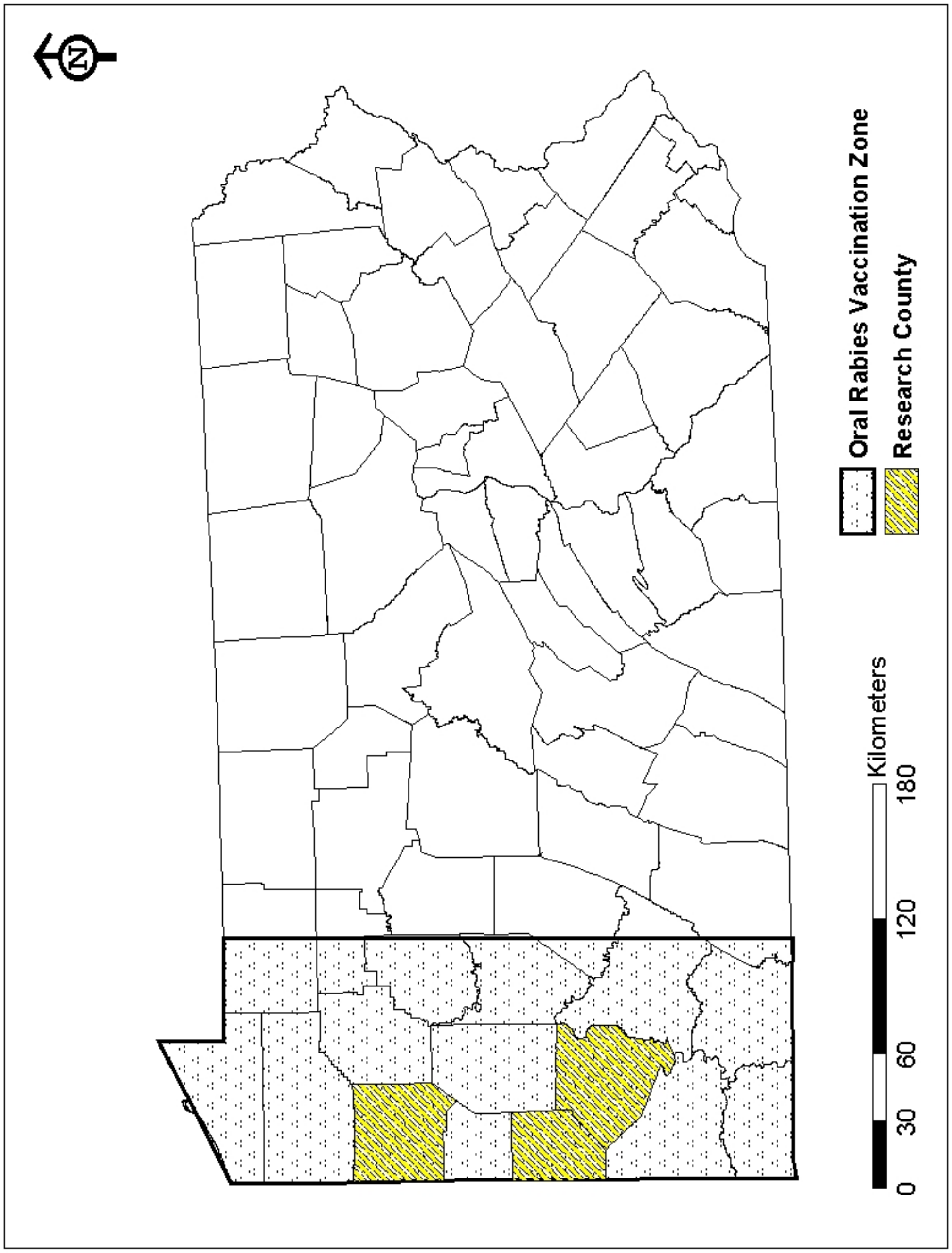

Fig. 1. The Oral Rabies Vaccination Zone in western Pennsylvania and the 3 study counties (Allegheny, Beaver, and Mercer), 2003–2006.

Raccoon Ecology

Raccoons are abundant and widely distributed in Pennsylvania, occupying agricultural areas, heavily wooded uplands, and urban areas (Wilson and Ruff 1999). Greatest raccoon densities are found in urban and suburban environments (Winkler and Jenkins 1991). Adaptation of raccoons to suburban environments may alter their population demographics as well as their behavior compared with populations of the same species occurring in forested or rural environments (McClennen et al. 2001, Gehring and Swihart 2003, Prange et al. 2003). Raccoons in suburban areas are a source for concern because of the potential for wildlife–human conflicts (Flyger et al. 1983, DeStefano and DeGraaf 2003). Raccoons have been successful in surviving in suburban areas and are considered a nuisance species (unwanted in a particular area for fear of property damage or physical harm) in many cities, causing injuries to people or pets that require medical or veterinarian attention (deAlmeida 1987, DeStefano and DeGraaf 2003).

Raccoons have expanded their natural range in the United States (Sutton 1964) and have been transplanted successfully to different parts of the world (Scheffer 1947, McKinley 1959, Aliev and Sanderson 1966). A much greater threat is health hazards associated with raccoons in suburban environments because they are capable of transmitting numerous diseases (e.g., rabies), parasites (e.g., *Baylisascaris procyonis*), and bacteria (e.g., *Salmonella enterica* serovars) to humans and domestic animals (Chamberlain et al. 1982, Kaufman 1982, Page et al. 1998).

Research Rationale

An understanding of sizes of home ranges of raccoons and their habitat use has become important as raccoon rabies developed into an enzootic throughout the mid-Atlantic region. Studies examining home ranges and habitat use of raccoons have been conducted throughout midwestern and southern United States (Greenwood 1981, Mosillo et al. 1999, Chamberlain et al. 2003), but this basic ecological knowledge is lacking for the mid-Atlantic region. Western Pennsylvania provided an opportunity to investigate raccoon ecology as related to landscapes, with the goal of aiding the ORV program in combating raccoon rabies.

The objectives of this study are to (1) identify sizes of home ranges and core areas among 3 landscapes (rural, forested, and suburban), (2) identify landscape differences regarding raccoon habitat use selection at the home-range and core-area scale, and (3) create raccoon resource selection function (RSF) models that are landscape specific.

My research examined sizes of raccoon home ranges and core areas within 3 landscape types (rural, forested, and suburban). Most animals live in limited areas termed home ranges, which has been defined as the area traversed by the animal in its normal activities of foraging, breeding, and caring for young (Burt 1943).

Through my research, I also examined habitat use at different spatial scales. I examined home-range (2^{nd}-order) and core-area (3^{rd}-order) selection processes of raccoons within 3 landscape types (rural, forested, and suburban) (Johnson 1980). Geographic range (1^{st}-order) is the study site, whereas the 2^{nd}-order selection determines the placement of the home range within that geographical region. Thirdorder selection examines the use made of various habitat components within the home range.

My research developed raccoon probability models of habitat use among 3 landscape types (rural, forested, and suburban). The process of building models has grown with the science of landscape ecology and has benefited from development of geographic information systems (GIS). I developed landscape-specific resource-selection function (RSF) models (Manly et al. 2002) that will contribute to the general body of knowledge describing raccoon ecology as well as help in meeting the objectives of the Pennsylvania ORV program.

Resource-selection functions coupled with predictive maps are practical tools, which APHIS WS can use for illustrating changes in habitat selection patterns by raccoons among the 3 distinct landscapes in western Pennsylvania. Predictive maps suggest levels of raccoon use across a landscape, which then can be directly integrated into ORV management practices. The ability to visualize habitat use across a site can be a powerful tool because it assists in understanding habitat use by raccoons with respect to other spatially placed habitats.

My study of raccoons in rural, forested, and suburban landscapes provides a more conclusive link between landscape differences and ecology of raccoons in these areas. This knowledge will assist in helping halt the westward expansion of raccoon rabies and secondarily to reduce incidences of rabies and eventually eliminate raccoon rabies throughout the state by providing information on raccoon ecology that can be implemented into future ORV management practices.

***Salmonella* Research**

A secondary study on the public health significance of asymptomatic *Salmonella* infection in raccoons also was performed. Serovars (group of closely related microorganisms distinguished by a characteristic set of antigens) of *Salmonella enterica* are zoonotic bacteria that cause significant public health and economic concerns (Smith et al. 2002). Many animal species carry *Salmonella enterica* serovars, including mammals, birds, reptiles, and humans (Handeland et al. 2002, Smith et al. 2002, Bonnedahl et al. 2005). The same strains of *Salmonella* have been isolated from humans and wildlife species, suggesting that wildlife may serve as a reservoir for *Salmonella* infections in humans (Bonnedahl et al. 2005).

Host susceptibility, varying pathogenicity of *Salmonella* serovars, and differences in immunity can influence the disease potential of *Salmonella* in humans and wildlife (Kapperud et al. 1998). The most common mode of transmission is through fecal-to-oral contact, either directly or indirectly by contact with contaminated surfaces (Kapperud et al. 1998). Animals may be asymptomatic intermittent dispersers of *Salmonella* serovars, or they may show clinical signs, such as diarrhea or fever and may even die (Jahraus and Philips 1999). The prevalence of *Salmonella* in most wild animal populations is unknown due to their difficult access, making sampling individual animals for epidemiologic studies a challenge.

In recent years, problems related to *Salmonella* have increased appreciably, both in terms of incidence and severity of human cases (Heir et al. 2002). Studies, such as the present study, help identify sources of contamination in the wild and are extremely important. The same serovar found in multiple animals or in wildlife from the same location suggests a point source of contamination. Identification of a point source may allow development of a plan to manage and minimize ongoing environmental contamination. Routine monitoring of *Salmonella* in wildlife can lead to a better understanding of patterns of transmission and epidemiology of *Salmonella* in wildlife and humans.

Salmonella serovars have been isolated from species of free-living and captive mammals, with a major emphasis being placed on studies of animals with close association to humans (Kapperud et al. 1998, Aabo et al. 2002, Handeland et al. 2002). This study reports the prevalence of infections of *Salmonella enterica* in raccoons in western Pennsylvania from 2003 to 2006.

Chapter 2

STUDY SITES

Mercer, Beaver, and Allegheny Counties in Pennsylvania provide ideal study sites for understanding landscape effects on raccoon ecology. The 3 study sites chosen in my research were established by APHIS WS personnel as representative landscapes (rural, forested, and suburban) existing on the western front of the rabies epizootic. These landscapes are representative of those within the whole of Pennsylvania and the larger mid-Atlantic region. Land-use types within the landscapes for the study sites were quantified by percentages of each type of land use within the site (agricultural, commercial, forested, open space, and residential) (Table 1). I defined and determined land-use type from the Pennsylvania Spatial Data Access (Office for Remote Sensing of Earth Resources, Penn State, 2000).

Western Pennsylvania provides a unique opportunity to investigate raccoon ecology as part of an effort to meet the objectives of the Pennsylvania ORV program. The program objectives are to halt the westward expansion of raccoon rabies and to reduce the incidence of rabies and eventually eliminate raccoon rabies in the state.

Regional Environmental Conditions

Pennsylvania landscapes are extremely varied because of their geology (Shultz 2002) and encompass 7 physiographic provinces (Fig. 2). My research was

Table 1. Percentages of land-use types in Mercer County, Beaver County, and Allegheny County study sites of western Pennsylvania (Office for Remote Sensing of Earth Resources, Penn State, 2000).

	Study Sites (%)		
Land-use type	Mercer County (rural)	Beaver County (forested)	Allegheny County (suburban)
Agricultural	50	27	15
Commercial	3	4	20
Forested	24	45	12
Open space (including water and coal fields)	16	15	15
Residential	7	9	38

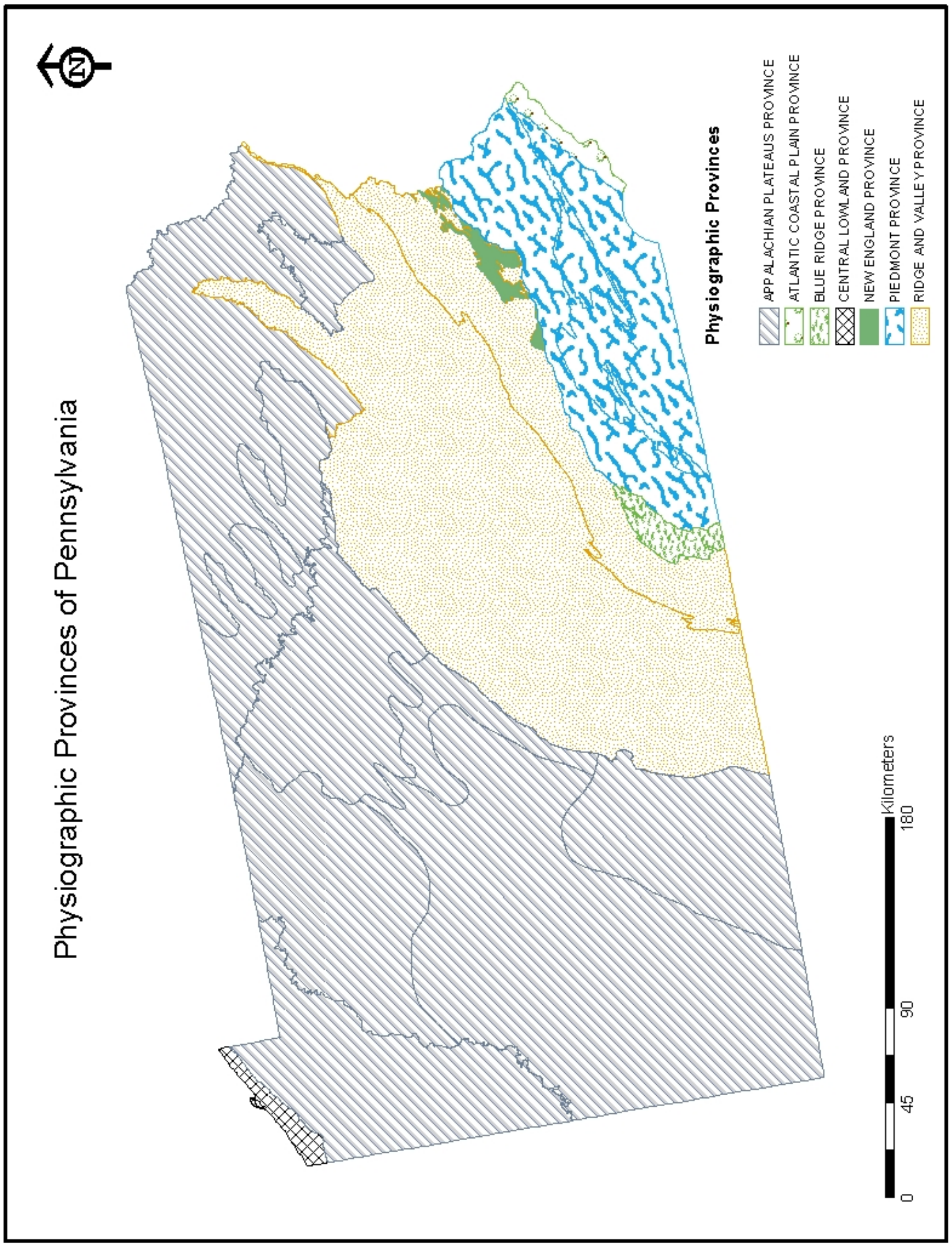

Fig. 2. Seven physiographic provinces of Pennsylvania. My research was conducted in the Appalachian Plateaus Province, which includes approximately 60% of the state (Office for Remote Sensing of Earth Resources 2000).

conducted in the Appalachian Plateaus Province, which includes roughly 60% of the state (Shultz 2002). This province has the highest mean elevation (≥370 m), the highest point (Mount Davis, 979 m) and the greatest general relief (120–550 m) in the state. Bedrock in the west is mainly subhorizontal coal-bearing Pennsylvanian strata, with sequences of sandstone, red and gray shale, conglomerate, clay, and limestone (Shultz 2002).

