ASSESSING TIMBER RATTLESNAKE MOVEMENTS NEAR A RESIDENTIAL DEVELOPMENT AND LOCATING NEW HIBERNACULA IN THE NEW JERSEY PINELANDS

KIM J. LAIDIG
PINELANDS COMMISSION

AND

DAVID M. GOLDEN
NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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By

KIM J. LAIDIG
Pinelands Commission
P.O. Box 7
New Lisbon, NJ 08064

And

DAVID M. GOLDEN
New Jersey Department of Environmental Protection
Division of Fish and Wildlife
Endangered and Nongame Species Program
2201 County Route 631
Woodbine, NJ 08270

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Pinelands Commission
P.O. Box 7
New Lisbon, NJ 08064

INTRODUCTION

A Pinelands timber rattlesnake (*Crotalus horridus*) monitoring program was initiated in 2001 by the Pinelands Commission and the New Jersey Division of Fish and Wildlife's Endangered and Nongame Species Program (ENSP). The objectives of the three-year study were to monitor timber rattlesnake movements in the vicinity of a partially constructed residential development in Evesham Township and to locate undocumented rattlesnake hibernacula throughout the Pinelands region. For the Evesham portion of the study, special consideration was given to the effectiveness of a fence and culvert system intended to direct the movements of timber rattlesnakes. Initial questions for the Evesham component of the study were: 1) How do the movement patterns of individual snakes vary before and after the construction of the residential development and the fence and culvert system, and 2) Does the fence and culvert system effectively direct rattlesnakes away from the development and toward forested areas? This report describes the methodology and results of the timber rattlesnake monitoring project for both the Pinelands-wide and Evesham components of the study.

Part I. Pinelands-wide Study

METHODS

From 2001 to 2003, ENSP biologists captured timber rattlesnakes throughout the Pinelands and used radiotelemetry to track the snakes to their hibernacula. All snakes were captured in an opportunistic fashion, with individuals notifying ENSP of snake sightings and members of a response team quickly reacting to capture the snakes. Members of the 15-person response team (primarily New Jersey state employees) were trained in proper snake-handling techniques and were on call to pick up rattlesnakes.

Timber rattlesnakes were surgically implanted with radio transmitters (AVM Instrument Company peritoneal transmitters, G-3 and G3-1V) at the NJ Division of Fish & Wildlife's Clinton office under the supervision of biologist Michael Valent. Aseptic techniques and the procedures described by Reinert and Cundall (1982) and Reinert (1992) were followed during each surgery. Implanted rattlesnakes were released at the point of capture. Following their release, snakes were not radiotracked or located again until early October when aerial telemetry was carried out from a low-flying aircraft. General locations for the snakes (± 500 m) were estimated from the air and exact locations were determined through ground searches. The snakes were then radiotracked every other day until they entered their hibernacula. The location of each hibernaculum was recorded using a global positioning system (GPS).

RESULTS

In 2001, ENSP captured a total of three rattlesnakes (Table 1). Two of these snakes were captured in Bass River Township (PL0101 & PL0103) and the third was captured in Pemberton Township (PL0102). PL0102 was unable to be revived following the surgical implantation of a radio transmitter. Though the exact cause of death was unknown it was attributed to some aspect of the surgical procedure. The two Bass River rattlesnakes each entered separate hibernacula located in Atlantic white cedar (*Chamaecyparis thyoides*) wetlands within Bass River State Forest in October 2001. The locations of these hibernacula were previously unknown.

In 2002, five rattlesnakes were collected from Bass River, Lacey, and Washington Townships. Four of these snakes entered previously undocumented hibernacula in October of the same year. Three hibernacula were located in Bass River State Forest, Bass River Township (PL0204, PL0206, & PL0207) and one (PL0208) was located in Wharton State Forest, Washington Township. All hibernacula were located in Atlantic white cedar wetlands. The fifth snake (PL0205) was found dead along Dover Road in August 2002, apparently killed by a car. Snakes PL0101 and PL0103, originally captured in 2001, were tracked again in 2002. These snakes entered the same hibernacula they had entered the previous year.