Pennsylvania generally is considered to have a humid continental climate, characterized by large annual ranges in temperature and precipitation (U.S. NOAA 1977). The climate is not entirely continental, however, because of influences from the Great Lakes, the Atlantic Ocean, and the diversity of physiographic features within the state (U.S. NOAA 1977). The Appalachian Mountains and the Great Lakes are the 2 major influences on the climate of the Pennsylvania (Shultz 2002). Most weather disturbances that affect Pennsylvania are carried from the interior of the continent by prevailing westerly winds (U.S. NOAA 1977).

Temperatures across the state normally are between –17 and 37°C and average from 6°C in the north central mountains to 13°C in southeastern Pennsylvania (U.S. NOAA 1977). Ranges of daily temperature from maximum to minimum are commonly about 10°C during summer and are a few degrees less during winter. During the warmest month (July), high temperatures range from 20–24°C in northern areas to 26–29°C in the southern areas. During the coldest month (January), the state experiences low temperatures between –10 and –7°C and high temperatures between –4 and 1°C.

Precipitation in Pennsylvania is evenly distributed spatially, with the maximum amount occurring in the late spring or early summer, primarily from thunderstorms (U.S. NOAA 1977). Annual amounts of precipitation in Pennsylvania normally range from 86 to 130 cm. Precipitation tends to be greater in the eastern areas because of oceanic influences. Prevailing westerly winds cause a secondary precipitation maximum on the western slopes of the Allegheny Mountain section of the Appalachian Plateaus Province in western Pennsylvania (Daily 1971). The average annual snowfall ranges from 58 cm in southeastern Pennsylvania to more than 203 cm in northwestern and northeastern Pennsylvania. Most snow occurs from November to April, with the greatest snowfall occurring in December and January (Daily 1971). The western 3rd of watersheds in Pennsylvania largely drains to the Gulf of Mexico via the Monongahela, Allegheny, and Ohio Rivers (Shultz 2002).

Rural Site—Mercer County

Agriculture is the primary industry in Pennsylvania, and Mercer County is among the most agriculturally productive counties in the state (USDA National Agricultural Statistics Service 2002). In 2002, Mercer County had 1,239 active farms, with 82,174 ha in cropland (USDA National Agricultural Statistics Service 2002). Another 22,314 ha of cropland is used for other purposes, such as grazing. The average farm size in Mercer County is 89 ha, with most farms being privately owned and operated (USDA National Agricultural Statistics Service 2002). The 2 most productive crops in the county are corn (*Zea mays*) and hay (hay, grass silage, and greenchop) (USDA National Agricultural Statistics Service 2002). Corn production accounts for 24,602 ha and a yield of 62,585 dry tons, whereas hay crops account for

38,331 ha and a yield of 98,917 dry tons (USDA National Agricultural Statistics Service 2002). Other frequently planted crops are wheat (*Triticum aestivum*), oat (*Avena fatua*), soybean (*Glycine max*), and sorghum (*Sorghum bicolor*).

In the rural study sites, fencerows, composed of several rows of trees with an understory vegetative layer, separate adjacent fields and crops. They also provide nesting cover and serve as wildlife corridors (Bowman and Fahrig 2002, Goheen et al. 2003). In addition to agricultural fields, other habitat types in the rural study site include riparian zones, marshes, and coniferous and deciduous forested stands. Northern red oak (*Quercus rubra*), white oak (*Q. alba*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), American beech (*Fagus grandifolia*), basswood (*Tilia americana*), eastern white pine (*Pinus strobus*), red pine (*P. resinosa*), and white ash (*Fraxinus americana*) dominate the woody habitats, with southern arrow-wood (*Viburnum dentatum*), winterberry (*Ilex verticillata*), and highbush blueberry (*Vaccinium corymbosum*) being common understory vegetation (Western Pennsylvania Conservancy 2003).

Forested Site—Beaver County

All forested land in Beaver County was previously cut and is now covered by regenerated 2^{nd}-growth and 3^{rd}-growth woodlands (Western Pennsylvania Conservancy1993). Many trees within the woodlands are mature and timber harvesting is occurring in numerous places (Western Pennsylvania Conservancy 1993). Mining for clay, sand, gravel, and coal continues to be an important land-use activity in the county. Reclaimed bituminous coal fields are present throughout the landscape. Reclamation conducted on surface mine operations have established early successional vegetative cover that is dominated by fescue (*Fescue* spp.) and clover (*Trifolium* spp.).

The topography in Beaver County is uneven, largely as the result of 2 deep, broad valleys that have been carved by the Ohio and Beaver rivers (Shultz 2002). In addition to the 2 broad river valleys, many streams associated with narrower valleys and bottomlands are present, such as Raccoon Creek, Little Beaver Creek, the North Fork of Little Beaver Creek, and Connoquenessing Creek (Western Pennsylvania Conservancy 1993).

Approximately 135 km^2 of the northwest portion of the county was glaciated during the late Pleistocene period (Welchley 1989). This glaciation resulted in flat-to-uneven terrain, with many low rounded hills and long ridges (Shultz 2002). In addition, scattered, poorly drained depressions are common. As a result of glacial activity, the county is covered with glacial till, sandy, and gravelly outwash lacustrine material (Smith 1982).

Beaver County exhibits a diversity of vegetation species across the landscape; in part, because of the varied physiography, bedrock, and soils of the region (Western Pennsylvania Conservancy 1993). The forest cover type is dominated by northern red oak, white oak, black oak (*Q. velutina)*, eastern white pine, and red pine. Other common tree species are sugar maple, red maple, American beech, pitch pine (*P. rigida*), chestnut oak (*Q. montana*), blackgum (*Nyssa sylvatica*), hickories (*Carya* spp.), and white ash.

Suburban Site—Allegheny County

Mineral extraction is a major land use activity in Allegheny County (Western Pennsylvania Conservancy 1994). Floodplains and bottomlands along the major rivers (Monongahela, Allegheny, and Ohio) have served as building places for large industry (e.g., steel mills, energy generating plants, and refining plants). In addition, these areas are locations for large cities and towns in Allegheny County. Some of the most unique natural lands that once existed along these rivers have been destroyed by development.

Clearing land for industrial, commercial, and residential development as well as strip mining permanently altered the land and vegetation in this county (Western Pennsylvania Conservancy 1994). The suburban sites in my research are dominated by residential housing, commercial buildings, and industrial parks. The forested portions of the suburban site are dominated by sugar maple, northern red oak, white oak, hickories, American beech, basswood, and white ash.

Salmonella Sites

Salmonella sampling took place in Allegheny, Armstrong, Erie, Greene, Mercer, and Westmoreland Counties in western Pennsylvania. The 6 counties were determined by APHIS Wildlife Service personnel as representative landscapes (rural: Mercer; forested: Armstrong, Greene, Westmoreland; and suburban: Allegheny, Erie), existing on the western front of the rabies epizootic (Fig. 3). Study site land-use and vegetation types are similar to previous descriptions given for rural, forested, and suburban landscapes.

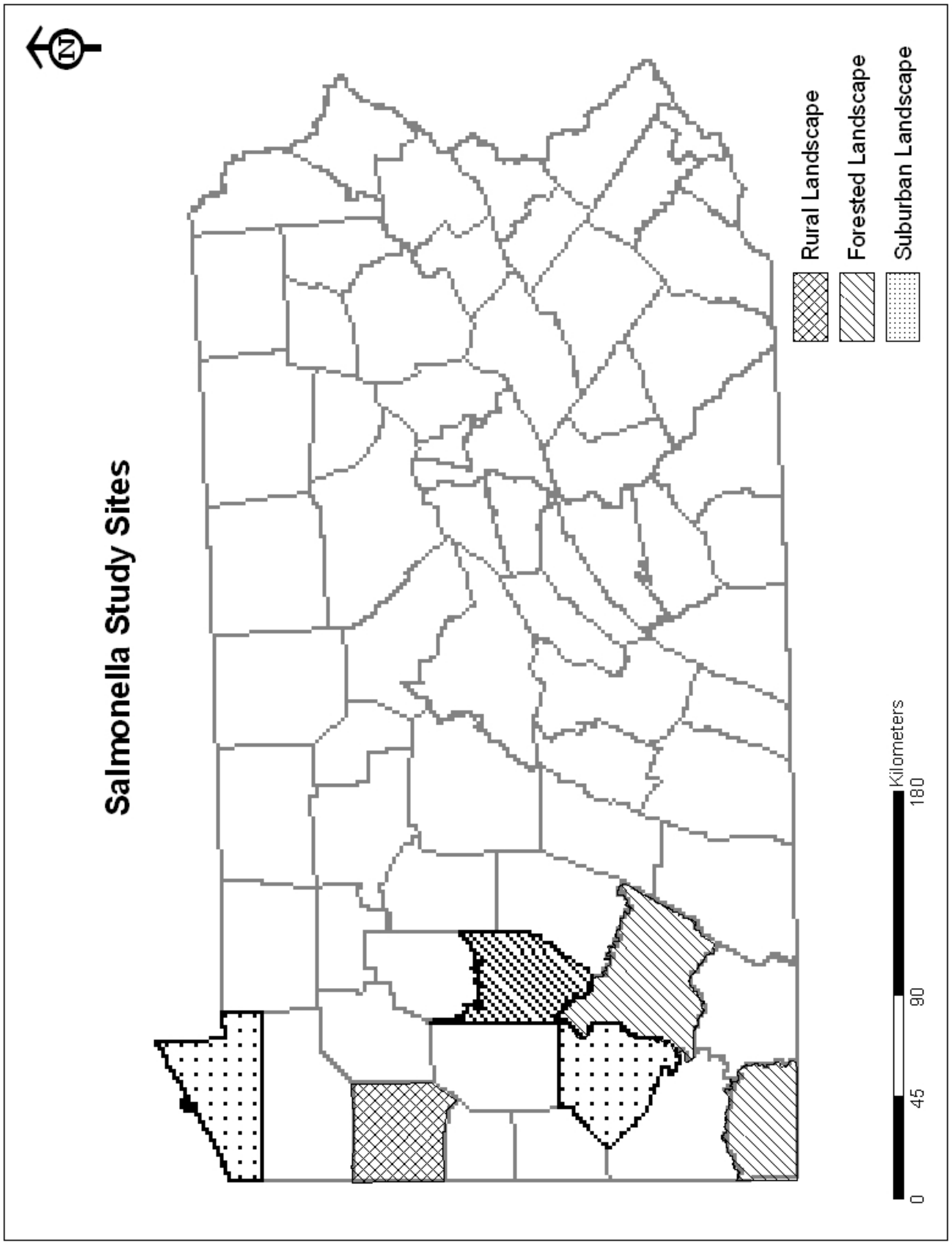

Fig. 3. *Salmonella* study sites in 3 landscapes in western Pennsylvania, 2003–2006.

Chapter 3

METHODS

Trapping Protocol

I conducted raccoon trapping along with APHIS Wildlife Service personnel from May to August in summers 2003, 2004, and 2005. A square-to-rectangular size trapping area was established representative of the landscape (rural, forested, and suburban) as determined by APHIS WS personnel. When achievable, study sites were placed in areas where a 3-km buffer area of similar landscape was present outside of the study site.

We set 50 live traps (Havahart, Woodstream Inc., Lilitz, PA) throughout (i.e., non-uniform distribution in order to maximize raccoon captures) the study site at locations likely to capture raccoons as determined by APHIS WS personnel. Traps were baited with a combination of marshmallows and oil of anise and set for 10 consecutive nights, giving 500 trap nights per site. Traps were checked every morning during the trapping period. To maximize captures and provide a consistent sampling approach, traps in which an unmarked raccoon was not captured in 2–4 days were moved to a new location, which was a minimum of 30 m away. If unmarked raccoons were continually captured in a trap, it was not moved until no unmarked raccoons were trapped during the 2–4-day interval. This approach resulted in more complete trap coverage of the study area. On average, we moved each trap twice during the trapping schedule.

Raccoons were anesthetized using a ketamine-xylazine immobilization drug that was administered by APHIS WS personnel. Anesthetized animals were weighed (kg), sexed, aged, and ear-tagged, and the first premolar was pulled. Fecal, hair, and blood samples also were taken from each raccoon. Additionally, general condition, such as injuries, presence of external parasites, and condition of teeth and digits, was noted. Current injuries were examined closely to determine whether they were trap related.

After all examinations were completed by APHIS WS personnel, I fitted a number of adult male (n = 57) and female (n = 32) raccoons with radio-collars (model M2200; Advanced Telemetry Systems, Isanti, MN). Raccoons ≥18 months of age were considered adults and independent from their mother (Gehrt 1994). I attached collars in the field by using prepunched holes that were designed to accommodate a range of raccoon neck sizes. A radio-collar should fit snugly to prevent it from coming off or chafing the animal as it moves, but it also must be sufficiently loose as to be comfortable and not interfere with swallowing or other actions and movements.

To achieve the best fit on raccoons with the collars, I used the general “2-finger” rule (ILMB 1998). The 2-finger rule allows me to place my index and middle finger between the collar and the neck of the animal and have a snug fit. Anything tighter than the 2-finger rule would not allow the animal to add weight as necessary in the fall, and anything looser could allow the collar to come off or cause chafing to the skin from to much collar movement. Collars were attached using 2 stainless steel screws and locking nuts, with the use of a nut-driver tool. Collars weighed approximately 67 g (1.0–1.7% of the animal’s weight), and battery life was 400 days.

All collars placed on raccoons included a motion sensor or a "mortality mode" so that if the collar did not move for 12 hours, the pulse rate of the signal doubled. I made an effort to retrieve all suspected radio-collared raccoon carcasses, and cause of death was determined when possible if carcass was found. I performed procedures on the animals (i.e., attaching radio-collars) in accordance with the Pennsylvania State University Institutional Animal Care and Use Committee, project 15948.

Den Sites

Den sites typically provide 3 main functions for raccoons (1) protection against adverse weather, (2) a secure environment to bear and raise young, and (3) protection from predators. I located den sites of radio-collared raccoons 1-2 times weekly by homing in on the signal with a portable receiver (Advanced Telemetry Systems, Isanti, MN,) and a 3-element handheld Yagi antenna (model FM100 scientific receiver; Advanced Telemetry Systems). Map coordinates of den sites and type of den site (e.g., tree den, ground den, and human structures) were determined and recorded in universal transverse mercator (UTM) coordinates with a hand-held global positioning system (GPS) unit (GPSmap 60CS; Garmin Corporation, Olathe, KS). I examined interactions between landscape, sex, and den type, using log-linear analyses.

Telemetry Protocol

I established nocturnal locations of the radio-collared raccoons through triangulation (White and Garrott 1990), using a portable receiver and a hand-held Yagi antenna. I recorded ≥2 bearings (usually ≥3) for each raccoon from established UTM coordinates. Universal transverse mercator coordinates were determined with the use of a hand-held GPS unit. I used location of a signal (LOAS) (Ecological Software Solutions, Sacramento, California, USA) in the field to estimate a location polygon based on Andrew's maximum likelihood estimator for each raccoon (White and Garrott 1990).

I conducted nocturnal tracking sessions 3-5 nights per week during the study period (May–December). I alternated night-tracking sessions between an early session that lasted from approximately 30 minutes after sunset until midnight and a late session that lasted from midnight until approximately 30 minutes before sunrise or until all animals had been located during the tracking sessions. I recorded all azimuths for a single radio location within a 30 minute interval to reduce error due to raccoon movement. This allowed me to gather location data for each raccoon over an activity range time period.

Telemetry Error

I calculated telemetry error by using transmitters placed at different locations throughout each study site. Estimated location of each transmitter was calculated using bearings from different GPS stations. I determined true locations of each transmitter by using GPS and compared true locations with locations calculated using triangulation. Average bearing error (mean of true bearing – measured bearing) for the rural site was 2.37°, which is a measure of bias, with a standard deviation of 5.42°, which is a measure of variation of the estimated bearings (White and Garrott 1990). Average bearing error for the forested site was 2.70°, with a standard deviation of 4.76°, and bearing error for the suburban site was 1.68°, with a standard deviation of 3.21°.

Home range

I defined seasons for telemetry analyses as spring (March–May), summer (June–August), fall (September–November), and winter (December–February), based on both climatological changes and raccoon biology. Pregnancy and parturition occur predominately in spring (March–May) (Johnson 1970); juveniles begin to move with their mother in summer (June–August); in fall (September–November), young are weaned and begin to move independently (Johnson 1970); and in winter (December–February), intense cold greatly reduces activity.

I constructed home-range estimates by using a kernel-density estimator (Worton 1989). Mean annual home range sizes (95% contour) and core-area sizes (50% contours) were determined using the adaptive-kernel method (Worton 1989) in the CALHOME home-range analysis program (Kie et al. 1996). CALHOME uses the Epanechnikov Kernel (Worton 1989) and assumes data follow a bivariate normal probability distribution when calculating the optimal bandwidth h_{opt} (termed a smoothing parameter). When animal locations seemed to be non-normally distributed (i.e., when animals apparently are using several core areas), I decreased the bandwidth until the lowest possible least-squares cross-validation score was reached without causing the 95% home range polygons to break up into several polygons (Kie et al. 1996). I derived home-range estimates for animals with ≥30 radio locations (Seaman et al. 1999). I only recorded 1 radio location per animal per tracking session or allowed a minimum of 6 hours between consecutive locations for any given raccoon to minimize spatial autocorrelation (Swihart and Slade 1985).

Also, I constructed seasonal sizes of home ranges and core areas. Because I only recorded 1 radio-location per tracking session per animal or 1 location every 6 hours to ensure independence, seasonal data were combined into 2 categories, spring–summer (March–August) and fall–winter (September–December) and to segregate between breeding versus nonbreeding periods. I examined differences in landscape and size of seasonal home ranges and core areas by using Student's *t*-test (Zar 1999).

Habitat Analyses

I performed habitat analyses by using radio-collared raccoon telemetry location data and GIS data layers supplied by the office for Remote Sensing of Earth Resources at Penn State University. A critical GIS data layer in the habitat analyses is the Pennsylvania Land Use and Land Cover with 9 habitat type classifications (Table 2). The map was generated from Enhanced Thematic Mapper satellite data with a pixel-resolution size of 30 × 30 meters (Office for Remote Sensing of Earth Resources, The Pennsylvania State University, 2000).

Habitat analyses followed the general framework of Neu et al. (1974) to determine the use of a given habitat. I used chi-square goodness-of-fit tests to test the null hypothesis that animals use habitats in proportion to their availability (Zar 1999). Observed counts of radio-collared raccoons in each habitat type were compared with the expected counts. Expected counts were based on the proportion of each available habitat type in the landscape. When a significant difference was detected using chi-square goodness-of-fit tests, I used a Bonferroni Z-statistic to determine what habitat types were used more or less frequently than expected (Neu et al. 1974).

Table 2. Habitat types, grid codes, and definitions used in analyses derived from Pennsylvania Land Use and Land Cover (Office for Remote Sensing of Earth Resources, The Pennsylvania State University, 2000).

Habitat Type	Grid Code	Definitions
Water	1	Rivers, lakes, and large ponds
Urban	2	Residential housing, commercial buildings, and industrial areas
Hay	3	Dominated by hay, grass silage, and greenchop
Row crops	4	Dominated by corn
Coniferous forest	5	Dominated by eastern white pine, red pine, and pitch pine
Deciduous forest	6	Dominated by northern red oak, white oak, black oak, sugar maple, red maple, and American beech
Mixed forest	7	Mixture of coniferous and deciduous forest
Coal fields	8	Reclaimed bituminous coal fields dominated by fescue and clover
Wetlands	9	Swamps, marshes, and bogs

Concepts of habitat availability and use are important in habitat analyses (Neu et al. 1974). Availability is defined as a habitat component being accessible to the animal (or population of animals) during the same period, and use of that component by the animal is the quantity of that component used by the animal in a fixed time period (Johnson 1980, Manly et al. 2002). When examining home-range selection on the landscape, the study site was designated as available habitat and when examining core-area selection, the home range was designated as available habitat (Johnson 1980). Use is selective if components are used disproportionately to their availability. Two assumptions must be met when using this technique: 1) each animal has an opportunity to select any habitat that is designated as available, and 2) observations are collected in an unbiased manner (Neu et al. 1974).

Resource Selection Function (RSF)

Similar to habitat analyses that followed the Neu et al. (1974) method, an understanding of use, availability, and selection is important in resource selection function (RSF). Selection refers to behavioral choices made by animals. A RSF is any statistical model that is proportional to the probability of use by a species (Manly et al. 2002), and these provide a framework for quantifying spatial probability of use and availability (Boyce and McDonald 1999, Manly et al. 2002).

The RSF analysis differs from the habitat analyses (described above) in that a RSF indicates habitat use in relation to another habitat type. The habitat analyses estimate whether habitats are used more or less with respect to availability. These concepts are fundamental in understanding the differences between the 2 methods of Neu et al. (1974) and RSF.

Logistic regression has become a common statistical analysis in a RSF to estimate habitat selection. Typically, these analyses relate used and unused habitats to environmental variables to predict site use by a species. Resource selection functions have been used for mapping species distributions, biodiversity, and land-management scenarios and determining predator–prey relationships and heavy-metal contamination (Gaines 2003, Araujo et al. 2004, Boyce 2006).

I included radio-telemetry error into each RSF model by creating a distribution of points around an original telemetry location that is based on my estimates of bearing error (Samuel and Kenow 1992). For each individual bearing, I used SAS code (SAS Institute 2004) to create 49 new bearings. New bearings were created by adding the standard deviation of my telemetry error to a normally distributed random number from –2 to 2 (number of standard deviations) to the original bearing. I calculated locations by using LOAS software (R. Fritsky, 2004-2006, Penn State, personal communication), using original and newly created bearings.

After new telemetry locations were generated, I transferred them into a GIS. Once in a GIS, I overlaid the locations and study site with a grid (10 × 10 m) system and designated each grid as 1 habitat cell. A cell was designated as used if it contained 1 or more estimated raccoon locations. Habitat classification followed the classification described under the habitat analyses section (Office for Remote Sensing of Earth Resources, The Pennsylvania State University, 2000). If a cell contained multiple habitat types, it was classified by the majority habitat type in that cell. For example, if a habitat cell contained 35% row crop and 65% deciduous, the habitat cell was classified as deciduous.

An RSF was developed from use and availability information derived from telemetry locations and GIS layers. I used PROC LOGISTIC (SAS Institute 2004) to derive a RSF by using independent and dependent variables (Manly et al. 2002). The dependent variable was determined by habitat cell use (1, used; 0, available), and independent variables were habitat classifications. Each location was assigned a weight of 1/50 in the logistic regression model to adjust sample sizes and account for the newly created error locations produced when I incorporated telemetry error into the model (R. Fritsky, 2004-2006, Penn State, personal communication). For example, if 7 locations fell inside 1 cell, the weight of that cell would be 7/50 in the logistic regression.

I designated the dominant habitat type within each landscape as the reference habitat type. Therefore, all habitat parameter estimates for the rural landscape indicate use in relation to row crops, because row crops were assigned the reference habitat in the design matrix. Deciduous forested stands were assigned as reference habitats in forested landscape, and urban habitats were assigned as reference habitats in the suburban landscape. I estimated parameters for all models by averaging parameter estimates of all raccoons at each site (Sawyer et al. 2006). The model developed from habitat use was derived from the radio-telemetry portion of this research. Model output is the relative probability that a raccoon will be located within a cell of a specific combination of variable attributes.

Two assumptions must be met when using the RSF technique: 1) habitat use of radio-collared adult raccoons is representative of all raccoons at the site; this assumption may be violated because juvenile raccoons may use habitat differently than adults (Fritzell 1978b), and 2) habitat types can explain habitat use. This assumption may be violated due to factors such as hunting pressures or other human disturbances affecting habitat use. However, due to the complexity of these relationships, I assumed all habitat types effectively can characterize habitat use patterns.

Sampling of *Salmonella*

Source and Collection Technique for *Salmonella*

Wildlife Service personnel and I collected fecal samples from anesthetized raccoons (see: Trapping Protocol) trapped in Allegheny, Armstrong, Erie, Greene, Mercer, and Westmoreland Counties in western Pennsylvania from 2003 to 2006. Fecal samples were obtained using rectal swabs, which then were placed into small plastic bags and frozen until further analysis was performed in the laboratory of Dr. Bhushan Jayarao (The Pennsylvania State University, University Park, PA).

Analysis of *Salmonella* Samples

I performed laboratory analysis to isolate *Salmonella enterica* serovars (Appendix A) from a subset of the fecal samples collected. I incubated fecal swabs in 9 ml of buffered peptone water at 37°C for 24 hours. I transferred 1 ml from each culture to 9 ml of tetrathionate broth, and then all cultures were incubated at 37°C for 48 hours (Nye et al. 2001). Next, I transferred 0.1 ml from each culture to 9.9 ml of Rappaport-Vassiliadis broth (RV), and incubated all cultures at 42°C for 24 hours. I vortexed (e.g., mixed rapidly) individual cultures of RV and loop-streak (e.g., a thin sterile loop of wire) plated them for isolation onto Hektoen Enteric agar plates and xylose lysine deoxycholate agar plates (Nye et al. 2001). Agar plates were incubated at 37°C for 24 hours. Presumptive *Salmonella* colonies were isolated onto Maconkeys agar and incubated at 37°C for 24 hours. I inoculated all *Salmonella*-positive samples on triple sugar iron agar (TSI) slants and incubated them at 37°C for 24 hours. I tested isolates from TSI growth for *Salmonella* O groups by using API (Analytab Products, Inc., Plainview, NY) tests (Nye et al. 2001). I sent positive O groups to the National Veterinary Services Laboratory (NVSL) for serovar identification. Once serovars were isolated, they were subtyped using pulse field-gel electrophoresis (PFGE).

Chapter 4

RESULTS

I captured and radio-collared 89 adult common raccoons in western Pennsylvania from spring 2003 to winter 2006 (Appendix B). Of the 89 radio-collared raccoons, 74 (24 females and 50 males) were used for the analysis; the other 15 raccoons were excluded from the analysis because of mortality or collar failure. Raccoons (n=74) were located 5,920 times. This number includes 4,703 nocturnal locations (1,223 rural, 1,531 forested, and 1,949 suburban) and 1,217 diurnal locations (339 rural, 397 forested, and 481 suburban).

Den Site

I located den sites of radio-collared raccoons an average of 1-2 times per week throughout the study period, with a total 1,217 locations recorded (339 rural, 397 forested, and 481 suburban) (Table 3). There was a significant 3-way interaction among sex, den type use, and landscape (G^2 = 391.52, df = 22, $P \leq 0.0001$) (Table 4). Den-type use differed by sex class (G^2 = 115.22, df = 4, $P \leq 0.0001$), with females using tree dens more often than males. Den type differed also by landscape type (G^2 = 270.66, df = 8, $P \leq 0.0001$), with raccoons in suburban landscapes using more human structures, such as buildings and storage sheds (Table 4).

I observed communal denning on 108 occasions (8.9%) within all landscapes, and they included males only. In the rural landscape, 2 adult males were observed sharing tree dens 20 times throughout the study period. In the forested landscape, 2

Table 3. Frequency of den-type use by male and female radio-collared raccoons (*n*=74) in 3 landscapes in western Pennsylvania, 2003–2006.

		Den types					
Landscape	Sex	Tree Den	Tree Roost	Ground Den	Barn Den	Other	Total
Rural	Male	76[a]	25	36	41	0	178
	Female	121	14	15	11	0	161
Forested	Male	101	57	22	0	0	180
	Female	183	22	12	0	0	217
Suburban	Male	131	36	11	0	75	253
	Female	176	18	6	0	28	228

[a] Number of times radio-collared raccoons were located in a particular den type.

Table 4. Log-linear analysis of 3-way interaction among sex, den-type use, and landscape for radio-collared raccoons (*n*=74) in 3 landscapes in western Pennsylvania, 2003–2006.

Source	G^2	df	*P*
Sex × den type use × landscape	391.52	22	≤0.0001
Sex × den type use	115.22	4	≤0.0001
Sex × landscape	5.58	2	0.0614
Den type use × landscape	270.66	8	≤0.0001
Sex × den type use (landscape)[a]	115.28	12	≤0.0001
Sex × landscape (den type use)[a]	5.64	10	0.8445
Den type use × landscape (sex)[a]	270.72	16	≤0.0001

[a] Represents 2-way interactions for each pair of variables, when the effects of the 3rd variable (in parentheses) are removed.

males shared a den tree on 6 occasions. In the suburban landscape, I observed 2 males sharing a pond gate-house 20 times, and 2 other males occupying the same tree den on 8 occasions.