In 2003, two rattlesnakes (PL0309 & PL0310) were captured in Bass River and Lacey Townships and one (TR2003.52) was collected from Mansfield Township. PL0309 over-wintered in the hibernaculum originally found by tracking snake PL0101 in 2001. PL0310 entered a hibernaculum in an Atlantic white cedar swamp that was previously identified by other researchers (Zappalorti, *pers. comm.*). This site was located in Greenwood Wildlife Management Area, Lacey Township. TR2003.52 was captured late in the season within a densely developed subdivision in a region considered to be outside the normal range of the Pinelands timber rattlesnake population. Because ENSP staff believed the snake may have escaped from captivity this individual was not implanted with a transmitter.

In summary, ENSP captured eleven rattlesnakes over the study period (Table 1). Nine of these snakes were successfully tracked to seven different hibernacula. Six hibernacula were previously undocumented. The seven hibernacula were located in Atlantic white cedar wetlands and all were located on publicly-owned land.

Part II. Evesham Study

METHODS

Sanctuary development and vicinity

The Sanctuary is a partially constructed residential development in Evesham Township, Burlington County, with an estimated planned buildout of approximately 250 single-residence dwellings on 1.0-acre lots (Figure 1). The development is located at the western edge of the Pinelands region and in the immediate vicinity of timber rattlesnake hibernacula. Hopewell Road, a heavily traveled county road, runs along the western boundary of the development. Much of the adjacent area to the west of the Sanctuary consists of residential development. The area to the north, east, and south (excluding an adjacent 30-unit residential development on 4.5-acre lots called Compass Point) consists of undeveloped public and private lands. These lands support characteristic Pinelands forested vegetation communities, including primarily pine (*Pinus* spp.) dominated upland and lowland forests. The Sanctuary is bisected by Kettle Run, a Rancocas Creek tributary, forming northern and southern sections of the development.

The Sanctuary is located in Rural Development Area, a management zone in which certain land uses are permitted (Pinelands Commission 1980, Collins and Russell 1988). In order of increasing permitted land-use intensity, management areas in the vicinity of the Sanctuary included Preservation Area District, Forest Area, Special Agricultural Production Area (blueberry and cranberry agriculture), Agricultural Production Area, Rural Development Area, and Regional Growth Area.

Most of the southern section of the Sanctuary development was already constructed prior to the start of this study, whereas very little construction had occurred on the north side of Kettle Run (Figure 1). Other than fence and culvert installation and minor site modifications, few changes occurred to the southern section during the study period. New housing construction and street paving occurred in the northern section primarily during 2002 and 2003. A significant portion of the Sanctuary remains to be constructed. Most of this future construction is slated to occur in the northern section. A number of housing units are also planned for the southern section along a currently unpaved connector street, Georgia O'Keefe Way, which would connect the northern and southern sections of the Sanctuary. A lake, formed by impounded surface water from Kettle Run, was drained when a dam failed. The partially vegetated lake basin was planned to be refilled for recreational uses and a control structure was installed on Kettle Run near Georgia O'Keefe Way for that purpose.

Fence and culverts

A 2.7-km fence and five culverts were installed at the Sanctuary in three stages over a three-year period in accordance with a court-mediated settlement agreement (Figure 1). The fence was intended to prevent timber rattlesnakes from entering the partially constructed southern portion of the development and to direct them to forested land to the east. All fence was constructed of 6.5 mm-mesh stainless-steel hardware cloth and installed to stand approximately 1-m high, with the lower 0.15 m of the fence buried beneath the ground surface. Two sections of fence, one extending 0.26 km from Kettle Run to the north and east and another extending 0.23 km from Kettle Run to the south and east, were constructed in 2001. Kettle Run flows through a 14 m-wide gap between the western ends of these two sections of fence. A 1.3-km section of fence was constructed as an extension to the previous fence early in 2002, prior to timber rattlesnakes emerging from their hibernacula. This section extended to the east and around an area planned for future residential development. Two sections of fence (0.42 and 0.46 km) and five concrete culverts were installed along Georgia O'Keefe Way in the autumn of 2002 after rattlesnakes had returned to the vicinity of the hibernacula. The culverts were intended to allow snakes to move beneath the street to minimize the risk of injury or death from vehicular traffic. Culverts were installed at ground level, perpendicular to Georgia O'Keefe Way, and at 90-m intervals. The culverts were 15 m long, with a 0.91-m wide by 0.41-m high opening. A metal grate with 0.15 m by 0.31 m openings was staked against culvert openings and connected to the fence so that no gaps were present between the fence and culverts. The complete fence and culvert system was operational prior to snake emergence in 2003. Fence and culvert locations were recorded with a GPS.