Home Range

Mean sizes of home ranges and core areas did not differ between male and female raccoons within the same landscapes (Table 5). As urbanization increased among landscapes, size of mean home ranges decreased; however, sizes of core areas did not follow a decreasing trend. Male and female raccoons in forested landscapes had significantly larger mean home ranges and core areas than those of male and female raccoons in either rural or suburban landscapes. Sizes of core areas for male and female raccoons in rural landscapes did not differ from those of male and female raccoons in suburban landscapes. Differences in seasonal sizes of home ranges were observed only in male raccoons within rural landscapes (Table 6).

Rural

Sizes of mean home range for male and female raccoons in rural landscapes were 144.2 ha (SE = 79.9 ha, $n = 13$, range 51.1–211.8 ha) and 119.9 ha (SE = 44.2 ha, $n = 7$, range 75.7–220.2 ha), respectively. Sizes of mean core areas for males and females were 16.9 ha (SE = 11.7, $n = 13$, range 6.7–36.1) and 20.1 ha (SE = 14.5, $n = 7$, range 9.9–37.2), respectively. Sizes of mean home range did not differ between male and female raccoons ($t = 0.81$, df = 15, $P = 0.433$) nor did sizes of mean core areas differ between sex classes ($t = 0.72$, df = 6, $P = 0.500$).

Table 5. Mean (± SE) size (ha) of home ranges and core areas used by male (*n*=50) and female (*n*=24) raccoons in 3 landscapes in western Pennsylvania, 2003–2006. Home ranges and core areas were estimated using the adaptive-kernel method (Worton 1989).

Landscape	Sex	Home range	Core area
Rural	Both sexes	136.6 ± 70.2	21.1 ± 14.2 (15.4)[a]
	Male (*n* =13)	144.2 ± 79.9	16.9 ± 14.7 (11.7)
	Female (*n* = 7)	119.9 ± 44.2	20.1 ± 14.5 (16.7)
Forested	Both sexes	254.4 ± 110.2	65.2 ± 31.3 (25.6)
	Male (*n* = 14)	244.3 ± 106.6	65.4 ± 30.8 (26.8)
	Female (*n* = 10)	264.3 ± 124.6	66.6 ± 34.7 (25.2)
Suburban	Both sexes	89.3 ± 27.3	15.1 ± 4.5 (16.9)
	Male (*n* = 23)	90.2 ± 28.8	14.7 ± 4.9 (16.3)
	Female (*n* = 7)	86.4 ± 19.3	16.2 ± 2.9 (18.8)

[a] Percentage of total home range size the core area represents is given in parentheses.

Table 6. Seasonal mean (± SE) sizes (ha) of home ranges and core areas used by male (*n*=50) and female (*n*=24) raccoons in 3 landscapes in western Pennsylvania, 2003–2006. Home ranges and core areas were estimated using the adaptive-kernel method (Worton 1989).

		Spring–summer[a]		Fall–winter[b]	
Landscape	Sex	Home range	Core area	Home range	Core area
Rural	Both sexes	69.1 ± 40.9	15.1 ± 11.7 (21.8)	119.8 ± 60.2	20.9 ± 12.6 (17.4)[c]
	Male (*n* = 13)	63.1 ± 47.6	16.8 ± 13.9 (26.6)	118.4 ± 60.3	20.8 ± 13.4 (17.6)
	Female (*n* =7)	80.2 ± 24.9	11.9 ± 5.1 (14.8)	122.7 ± 65.6	20.9 ± 11.0 (17.0)
Forested	Both sexes	245.6 ± 88.1	59.7 ± 25.4 (24.3)	177.8 ± 90.1	40.2 ± 23.6 (22.6)
	Male (*n* = 14)	255.5 ± 108.5	61.4 ± 25.1 (24.0)	188.5 ± 83.9	43.3 ± 26.5 (23.0)
	Female (*n* = 10)	231.7 ± 49.6	57.3 ± 27.2 (24.7)	162.8 ± 100.7	35.9 ± 19.4 (22.0)
Suburban	Both sexes	66.1 ± 34.9	16.7 ± 13.2 (25.3)	68.1 ± 29.4	16.3 ± 8.9 (23.9)
	Male (*n* = 23)	75.6 ± 28.6	19.1 ± 14.5 (25.3)	75.5 ± 33.5	18.4 ± 10.0 (24.4)
	Female (*n* = 7)	59.1 ± 16.5	14.9 ± 13.1 (25.2)	63.9 ± 25.8	14.8 ± 7.9 (23.2)

[a] Parturition: early kit rearing (May–August) (Johnson 1970).

[b] Kit rearing: increased foraging activity, early denning (September–December) (Johnson 1970).

[c] Percentage of total home range size the core area represents is given in parentheses.

Male raccoons in rural landscapes showed a significant difference in mean seasonal sizes of home ranges (t = 2.45, df = 20, P = 0.024), a mean home range size of 63.1 ha (SE = 47.6, n = 6, range 33.4–88.9) during the spring–summer and 118.4 ha (SE = 60.3, n = 6, range 77.5–287.5) in the fall–winter. Sizes of seasonal mean home ranges in females did not differ between spring–summer and fall–winter (t =1.49, df = 6, P = 0.188) (Table 6).

Forested

Sizes of mean home range for male and female raccoons in forested landscapes were 244.3 ha (SE = 106.6, n = 14, range 119.3–458.2) and 264.3 ha (SE = 124.6, n = 10, range 145.9–566.4), respectively. Sizes of mean core areas for males and females were 65.4 ha (SE = 30.8, n = 14, range 33.9–107.8) and 66.6 ha (SE = 34.7, n = 10, range 25.5–125.4), respectively. Sizes of mean home ranges did not differ between male and female raccoons (t = 0.12, df = 17, P = 0.906) nor did sizes of mean core areas differ between sexes (t = 0.79, df = 21, P = 0.439).

Suburban

Sizes of mean home range for male and female raccoons in suburban landscapes were 90.2 ha (SE = 28.8, n = 23, range 47.7–158.9) and 86.4 ha (SE = 19.3, n = 7, range 35.2–104.4), respectively. Sizes of mean core area for males and females were 14.7 ha (SE = 4.9, n = 23, range 5.7–23.1) and 16.2 ha (SE = 2.9, n = 7, range 4.2–22.6), respectively. Sizes of mean home ranges did not differ between male and female raccoons (t = 0.36, df = 12, P = 0.72) nor did sizes of mean core areas differ between sexes (t = 0.90, df = 9, P = 0.930).

Habitat Analyses

Raccoons within rural, forested, and suburban landscapes used habitat types disproportionately to availability (Appendix C). Habitat use by raccoons differed among landscapes, with different habitat types being selected within the 3 landscapes.

Rural

Raccoons in rural landscapes used habitat types disproportionately to their availability within home ranges (χ^2 = 911.7, df = 7, $P \leq 0.001$) and core areas (χ^2 = 168.9, df = 7, $P \leq 0.001$). In rural landscapes, raccoons used deciduous stands, mixed-forested stands, and wetlands at the home-range scale more than expected based upon habitat availability. At this same scale, urban areas and water were used less than expected based upon availability within the landscape (Table 7). Within core areas, raccoons used deciduous stands and wetlands more than expected. Moreover, raccoons used urban areas, water, coniferous stands, and mixed-forested stands less than expected at the core-area scale (Table 8).

Forested

Raccoons in forested landscapes used certain habitat types more than expected, as indicated by the composition of their home range (χ^2 =219.5, df = 7, $P \leq 0.001$) and core area (χ^2 = 137.8, df =7, $P \leq 0.001$). In these landscapes, raccoons used mixed-forested stands and coal fields at the home-range scale more than expected based upon habitat type availability. Urban areas, however, were used far less than expected within a home range in this landscape (Table 7). Raccoons used deciduous stands and coal fields at the core-area scale, whereas they used coniferous stands, mixed-forested

Table 7. Patterns of home range habitat-type use of radio-collared raccoons (*n*=74) in 3 landscapes in western Pennsylvania, 2003–2006. Plus (+) signs indicate habitat types that were used more frequently than expected based upon availability within the landscape. Minus (–) signs indicate habitat types that were used less frequently than expected based upon availability within the landscape. Habitat types not used differently than expected based on their availability are denoted as not significant (NS).

Habitat Type	Rural Landscape	Forested Landscape	Suburban Landscape
Water	–	NS	NS
Urban	–	–	–
Hay	NS	NS	*
Row crops	NS	NS	NS
Coniferous forest	NS	NS	+
Deciduous forest	+	NS	+
Mixed forest	+	+	+
Coal fields	*	+	*
Wetland	+	*	*

(*) Asterisk indicates habitat types not available to raccoons within the landscape.

Table 8. Patterns of core area habitat-type use of radio-collared raccoons (*n*=74) in 3 landscapes in western Pennsylvania, 2003–2006. Plus (+) signs indicate habitat types that were used more frequently than expected based upon availability within the landscape. Minus (–) signs indicate habitat types that were used less frequently than expected based upon occurrence within the landscape. Habitat types not used differently than expected based on their availability are denoted as not significant (NS).

Habitat Type	Rural Landscape	Forested Landscape	Suburban Landscape
Water	–	NS	NS
Urban	–	NS	–
Hay	NS	–	*
Row crops	NS	–	NS
Coniferous forest	–	–	NS
Deciduous forest	+	+	+
Mixed forest	–	–	+
Coal fields	*	+	*
Wetland	+	*	*

(*) Asterisk indicates habitat types not available to raccoons within the landscape.

stands, hay fields, and row crops less than expected, based upon availability (Table 8).

Suburban

Raccoons in suburban landscapes used habitat types disproportionately to their availability within home ranges (χ^2 = 354.4, df = 5, $P \leq 0.001$) and core areas (χ^2 =310.2, df = 5, $P \leq 0.001$). At the home-range scale, raccoons used coniferous stands, deciduous stands, and mixed-forested stands more than expected (Table 7). Urban areas, however, were used less than expected at the home-range scale based upon availability within the landscape. Within core areas, raccoons used deciduous stands and mixed-forested stands more than expected (Table 8). As with the home-range scale, raccoons at the core-area scale used urban areas less than expected based upon availability.

Resource Selection Function

Rural

The RSF indicated that hay fields and deciduous stands were used significantly more relative to row crops (Table 9). Water, mixed-forested stands, coniferous stands, wetlands, and urban areas were used significantly less relative to row crops within the landscape. Habitat types used less frequently than the reference habitat type were characterized by negative parameter estimates in the model. A relative probability map indicated raccoon habitat use was highest in deciduous and coniferous stands adjacent to row crops and hay fields and lowest in forested stands close to urban areas (Fig. 4).

Table 9. Coefficients (± SE) of RSF habitat-use model for radio-collared raccoons (*n*=20) in rural landscapes, western Pennsylvania, 2003–2004. All habitat-type estimates for the rural landscape indicate use in relation to row crops, because row crops were assigned the reference habitat type in the design matrix.

Habitat Type	β	SE
Intercept	–9.693	1.076
Water	–11.330	0.798
Urban	–14.374	0.416
Hay fields	0.638	0.011
Coniferous	–1.560	0.248
Deciduous	0.397	0.018
Mixed	–2.908	0.589
Wetlands	–1.582	0.393

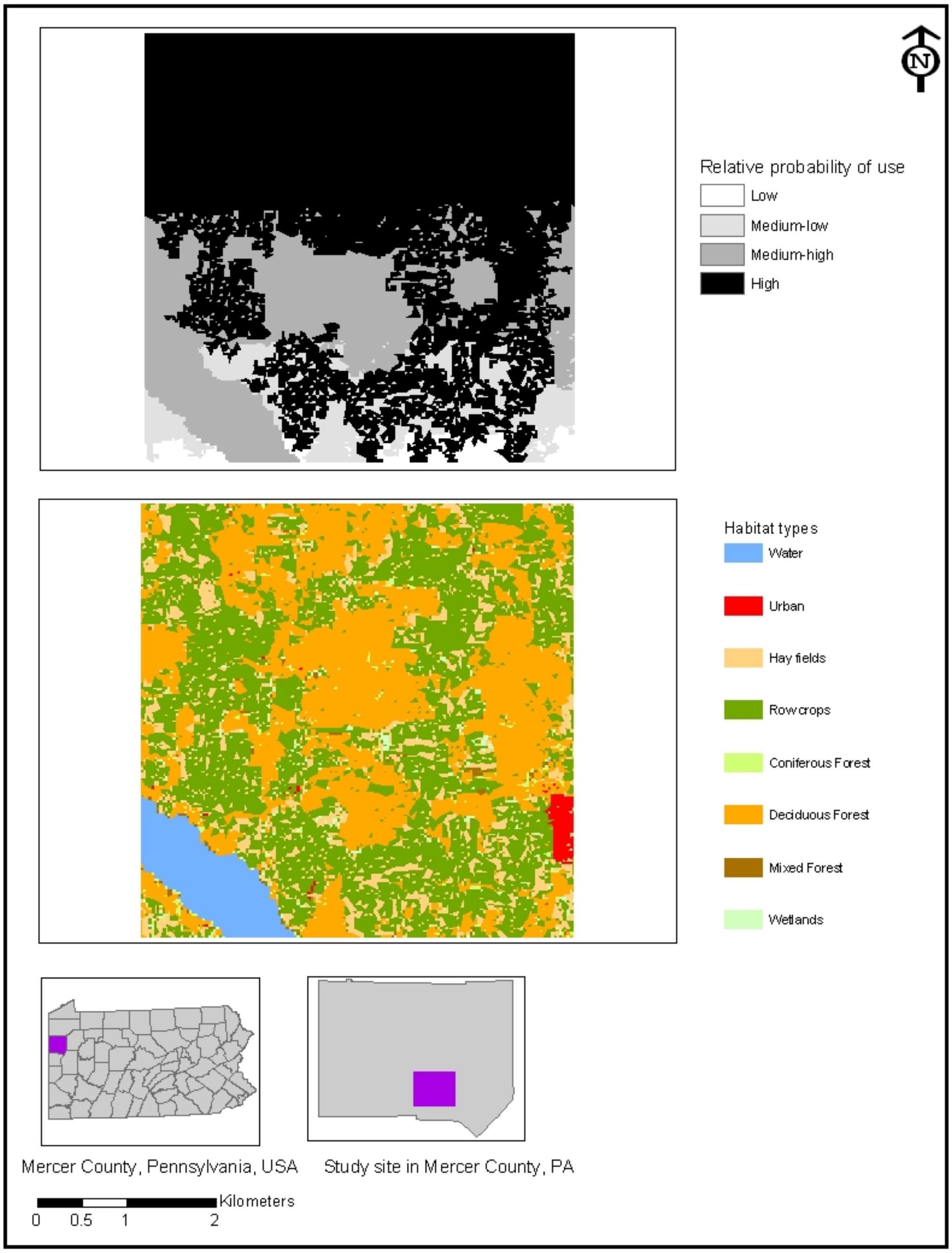

Fig. 4. Relative probability of use by radio-collared raccoons (n=20) for the rural landscape based on telemetry location data obtained in 2003–2004 in western Pennsylvania.

Forested

The forested RSF indicated that raccoons used row crops and coal fields significantly more relative to deciduous stands. Urban areas, water, coniferous stands, and mixed-forested stands were used significantly less relative to deciduous stands (Table 10). A relative probability map indicated raccoon habitat use was highest in deciduous stands and coniferous stands adjacent to row crops and coal fields and lowest in all types of forested stands adjacent to urban areas (Fig. 5).

Suburban

The suburban RSF indicated that raccoons in this landscape used row crops, deciduous stands, and mixed-forested stands significantly more relative to urban habitats (Table 11). Coniferous stands and water were used significantly less relative to urban habitats, based upon availability within the landscape (Table 11). A relative probability map indicated habitat use by raccoons was highest in deciduous stands, coniferous stands, and urban areas adjacent to any forested stand type. Habitat use was lowest in row crops adjacent to urban areas (Fig. 6).

Research Results for *Salmonella*

Salmonella enterica serovars were isolated from 7.4% of all samples examined from western Pennsylvania (Table 12) (Appendix D). Ten serovars were identified among 6 counties (Allegheny, Armstrong, Erie, Greene, Mercer, and Westmoreland) (Table 13). Pulse field gel electrophoresis analysis revealed 13 unique *Salmonella enterica* serovar isolate profiles within the 10 serovars (Table 14 and Appendix E).

Table 10. Coefficients (± SE) of RSF habitat-use model for radio-collared raccoons (*n*=24) in forested landscapes, western Pennsylvania, 2004–2005. All habitat-type estimates for the forested landscape indicate use in relation to deciduous, because deciduous was assigned the reference habitat type in the design matrix.

Habitat Type	β	SE
Intercept	–9.404	0.528
Water	–8.138	1.323
Urban	–3.848	1.430
Row crops	0.077	0.470
Coniferous	–0.007	0.069
Mixed	–0.453	0.491
Coal mines	0.148	0.051

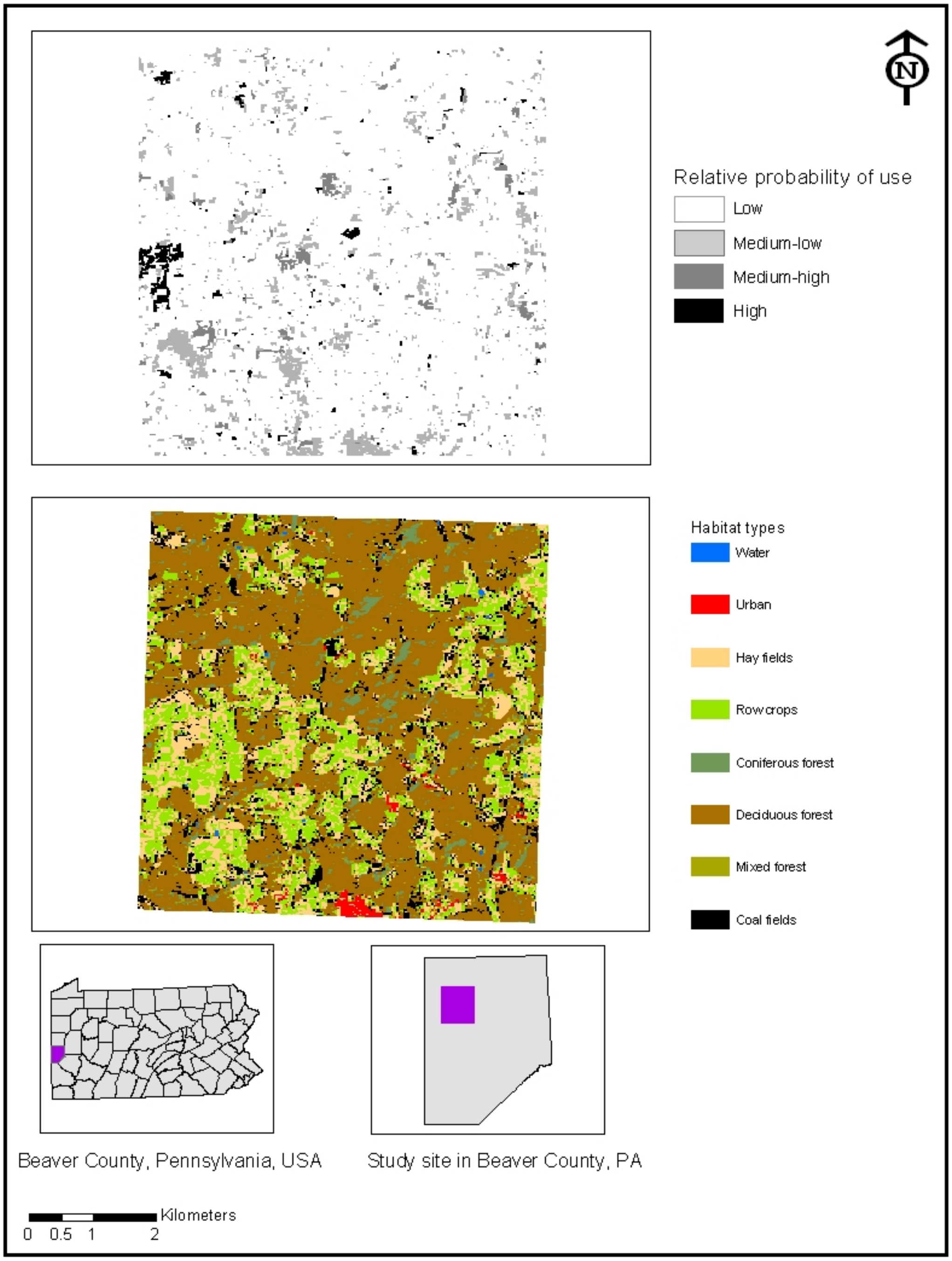

Fig. 5. Relative probability of use by radio-collared raccoons (*n*=24) for the forested landscape based on telemetry location data obtained in 2004–2005 in western Pennsylvania.

Table 11. Coefficients (± SE) of RSF habitat-use model for radio-collared raccoons (*n*=30) in suburban landscapes, western Pennsylvania, 2005–2006. All habitat-type estimates for the suburban landscape indicate use in relation to urban, because urban was assigned the reference habitat type in the design matrix.

Habitat Type	β	SE
Intercept	–6.867	0.192
Water	–7.959	0.277
Row crops	0.172	0.155
Coniferous	–0.944	0.096
Deciduous	1.124	0.185
Mixed	0.007	0.002

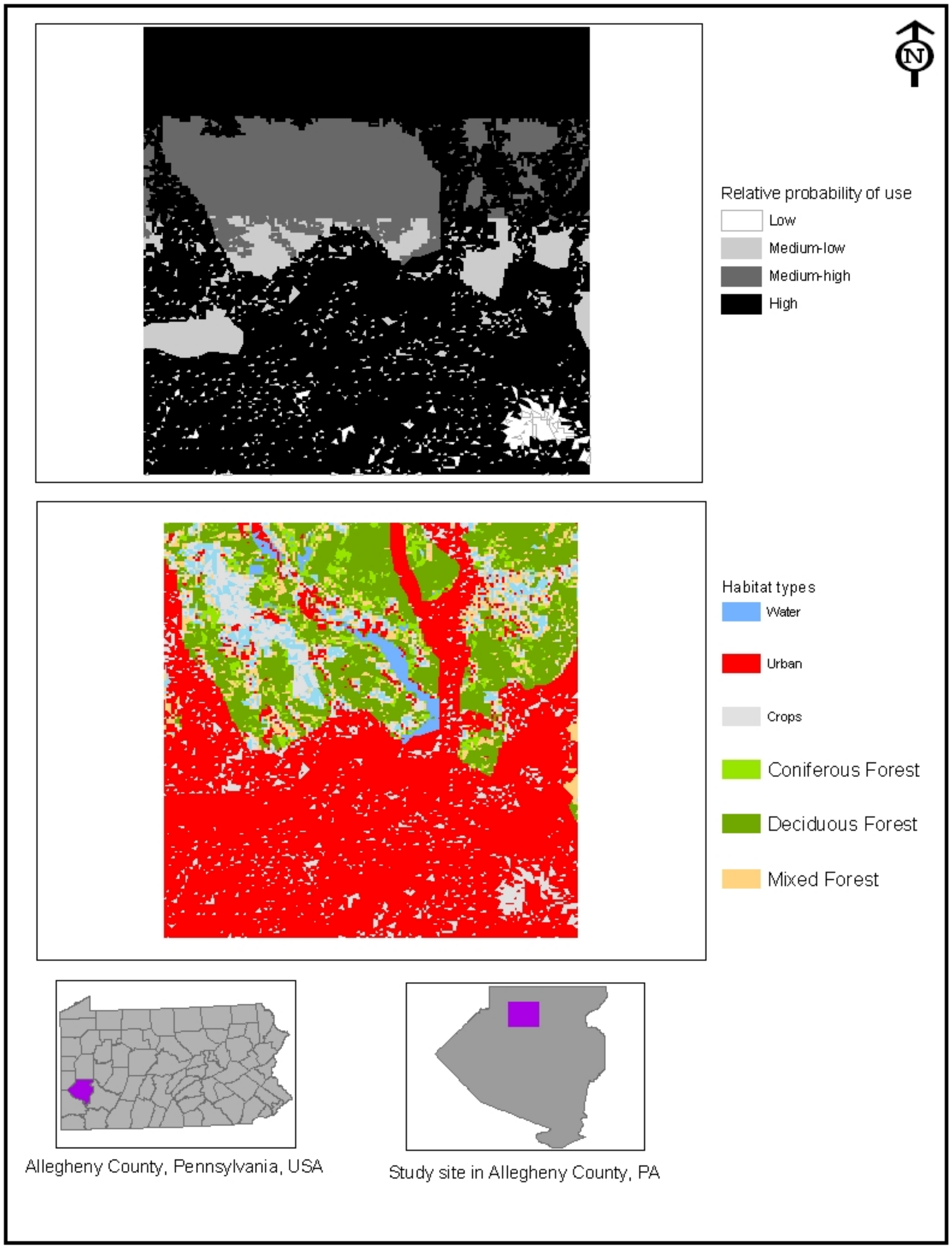

Fig. 6. Relative probability of use by radio-collared raccoons (*n*=30) for the suburban landscape based on telemetry location data obtained in 2005–2006 in western Pennsylvania.

Table 12. Prevalence of serovars of *Salmonella enterica* in raccoons (*n*=738) in 3 landscapes in western Pennsylvania, 2003–2006.

Landscape	No. of samples[a]	*Salmonella enterica* serovars
Rural	128 (10)	*S. Hartford*, *S. Thompson*
Forested	332 (28)	*S. Berta*, *S. Hartford*, *S. Infantis*, *S. Newport*, *S. Oranienburg*, *S. Typhimurium*, *S. Typhimurium* (*copenhagen*)
Suburban	278 (16)	*S. Bardo*, *S. Newport*, *S. Oranienburg*, *S. Paratyphi* B var. L-tartrate+

[a] The total number of samples tested (number positive samples of *Salmonella enterica* serovars) is given in parentheses.

Table 13. Number of positive serovars of *Salmonella enterica* collected from raccoons (*n* = 738) in 3 landscapes in 6 western Pennsylvania counties, 2003–2006.

Salmonella enterica serovars	No. of positive samples	Landscape	County
S. Bardo	1	Suburban	Erie
S. Berta	3	Forested	Armstrong
S. Hartford	9	Rural	Mercer
S. Hartford	1	Forested	Greene
S. Infantis	6	Forested	Westmoreland
S. Infantis	2	Forested	Greene
S. Newport	3	Suburban	Erie
S. Newport	3	Suburban	Allegheny
S. Newport	3	Forested	Armstrong
S. Newport	3	Forested	Greene
S. Oranienburg	1	Suburban	Erie
S. Oranienburg	2	Forested	Greene
S. Paratyphi B var. L-tartrate+	8	Suburban	Allegheny
S. Thompson	1	Rural	Mercer
S. Typhimurium	4	Forested	Greene
S. Typhimurium	2	Forested	Armstrong
S. Typhimurium (*copenhagen*)	2	Forested	Armstrong

Table 14. Serovar isolates of *Salmonella enterica* from raccoons (*n*=738) in 3 landscapes in western Pennsylvania, 2003–2006, sharing the same serovar profile.

Lane (unique profiles)	*Salmonella enterica* serovars	Serovar isolates sharing same profile
1	*S. Bardo*	1
2	*S. Berta*	3
6	*S. Hartford*	9
7	*S. Hartford*	1
15	*S. Infantis*	8
25	*S. Newport*	3
26	*S. Newport*	4
27	*S. Newport*	5
35	*S. Oranienburg*	3
38	*S. Paratyphi* B var. L-tartrate+	8
47	*S. Thompson*	1
52	*S. Typhimurium*	6
54	*S. Typhimurium* (*copenhagen*)	2
Std.	*S. Braenderup*	

Salmonella-positive samples occurred in all counties sampled. The greatest frequency of raccoon infection occurred in Westmoreland county, with 13% of samples testing positive. All samples from this county were identified as one serovar, *S. Infantis*. In Greene County, 12 positive cases (8.7%) with five unique *Salmonella enterica* serovars were identified (*S. Infantis, S. Typhimurium, S. Newport, S. Hartford, and S. Oranienburg*). One sample from Greene County was unable to be confirmed due to laboratory error and was excluded from the analysis.

In rural landscapes (Mercer County), 2 unique *Salmonella enterica* serovas were identified (*S. Hartford* and *S. Thompson*) from raccoon samples. Raccoons in forested landscapes (Armstrong, Greene, and Westmoreland Counties) were identified with 7 unique *Salmonella enterica* serovas (*S. Infantis, S. Typhimurium, S. Newport, S. Hartford, S. Berta, S. Oranienburg*, and *S. Typhimurium* (*copenhagen*)). In suburban landscapes (Allegheny and Erie Counties), raccoons were identified with 4 unique *Salmonella enterica* serovars (*S. Newport*, *S. Oranienburg*, *S. Bardo*, and *S. Paratyphi* B var. L-tartrate+).

Chapter 5

DISCUSSION

Den Site

Females used tree dens more often than males in my study, possibly as refuge from predators and weather, particularly during young rearing (Shirer and Fitch 1970, Rabinowitz 1981). Females may have chosen den trees over other sites because of extreme weather conditions exhibited in western Pennsylvania in 2003 and 2004, with 2 of the wettest years on record occurring since 1899 in that region (The Pennsylvania State Climatologist 2006). Ground dens provide better thermal regulation than tree dens; however, ground dens may have had reduced availability due to extreme amounts of rain that caused frequent, but short-term flooding throughout much of the spring, summer, and fall. Most ground dens used by raccoons in my study were abandoned woodchuck (*Marmota monax*) dens. Although I have no evidence of den-site competition, with reduced availability due to weather, ground-den use may have been influenced by intraspecific and interspecific interactions among raccoons, foxes, woodchuck, and striped skunks. On several occasions, I did witness aggressive interactions among raccoons for foraging resources, so possible aggressive interactions for den sites may have occurred as well. Reduced interspecific competition for tree dens could be another possible reason why females used tree dens more than other den types.

Den types in my study may have been influenced by landscape characteristics because den use is related to foraging resources within the landscape (Rabinowitz 1981, Henner et al. 2004). Tree dens were the most frequently used den types throughout all landscapes; however, all other den-type use varied between landscapes. In rural landscapes, barns were the second most common den type used by raccoons, followed closely by ground dens. Most tree dens and ground dens in rural landscapes often were located in deciduous forested stands adjacent to row crops. In forested landscapes, tree roosts were the second most common den type used, followed by ground dens. Ground dens in forested landscapes accounted for only 8.5% of all dens used, which is possibly a reflection of the wet weather during that year. Human structures were used as the second most common den type in suburban landscapes. Garages, sheds, and other structures were used on several occasions. One male raccoon in a suburban landscape was found in the same den site on all but 1 occasion. The den site was a concrete gate house, located on a large pond, which was adjacent to residential housing, a convenient store, and a small deciduous forested stand. This den site was in proximity to dumpsters and gardens.

Home Range

My observations of the size of raccoon home ranges decreasing with the increase of urbanization were consistent with previous reports of raccoons (Slate 1985, Feigley 1992, Hatten 2000). Similarly, size of home ranges in coyote (*Canis latrans*) (Shargo 1988, Riley et al. 2003, Atwood et al. 2004), gray fox (Trapp and Hallberg 1975, Fuller 1978, Harrison 1997), and red fox (Ables 1969, Trewhella et al. 1988) have been shown to decrease with an increase in urbanization from forested to urban landscapes. My results indicate that, unlike home ranges, sizes of core areas do not show the same reduction with a similar increase in urbanization. Instead, sizes of core areas remained similar between rural and suburban landscapes. Core areas are sites of concentrated use and are likely to contain resources important to animals, including den sites, cover, resting areas, and quality foraging areas (Ewer 1968, Kaufmann 1982). Similar-sized core areas between rural and suburban landscapes could be explained by resource abundance, such as den sites, cover, and foraging areas as well as by spatial distribution of these resources in proximity to each other.

My data indicated that sizes of home ranges of raccoons in 3 landscapes in western Pennsylvania were within the typical range described in other studies (Johnson 1970, Shirer and Fitch 1970, Urban 1970). Sizes of home ranges and core areas in raccoons did not differ by sex, with male and female raccoons in the same landscape having similar-sized home ranges and core areas. Slate (1985) described similar findings in a suburban landscape in New Brunswick, New Jersey, in which males and females had similar-sized home ranges, but no information on sizes of core areas was presented in his study. Most other studies in rural and forested areas have reported that sizes of home ranges of male raccoons are larger than those of females (Hoffmann and Gottschang 1977, Fritzell 1978a,b, Chamberlain et al. 2003).

In rural landscapes, resources are probably distributed heterogeneously both spatially and temporally, with crops fragmenting the landscape and being only seasonally available (Western Pennsylvania Conservancy 2003). Male raccoons in my study responded to this heterogeneity by a change in size of home range between spring–summer and fall–winter. Row crops and hay fields were harvested in fall, removing a valuable foraging resource for raccoons from the landscape. With the removal of a valuable forage resource, male raccoons exhibited a significant increase in their fall–winter home range size.

Males in rural landscapes also may be responding with an increase in home range because of breeding activity. With the coming onset of winter, male raccoons begin actively searching for mates, thereby traveling greater distances (Johnson 1970). Increased size of home range in males probably increased the chance of encountering receptive females during breeding season.

Raccoons in forested landscapes exhibited the largest home ranges and core areas, perhaps because of distributions of available of foraging resources within the landscape (Fritzell 1978b, Rabinowitz 1981, Chamberlain et al. 2003). Home ranges and core areas in areas of decreased resource abundance would be expected to be larger because the energetic needs of an animal are less easily met (Pedlar et al. 1997). Foraging resources in forested landscapes are seasonally abundant (e.g., berries and mast); however, they often are more dispersed within the landscape. The distribution of foraging resources probably caused an increased size of home ranges and core areas. Den sites are an important resource for raccoons (Rabinowitz 1981), and lack of den locations could possibly cause raccoons to expand home ranges and core areas. However, in my study, den sites were abundant throughout the forested landscape, so den-site abundance is unlikely to be related to the sizes of home ranges and core areas.

My research has shown that sizes of home ranges of raccoons in suburban landscapes are smaller than those in rural or forested landscapes, which is similar to findings of previous studies with bobcats (*Lynx rufus*) (Lovallo and Anderson 1996), coyotes (Shargo 1988, Atwood 2002), and gray foxes (Allen and Sargeant 1993). Reduced home range in suburban landscapes is probably due to a variety of additional foraging resources and abundant den sites. During my study, the 2 largest additional foraging resources found in suburban landscapes were human refuse found in residential and commercial areas and native and ornamental fruit found in gardens and yards. Human refuse is readily accessible year-round to raccoons and other wildlife species.

Habitat Analyses

Multiple spatial scales must be considered to understand the hierarchical nature of habitat use (Johnson 1980) because use may be dependent on scale of perception of an animal (Kotliar and Wiens 1990). Landscape perception by mammals may be dependent on body size, with larger bodied mammals perceiving landscapes as more homogeneous compared with smaller species (MacArthur and Levins 1964, Lidicker and Koeing 1996). Larger, more mobile mammals view the landscape matrix as more connected patches and less isolated and divided (Addicott et al. 1987).

Raccoons often are very mobile and can traverse considerable distances, allowing them to perceive habitat availability at multiple spatial scales (Kaufmann 1982, Lima and Zollner 1996). Raccoons in my study selected different habitat types at the home-range and the core-area scale, indicating that raccoons recognized habitat availability at these 2 scales. Habitat use by raccoons in my study also varied with landscape, indicating raccoons used habitat types within each landscape that would provide quality foraging areas and den site locations (Dijak and Thompson 2000).

Raccoons are common in rural landscapes and are able to take advantage of agricultural practices by exploiting crops for food (Soneshine and Winslow 1972, Herkert 1994, Walk 2001) and using forested stands for cover and den sites. I often located raccoons near edges of agricultural areas, which provide numerous resources for raccoons such as nests of edge-dwelling bird species (Odum 1971, Wilcove 1985). Austin (2002) and Dijak and Thompson (2000) reported similar accounts of increased raccoon activity along forest edges adjacent to agricultural fields.

Raccoon habitat use can be influenced by availability of free water (Kaufmann 1982, Gehrt and Fritzell 1998a,b). During my study, western Pennsylvania experienced 2 of the wettest years on record, going back to 1899 (The Pennsylvania State Climatologist 2006); as a result of increased precipitation, pools of standing water were abundant throughout the rural and forested landscape between May and October 2003 and 2004. This additional source of water could be responsible for the decrease in observed use of water, compared with that in previous studies (Kaufmann 1982 Gehrt and Fritzell 1997, 1998a,b).

My finding that raccoons selected for wetlands is consistent with the results of most other studies (Fritzell 1978b, Greenwood 1982, Kaufman 1982). Wetlands only accounted for a small fraction of the landscape available to raccoons; however, raccoons were observed in these areas more than expected at home-range and core-area scales. In my study, wetlands provided important resources, such as den sites, cover, and foraging sites, for raccoons.

In forested landscapes, raccoons used urban habitats less than expected based on availability within the landscape, similar to the findings of previous research on coyotes (Shargo 1988, Quinn 1997, Grinder and Krausman 2001), bobcats (Riley et al. 2003), and gray foxes (Adkins and Stott 1998) in forested or rural landscapes.

Reclaimed coal fields are numerous in the landscape of western Pennsylvania forests, which provided quality foraging areas for raccoons because I frequently located raccoons in or near blackberry (*Rubus fruticosus*) plants within these coal fields. Blackberry plants often were abundant in these coal fields and maintained berries late into the fall, possibly due to record rainfall in 2004 (The Pennsylvania State Climatologist 2006) that allowed for growing conditions to extend later into the year. In addition to providing quality foraging areas, coal fields are adjacent to forested stands that provide cover and den sites. Previous research has shown that raccoons will use reclaimed coal mines as foraging areas, often preying on reptiles, amphibians, and small mammals (Winkler and Adams 1972, Humphrey et al. 1977, Munson and Keith 1984).

Mixed-forested stands and deciduous stands provided high value foraging locations, and deciduous stands provided also abundant den-site locations. Raccoons in forested landscapes used row crops, predominately corn, when available for augmenting their diets. Similar findings for raccoons in forest or suburban landscapes suggest that, when available, agricultural crops often are used as a supplementary resource (Sonenshine and Winslow 1972, Slate 1985).

In suburban landscapes, my research showed that raccoons minimize exposure to urban habitats and maximize use of more natural habitats. Findings are similar to those of previous studies on mid-sized carnivores, such as coyotes (Shargo 1988, Quinn 1997, Atwood 2002), bobcats (Riley et al. 2003), and red foxes (Adkins and Stott 1998). Raccoons selected for forested stands at home-range and core-area scales, but they used urban habitats less than expected. Forested stands provided raccoons with den sites, foraging areas, travel corridors between foraging areas, and safety from people and pets.

Core areas of raccoons in suburban landscapes were predominately located in forested areas adjacent to concentrations of foraging resources and den sites. The 2 largest additional foraging resources in this landscape were refuse and gardens. Garbage cans in residential housing and dumpsters in apartment complexes and commercial property was the primary source of human refuse. Native and ornamental fruit gardens were found most often in yards of residential housing areas.

Resource Selection Function

In all landscapes, I estimated raccoon habitat use (via RSF) to be negatively related to coniferous stands, which suggests that this habitat does not provide preferred resources, such as den sites and quality foraging opportunities. This is similar to previous research that found raccoons prefer deciduous stands that often provide more den sites and foraging opportunities, such as hard mast (Rabinowitz 1981, Kaufmann 1982). In all landscapes, deciduous stands were frequently used by raccoons as places for den sites and foraging.

Raccoons used habitats in rural, forested, and suburban landscapes where cover was available in proximity to foraging areas. Raccoons in rural landscapes were consistently located next to row crops and hay fields adjacent to deciduous forested stands where the edge of agricultural areas provides numerous resources for raccoons (Odum 1971, Wilcove 1985, Austin 2002). In the forested RSF model, raccoons were shown to use row crops and coal fields adjacent to deciduous forested stands; but in suburban landscapes, the RSF model suggested that raccoons are using forested areas adjacent to urban habitats when available, which is similar to that found near New Brunswick, New Jersey (Slate 1985).

Predictive maps coupled with an RSF are practical tools for illustrating changes in habitat selection patterns between 3 distinct landscapes (Manly et al. 2002). Predictive maps suggest levels of raccoon use across a landscape, which can then be directly integrated into ORV management practices. The ability to visualize habitat use across a site can be a powerful tool because it assists in the understanding of habitat use by raccoons with respect to other habitats.

Research Discussion for *Salmonella*

My study found raccoons in several western Pennsylvania counties are infected with numerous *Salmonella enterica* serovars. The serovars isolated have a wide host range and most commonly cause gastroenteritis in humans but occasionally lead to more severe illnesses and death (Thornton et al. 1998). Raccoons may acquire infection and become intermediate hosts through consumption of infected wildlife, poultry, fish, shellfish, contaminated soil, water, and plant material (Ashbolt and Kirk 2006). The link between wildlife as intermediate hosts and human cases of salmonellosis (*Salmonella* infection in humans) has been documented in several cases (Bonnedahl et al. 2005, Ashbolt and Kirk 2006, Martinez-Urtaza et al. 2006). In Norway, outbreaks of human *S. Typhimurium* infection have been paralleled with the same PFGE strains of *S. Typhimurium* in hedgehogs (*Erinaceus europaeus*) (Handeland et al. 2002).

Raccoons in my study likely acquired *Salmonella enterica* serovars from their immediate surroundings, as suggested by the distinct serovars associated with each habitat. In rural landscapes, raccoons were infected with *S. Hartford* and *S. Thompson*, which often are associated with pets, livestock, and poultry, as well as unpasteurized milk and other liquids (Cook et al. 1998, Guerin et al. 2005). In forested landscapes, raccoons were infected with *S. Infantis, S. Typhimurium*, *S. Newport*, *S. Hartford*, *S. Berta*, *S. Oranienburg*, and *S. Typhimurium* (*copenhagen*), which have been associated with livestock, water supplies, and poultry (You et al. 2006). Raccoons in suburban landscapes were infected with *S. Newport*, *S. Oranienburg*, *S. Bardo*, and *S. Paratyphi* B var. L-tartrate+, which often are linked to raw shellfish, fish, and water quality (Martinez-Urtaza et al. 2006).

Salmonella Iinfantis has been recovered in humans and animals of many species, as well as in animal products, such as eggs and dog-treats (Cox et al 2002). According to CDC data collected through the Public Health Laboratory Information System, *S. Infantis* is within the top 15 most frequently reported human serovars in the last decade (CDC 2000). In animals, *S. Infantis* contributes 1–2% of the nonhuman *Salmonella enterica* serovar isolates reported to CDC from the NVSL. Infections often are transmitted through birds, such as domestic chickens (*Gallus domesticus*), ducks (*Anas* spp.), geese (*Branta* spp.), wild turkeys (*Meleagris gallopavo*), and pheasants (*Phasianus* spp.) (Wilkins et al 2002). Raccoons are well-documented as nest predators (Greenwood 1981, Wilcove 1985), and they may have acquired *S. Infantis* from consuming eggs from various bird species present in forested landscapes.

In this study, *S. Newport* was isolated from raccoons in forested and suburban landscapes and was the most prevalent serovar, which was recently named an emerging disease organism by the American Association of Veterinary Laboratory Diagnosticians (Guerin et al. 2005). Although most serovars are potential human and animal pathogens, only 10 serovars are responsible for most disease in cattle. The NVSL listed *S. Newport* as 1 of the top 10 most frequently identified *Salmonella enterica* serovars from U.S. cattle, and it causes significant clinical disease, particularly in livestock and humans (You et al. 2006). All strains of *S. Newport* are multiple antimicrobial drug resistant, and many of these strains are showing immediate resistance to third-generation antibiotics (Guerin et al. 2005). Infection most often is transmitted from livestock and rodents and by consuming contaminated animal feed (Simmons 2002).

In this study, I isolated *S. Oranienburg* from raccoons trapped in forested and suburban landscapes, it is a relatively uncommon serovar in the United States, and has been associated with outbreaks in several countries (Kumao et al. 2002). It can cause gastroenteritis, vertebral osteomyelitis, soft tissue and cartiliage infection, and retroperitoneal abscess in humans (Smith 1998). The presence of *S. Oranienburg* in raccoons should not be underestimated, because it can cause severe infection, particularly in children and people with compromised immune functions (Smith 1998). *S. Oranienburg* is primarily transmitted through foods of animal origin and contaminated produce.

S. Paratyphi B var. L-tartrate+ is of particular concern. Many *Salmonella enterica* serovars can cause illness and disease in humans; however, *S. Paratyphi* B var. L-tartrate+ has been show to be more viral than other serovars (Ochiai et al. 2005), causing bacterial enteric fever, which is characterized by fever, vomiting, headache, bradycardia, and constipation in humans (Ochiai et al. 2005). It is clinically similar to typhoid fever but milder and with a lower fatality rate. Most strains of *S. Paratyphi* B var. L-tartrate+ are multiple antimicrobial drug resistant, which poses a notable public health risk for humans who become infected; *S. Paratyphi* B var. L-tartrate+ is transmitted primarily by fish, shellfish, and contaminated foods (Thornton et al. 1998). Raccoons in suburban landscapes possibly acquired S. *Paratyphi* B var. L-tartrate+ from foods found in garbage cans, dumpsters, or live fish found in large ponds that are present within the landscape.

S. Typhimurium is the most common *Salmonella enterica* serovar and is the leading cause of human gastroenteritis (You et al. 2006). The incidence of *S. Typhimurium* salmonellosis is increasing in the United States, leading to millions of infections and more than 600 deaths a year in humans (Wilkins et al 2002). Over 70% of *S. Typhimurium* isolates are resistant to multiple anti-microbial drugs, which could further increase the severity of human illnesses and number of deaths. The most common *Salmonella enterica* serovar in humans, *S. Typhimurium*, is commonly isolated from cows, chickens, and contaminated water supplies (Handeland et al. 2002). Both farm animals and wildlife may acquire infection and become intermediate hosts via consumption of infected animals, contaminated soil, plant material, and insects.

In recent years, problems related to *Salmonella enterica* serovars have increased significantly, both in terms of incidence and severity of human cases (Heir et al. 2002). Studies, such as mine, where DNA fingerprinting of *Salmonella enterica* serovars through PFGE may help identify the source of contamination in the wild, are extremely important. The same serovars found in multiple animals or in wildlife from the same location suggests a point source of contamination. Identification of a point source may allow the development of a plan to manage and minimize ongoing environmental contamination. Routine monitoring of serovars in wildlife can lead to a better understanding of patterns of transmission and epidemiology of *Salmonella enterica* serovars in wildlife and humans.

Chapter 6

MANAGEMENT IMPLICATIONS

Rabies has the potential to be eliminated from regional wildlife populations, demonstrated in recent years by the eradication of rabies in wildlife populations in many western European countries (Holmala and Kauhala 2006), canine rabies in coyotes from southern Texas (Fearneyhough et al. 1998), and its near elimination from red foxes in southern Ontario, Canada (MacInnes et al. 2001). Access to highly immunogenic oral vaccines, combined with baits for their delivery, is a critical strategic component of the ORV program (Slate et al. 2005). Another critical component to the success of the ORV program is ecological information on terrestrial carnivores that are reservoirs for the rabies virus.

Field research on reservoir carnivorous species that determine sizes of home ranges and habitat-use preferences are important data that need to be considered for ORV effectiveness. My research has provided critical information that can be implemented into future management practices for the ORV program. Although this study took place in western Pennsylvania, my findings can be used by other state agencies and in the national collaborative effort to combat the spread of raccoon rabies.

Since the start of the mid-Atlantic epizootic of raccoon rabies, the raccoon rabies front has progressed at approximately 29–39 km each year in eastward and northward directions (Moore 1999), with progress of the rabies epizootic being most rapid in preferred raccoon habitats (Carey and McLean 1983, Wilson et al. 1997). Knowledge of habitat use within each landscape is critical to the success of the ORV program. I found that raccoon habitat use is nonrandom; therefore, ORV application should follow a nonrandom distribution pattern. Baits should be targeted to areas of favorable raccoon habitat rather than uniformly distributed when establishing and maintaining a vaccination barrier to the spread of rabies (J. Suckow, Pennsylvania State Director of Wildlife Services, personal communication). Medium-to-low density baiting, with additional baits placed in prime raccoon habitats (landscape specific), could be the most efficient and economical method of vaccinating raccoons.

My research examined annual and seasonal sizes of raccoon home ranges because these data are needed in the development of a successful ORV program. I examined annual and seasonal home range size because ORV baiting in Pennsylvania is conducted biannually, in late April and again in early to mid-September. My study established that sizes of raccoon home ranges decreased as urbanization increased, along a forested to rural to suburban gradient. The largest raccoon home ranges were found in forested landscapes, followed by rural landscapes, with the smallest found in suburban landscapes. Male and female raccoons had similar-sized home ranges in the same landscape, and only male raccoons in rural landscapes showed a seasonal change in size of home range.

With current ORV flight-line distances of 500 m apart, the average home range of a raccoon will be flown over approximately 1 to 5 times depending on the landscape. I recommend that baiting be landscape specific and focus in areas of high probability of raccoon use, as suggested by the habitat analyses and RSF models.

Habitat use is not uniform, so baiting strategies should include the distribution of more baits in areas that are likely to support greater raccoon use and fewer baits in areas where raccoons are less likely to occur. Currently, the absolute number of baits per unit area (bait density) needed to control rabies is not well-defined but appears to be related to habitat and densities of raccoon populations.

My research findings, along with logistical complications of ORV distribution by small aircraft, suggested that ORV baiting can be conducted in a similar manner in spring and fall with respect to flight-line distances in forested landscapes. In rural landscapes, however, I recommend that spring flight-line distances be closer than those used in fall. In determining flight line distance with respect to landscape, sizes of raccoon home ranges should be taken into account in an effort to increase the likelihood of a raccoon coming into contact with an ORV bait.

Oral rabies vaccination baiting lines can be wider over forested landscapes than those in rural landscapes because raccoons are using larger home ranges in forested landscapes. In suburban landscapes, ORV baiting should be conducted by hand only, placing baits strategically in areas of preferred raccoon habitat use and not distributed uniformly on all streets because it is not a cost-effective method of raccoon vaccination in this landscape. A large number of baits currently distributed by small aircraft in suburban areas are distributed in areas raccoons are not likely to visit, such as parking lots and building roof tops (J. Suckow, Pennsylvania State Director of Wildlife Services, personal communication).

The ORV program for wildlife is the first immunological tool to fight rabies in animal hosts since vaccination of dogs became widely available in the 1940s

(Foroutan et al. 2002). Successful application of ORV programs for rabies in red foxes in parts of Europe are recognized (Robbins et al. 1998); however, ORV efficacy for raccoon rabies in the United States is yet to be determined. Information gathered in this study can be combined with knowledge of epidemiological characteristics of rabies in raccoons to combat the future spread of rabies in a more cost-effective and efficient manner.

Although my research did not show a seasonal change in sizes of most raccoon home ranges, this finding may be attributed to not collecting field data most of the winter and early spring. A field study that includes data collected throughout all seasons may refine further bait application based more directly on sizes of seasonal home ranges.

Skunks are a major contributor to rabies in North America with 38% of cases associated with the raccoon variant rabies virus involving skunks in 2001, which suggests that skunks maintain an independent cycle of raccoon rabies (Krebs et al. 2002). Skunk rabies virus has the broadest geographic distribution of all terrestrial rabies variants in the United States (Krebs et al. 1995). Currently, the only method of treating skunks for rabies is through local trap–vaccinate–release or population suppression programs (Krebs et al. 2002). The ORV program goal of containing and eliminating the rabies virus will probably remain elusive until an oral vaccine is produced that is effective in all terrestrial rabies reservoir species.

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Appendix A

Bacteria sampling protocol for *Salmonella enterica* serovar isolation from raccoon fecal swabs (*n*=738).

Bacteria Sampling Protocol: *Salmonella enterica* serovar isolation for raccoon fecal swabs

*** All incubations with lid cracked to allow air exchange

-Put fecal swab in 9 ml of BPW and vortex

-Incubate at 37 C for 24hrs

-Transfer 1 ml of slurry in 9 ml of TT broth

-Incubate at 37 C for 48 hrs

-Transfer 0.1 ml to 9.9 ml of RV broth

-Incubate at 42 C for 24 hrs

-Streak plate loop of vortexed RV on:

  -XLD and HEA plates

  -incubate at 37 C for 24 hrs

*** (+)= blue to blue/green with or without black centers on HEA

***(+)= pink with black centers on XLD

-Transfer (+) colonies (at least 2) to MAC plates

-Incubate at 37 C for 24 hrs

-Inoculate TSI slant with (+) from MAC plates

-Incubate at 37 C for 24 hrs

-Examine TSI slants and do API on positives

-If (+) do O group tests

-Send to NVSL for serotyping if (+)

BPW – Buffered Peptone Water

TT – Tetrathionate Broth

RV – Rappaport-Vassiliadis Broth

HE – Hektoen Enteric Agar

XLD – XLD Medium (Agar)

TSI – Triple Sugar Iron Agar (in slants)

MAC – Maconkeys Agar

Appendix B

Information on radio-collared raccoons (*n*=89) in 3 different landscapes in western Pennsylvania, 2003—2006.

Raccoon ID	Sex	Landscape	Fate
0494	Male	Rural	Survived
0734	Male	Rural	Trapping Mortality
0794	Male	Rural	Survived
0554	Female	Rural	Nuisance Mortality
0534	Male	Rural	Unknown Mortality
0993	Male	Rural	Survived
0754	Female	Rural	Vehicle Mortality
0833	Male	Rural	Survived
0474	Male	Rural	Nuisance Mortality
0634	Male	Rural	Land Management Mortality
0834	Female	Rural	Survived
0853	Female	Rural	Vehicle Mortality
0673	Female	Rural	Survived
0973	Female	Rural	Survived
0954	Male	Rural	Survived
0894	Female	Rural	Survived
0654	Male	Rural	Vehicle Mortality
0694	Male	Rural	Survived
0613	Male	Rural	Survived
0913	Male	Rural	Survived
0514	Male	Rural	Land Management Mortality
0812	Male	Rural	Survived

0713	Male	Rural	Signal Lost
0114	Female	Rural	Survived
0245	Female	Rural	Trapping Mortality
0021	Female	Forested	Survived
0063	Male	Forested	Crushed by falling tree
0244	Male	Forested	Survived
0254	Female	Forested	Vehicle Mortality
0263	Male	Forested	Survived
0273	Male	Forested	Survived
0284	Male	Forested	Survived
0334	Female	Forested	Vehicle Mortality
0373	Male	Forested	Survived
0403	Female	Forested	Survived
0444	Male	Forested	Trapping Mortality
0544	Female	Forested	Survived
0011	Male	Forested	Survived
0033	Female	Forested	Survived
0085	Male	Forested	Survived
0104	Female	Forested	Unknown Mortality
0124	Male	Forested	Vehicle Mortality
0164	Female	Forested	Survived
0214	Female	Forested	Survived

0224	Male	Forested	Survived
0293	Female	Forested	Trapping Mortality
0314	Male	Forested	Survived
0454	Male	Forested	Survived
0394	Male	Forested	Vehicle Mortality
0464	Male	Forested	Survived
0742	Female	Forested	Survived
0484	Female	Forested	Survived
0383	Female	Forested	Nuisance Mortality
0642	Female	Forested	Survived
0045	Male	Suburban	Vehicle Mortality
0072	Male	Suburban	Survived
0145	Female	Suburban	Vehicle Mortality
0172	Male	Suburban	Survived
0203	Male	Suburban	Survived
0234	Male	Suburban	Vehicle Mortality
0301	Male	Suburban	Survived
0324	Female	Suburban	Survived
0343	Male	Suburban	Nuisance Mortality
0355	Male	Suburban	Survived
0364	Male	Suburban	Vehicle Mortality
0424	Male	Suburban	Survived
0433	Male	Suburban	Nuisance Mortality

0483	Female	Suburban	Vehicle Mortality
0504	Male	Suburban	Survived
0523	Female	Suburban	Survived
0054	Male	Suburban	Survived
0094	Male	Suburban	Survived
0115	Male	Suburban	Unknown Mortality
0183	Female	Suburban	Survived
0192	Female	Suburban	Nuisance Mortality
0384	Male	Suburban	Survived
0414	Male	Suburban	Nuisance Mortality
1055	Male	Suburban	Vehicle Mortality
1076	Male	Suburban	Survived
1094	Male	Suburban	Survived
1135	Female	Suburban	Vehicle Mortality
1155	Male	Suburban	Survived
1174	Female	Suburban	Survived
1196	Male	Suburban	Survived
1225	Male	Suburban	Survived
1235	Male	Suburban	Survived
1245	Male	Suburban	Survived
1255	Female	Suburban	Survived
1265	Male	Suburban	Survived

Mortality sources:

Trapping Mortality -- killed by trappers/hunters during trapping season

Nuisance Mortality -- killed by landowners

Unknown Mortality -- unable to determine cause of death

Vehicle Mortality -- killed by vehicle

Land Management Mortality – killed when fields were plowed or mowed

Crushed by falling tree -- found crushed by fallen tree

Appendix C

Expected versus observed proportions of habitats used by radio-collared raccoons (*n*=74) in 3 different landscapes in western Pennsylvania, 2003—2006.

Expected (exp) versus observed (obs) proportions of habitat types used in home ranges of radio-collared raccoons (*n*=20) in rural landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the landscape, and observed use was based on recorded radio-telemetry locations (*n*=1,562) of raccoons within the landscape. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine home range habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	1.3%	0.1%	0.0% – 0.1%	-
Urban	7.7%	0.5%	0.0% – 1.1%	-
Hay	11.9%	12.0%	9.9% – 14.1%	NS
Row Crops	35.0%	32.5%	28.8% – 36.2%	NS
Coniferous Forest	4.1%	6.0%	3.7% – 8.3%	NS
Deciduous Forest	39.1%	42.6%	41.1% – 44.1%	+
Mixed Forest	0.6%	4.4%	2.7% – 6.1%	+
Wetland	0.3%	2.0%	0.6% – 3.4%	+

[a] $\chi^2 = 911.7$, df = 7, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Expected (exp) versus observed (obs) use of habitat types in core areas of radio-collared raccoons (*n*=20) in rural landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the home-range estimates, and observed use was based on recorded radio-telemetry locations (*n*=1,562) of raccoons within the home-range. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine core area habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	0.1%	0.0%	0.0% – 0.0%	-
Urban	0.5%	0.0%	0.0% – 0.0%	-
Hay	12.0%	11.0%	8.2% – 13.8%	NS
Row Crops	32.5%	28.7%	22.0% – 35.4%	NS
Coniferous Forest	6.0%	1.6%	0.2% – 3.0%	-
Deciduous Forest	42.6%	49.3%	45.0% – 53.6%	+
Mixed Forest	4.4%	0.3%	0.0% – 0.7%	-
Wetland	2.0%	9.0%	5.1% – 12.9%	+

[a] $\chi^2 = 168.9$, df = 7, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Expected (exp) versus observed (obs) use of habitat types in home ranges of radio-collared raccoons (*n*=24) in forested landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the study site landscape, and observed use was based on recorded radio-telemetry locations (*n*=1,928) of raccoons within the landscape. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine home range habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	1.4%	1.8%	1.0% – 2.6%	NS
Urban	11.3%	1.3%	0.3% – 2.3%	-
Hay	15.1%	14.0%	12.3% – 15.7%	NS
Row Crops	15.3%	15.0%	12.6% – 17.4%	NS
Coniferous Forest	4.8%	5.6%	4.2% – 7.0%	NS
Deciduous Forest	45.8%	46.8%	45.0% – 48.6%	NS
Mixed Forest	4.2%	10.9%	8.2% – 13.4%	+
Coal Fields	2.1%	4.5%	3.3% – 5.7%	+

[a] χ^2 =219.5, df = 7, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Expected (exp) versus observed (obs) use of habitat types in core areas of radio-collared raccoons (*n*=24) in forested landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the home-range estimate, and observed use was based on recorded radio-telemetry locations (*n*=1,928) of raccoons within the home-range. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine core area habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	1.8%	1.9%	1.5% – 2.3%	NS
Urban	1.3%	0.7%	0.0% – 1.4%	NS
Hay	14.0%	9.4%	8.0% – 10.8%	-
Row Crops	15.0%	11.8%	10.0% – 13.6%	-
Coniferous Forest	5.6%	3.7%	2.5% – 4.9%	-
Deciduous Forest	46.8%	60.7%	54.9% – 66.5%	+
Mixed Forest	10.9%	1.2%	0.3% – 2.1%	-
Coal Fields	4.5%	10.6%	9.1% – 12.1%	+

[a] $\chi^2 = 137.8$, df =7, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Expected (exp) versus observed (obs) use of habitat types in home ranges of radio-collared raccoons (n=30) in suburban landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the study site landscape, and observed use was based on recorded radio-telemetry locations (n=2,430) of raccoons within the landscape. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine home range habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	1.6%	1.6%	0.8% – 2.4%	NS
Urban	68.8%	56.8%	54.4% – 59.2%	-
Crops	3.7%	4.8%	3.3% – 6.3%	NS
Coniferous Forest	3.5%	5.2%	4.0% – 6.4%	+
Deciduous Forest	19.2%	26.2%	23.0% – 29.4%	+
Mixed Forest	3.1%	5.4%	3.7% – 7.1%	+

[a] $\chi^2 = 354.4$, df = 5, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Expected (exp) versus observed (obs) use of habitat types in core areas of radio-collared raccoons (*n*=30) in suburban landscapes in western Pennsylvania, 2003-2004. Expected use of habitat type was based on proportions of habitats available to raccoons within the estimated home-range, and observed use was based on recorded radio-telemetry locations (*n*=2,430) of raccoons within the home-range. Bonferonni 95% confidence intervals (CI) supplemented the chi-square tests to determine core area habitat selection.

Habitat Type	Exp[a]	Obs	CI	Test Result[b]
Water	1.6%	1.4%	0.7% – 2.1%	NS
Urban	56.8%	42.3%	39.1% – 45.5%	-
Crops	4.8%	4.7%	3.5% – 5.9%	NS
Coniferous Forest	5.2%	6.9%	4.2% –9.6%	NS
Deciduous Forest	26.2%	31.4%	28.7% – 34.1%	+
Mixed Forest	5.4%	13.5%	9.3% – 17.7%	+

[a] χ^2 =310.2, df = 5, $P \leq 0.001$.

[b] Positive (+) signs indicate habitats that were selected for by raccoons within the landscape, minus (-) signs indicate habitats that were used less frequently than expected based upon occurrence within the landscape, and habitat types not used differently than expected based on their availability are denoted as not significant (NS), based on Bonferonni 95% confidence intervals.

Appendix D

Isolates of *Salmonella enterica* serovars from raccoons (*n*=738) in 3 different landscapes in western Pennsylvania, 2003—2006.

County	Habitat Type	sample ID	other ID	***Salmonella enterica*** **serovar**	NVSL ID	NVSL rcv'd	Isolate ID
Mercer	Agricultural	1	fec. samp.	*S. Hartford*	1	1/22/2004	1
Mercer	Agricultural	2	fec. samp.	*S. Hartford*	2	1/22/2004	2
Mercer	Agricultural	4	fec. samp.	*S. Hartford*	3	1/22/2004	4
Mercer	Agricultural	5	fec. samp.	*S. Hartford*	4	1/22/2004	5
Mercer	Agricultural	7	fec. samp.	*S. Hartford*	5	1/22/2004	7
Mercer	Agricultural	10	fec. samp.	*S. Hartford*	6	1/22/2004	10
Mercer	Agricultural	12	fec. samp.	*S. Hartford*	7	1/22/2004	12
Mercer	Agricultural	13	fec. samp.	*S. Hartford*	8	1/22/2004	13
Mercer	Agricultural	14	fec. samp.	*S. Hartford*	9	1/22/2004	14
Mercer	Agricultural	21cbxld	20060327	*S. Thompson*	22	4/28/2006	80
Armstrong	Forested	30361	fecal swab	*S. Newport*	15	5/19/2004	30361
Armstrong	Forested	30427	fecal swab	*S. Newport*	16	5/19/2004	30427
Armstrong	Forested	30675	fecal swab	*S. Typhimurium*	18	5/19/2004	30675
Armstrong	Forested	30413	fecal swab	*S. Typhimurium*	20	5/19/2004	30413
Armstrong	Forested	30183	fecal swab	*S. Typhimurium (copenhagen)*	21	5/19/2004	30183

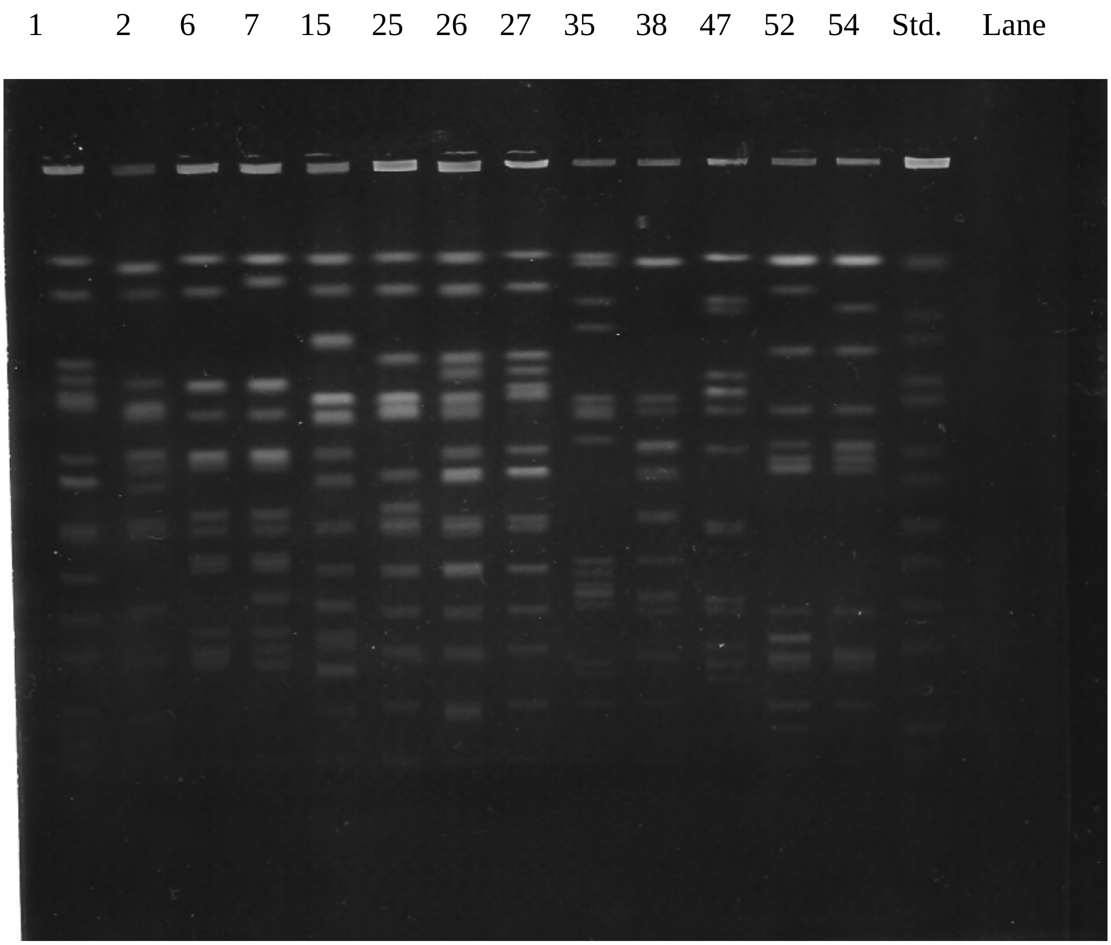
Armstrong	Forested	30430	fecal swab	*S. Newport*	22	5/19/2004	30430
Armstrong	Forested	30221	fecal swab	*S. Berta*	23	5/19/2004	30221
Armstrong	Forested	30438	fecal swab	*S. Berta*	24	5/19/2004	30438
Armstrong	Forested	30444	fecal swab	*S. Berta*	25	5/19/2004	30444
Armstrong	Forested	30183c	fecal swab	*S. Typhimurium (copenhagen)*	27	5/19/2004	30183c
Greene	Forested	5hea	20060214	*S. Newport*	1	4/28/2006	2
Greene	Forested	6xldc	20060214	*S. Paratyphi B var. L-tartrate+*	2	4/28/2006	15
Greene	Forested	1heb	20060214	*S. Oranienburg*	4	4/28/2006	18
Greene	Forested	10hea	20060214	*S. Newport*	9	4/28/2006	29
Westmorland	Forested	23xlda	20060220	*S. Infantis*	10	4/28/2006	51
Westmorland	Forested	20xlda	20060220	*S. Infantis*	11	4/28/2006	55
Westmorland	Forested	28hea	20060220	*S. Infantis*	12	4/28/2006	53
Westmorland	Forested	15xldb	20060220	*S. Infantis*	13	4/28/2006	36
Westmorland	Forested	14xlda	20060220	*S. Infantis*	14	4/28/2006	43

Greene	Forested	10xldb	20060220	*S. Infantis*	15	4/28/2006	38
Greene	Forested	9xldc	20060220	*S. Infantis*	16	4/28/2006	47
Greene	Forested	a12xldb1	20060227	*S. Typhimurium*	17	4/28/2006	64
Greene	Forested	a9xlda	20060227	*S. Newport*	18	4/28/2006	67
Greene	Forested	a7heb	20060227	*S. Typhimurium*	19	4/28/2006	71
Greene	Forested	a6heb	20060227	*S. Typhimurium*	20	4/28/2006	75
Greene	Forested	a3xlda2	20060227	*S. Hartford*	21	4/28/2006	61
Westmorland	Forested	18xldb	20060220	*S. Infantis*	12a	4/28/2006	30
Greene	Forested	a12hea	20060227	*S. Typhimurium*	17a	4/28/2006	63
Greene	Forested	1xlda	20060214	*S. Oranienburg*	4a	4/28/2006	22
Erie	Suburban	30495	fecal swab	*S. Newport*	14	5/19/2004	30495
Erie	Suburban	30796	fecal swab	*S. Newport*	17	5/19/2004	30796
Erie	Suburban	30454	fecal swab	*S. Newport*	19	5/19/2004	30454

Erie	Suburban	30560	fecal swab	*S. Oranienburg*	26	5/19/2004	30560
Erie	Suburban	30495	fecal swab	*S. Bardo*	28	5/19/2004	30495
Allegheny	Urban	21hea	20060214	*S. Newport*	3	4/28/2006	12
Allegheny	Urban	20heb	20060214	*S. Newport*	5	4/28/2006	24
Allegheny	Urban	12xlda	20060214	*S. Paratyphi B var. L-tartrate+*	6	4/28/2006	28
Allegheny	Urban	13hea	20060214	*S. Newport*	7	4/28/2006	25
Allegheny	Urban	15hea	20060214	*S. Paratyphi B var. L-tartrate+*	8	4/28/2006	26
Allegheny	Urban	24dhea	20060403	*S. Paratyphi B var. L-tartrate+*	23	4/28/2006	94
Allegheny	Urban	23dhea	20060403	*S. Paratyphi B var. L-tartrate+*	24	4/28/2006	98
Allegheny	Urban	22dxldb	20060403	*S. Paratyphi B var. L-tartrate+*	25	4/28/2006	101
Allegheny	Urban	16dhea	20060403	*S. Paratyphi B var. L-tartrate+*	26	4/28/2006	90
Allegheny	Urban	21dxlda	20060403	*S. Paratyphi B var. L-tartrate+*	27	4/28/2006	84
Allegheny	Urban	12hea	20060214	*S. Paratyphi B var. L-tartrate+*	6a	4/28/2006	27

Appendix E

Pulse Field Gel Electrophoresis analysis of isolates of *Salmonella enterica* serovars from raccoons (*n*=738) in 3 different landscapes in western Pennsylvania, 2003—2006.



PFGE patterns of XbaI-generated genomic fingerprints of *Salmonella enterica* serovars, collected from raccoons in western Pennsylvania, 2003–2006. Lane 1, *S. Bardo*; lane 2, *S. Berta*; lanes 6 and 7, S. *Hartford*; lane 15, *S. Infantis*; lanes 26 and 27, *S. Newport*; lane 35, *S. Oranienburg*; lane 38, *S. Paratyphi* B var. L-tartrate+; lane 47, *S. Thompson*; lane 52, *S. Typhimurium*; lane 54, *S. Typhimurium* (*copenhagen*); and lane Std, S. *Braenderup*.

CURRICULUM VITAE

Justin A. Compton

EDUCATION

2007 **The Pennsylvania State University**, University Park, PA
Ph.D. Wildlife & Fisheries Sciences

2002 **Michigan Technological University**, Houghton, MI
M.S. Ecology

2000 **University of California**, Davis, CA
B.S. Wildlife, Fish, & Conservation Biology

RESEARCH & TEACHING INTERESTS

- Human-wildlife interactions, zoonotic diseases, and wildlife management in urban environments.
- Epidemiology of wildlife diseases and the relationships these diseases have to public health.
- Dynamics between avian and wildlife conservation and habitat fragmentation and alteration.
- Conservation, population, community, behavioral, and landscape ecology.
- Functional relationships between population parameters (e.g., survivorship, reproductive output, dispersal rate) and environmental conditions.
- Social-ecological systems, land use practices, resilience, adaptability, sustainability, and conservation.
- Avian migration and landscape relationships.
- Public outreach and community environmental stewardship.

ADDITIONAL INTERESTS

- Traditional ecological knowledge
- Land ethics and philosophy
- Subsistence systems
- Cultural anthropology
- Backpacking
- Kayaking
- Guitar