Radiotelemetry and Data Collection

Nine timber rattlesnakes were monitored over three field seasons (2001-2003). Other than two snakes recovered from previous telemetry work conducted at the Sanctuary, all snakes were captured opportunistically. Prior telemetry work by other researchers in 2000 (Zappalorti, *pers. comm.*) led to the discovery of the overwintering area at the Sanctuary after three female timber rattlesnakes were tracked to their hibernacula. Two of these snakes were radiotracked as part of the current study. The third snake tracked in 2000 was not recovered. Transmitter-implantation procedures were the same as those described in the Pinelands-wide study. With one exception, all snakes were released at the capture location after surgery. TR6, a gravid (pregnant) female found basking near a street at the time of capture, was released at a remote and presumably suitable basking site approximately 0.6 km from the capture location. The snake immediately returned to the original capture location. Most snakes were characterized with respect to weight, length, and surface marks (e.g., blotch patterns, scars, etc.) in the lab at the time of surgery. Initial measurements are presented for general comparisons among individuals. A female timber rattlesnake, captured very late in the field season of 2003 in the vicinity of the hibernacula, was not implanted with a transmitter. Transmitters were removed from snakes in June 2004.

Radiotelemetry equipment was used to locate transmitter-implanted rattlesnakes at the Sanctuary approximately every other day until the snakes reentered hibernacula in the fall or until snakes were lost to death or transmitter failure. The locations of each snake were recorded with a GPS. Care was taken during searches to avoid disturbance of the snakes. Snakes were allowed to move freely except if found in the immediate vicinity of a paved road or residence. In these cases the snake was generally moved approximately 10-15 m into the nearest forested area.

Data Analysis

The GPS data, ArcView software (Environmental Systems Research Institute, ESRI, Inc., Redlands, CA, 1992-2000, 1999-2001), and the Animal Movement Program 2.0 (Hooge et al. 1999) were used to construct activity-range maps and calculate activity-range sizes. Default settings were used with the Animal Movement Program. An activity range, as defined with the minimum convex-polygon method, consisted of the area bounded by the outermost telemetry locations of a snake (Hooge et al. 1999). The kernel method was used to estimate general (95% isopleth) and core (50% isopleth) activity areas which correspond to the intensity of snake activity in an area (Hooge et al. 1999). Values were calculated for other activity measures defined by Reinert (1992), including total distance moved (the sum of all linear distances between locations), range length (linear distance between the two most distant locations), mean distance moved per day (total distance moved, divided by the total number of days monitored), and mean distance per move (average of all distances between locations). The distance moved from hibernaculum (linear distance between the hibernaculum and the most distant location) was also calculated. Activity measures were calculated for snakes that were radiotracked for complete or nearly complete active seasons. A complete active season covers the period beginning with snake emergence from hibernacula in the spring and ending with snake reentry to hibernacula in the fall. An overall snake activity range was defined by constructing a minimum convex-polygon for the locations of all transmitter-equipped snakes for the entire three-year period.

Land Use/Land Cover Profiles. Land use/land cover profiles for the overall snake activity range and for individual activity ranges of each timber rattlesnake tracked for a complete season were compiled using ArcView software and a land use/land cover coverage (NJDEP, 1995/97 Land Use/Land Cover Update 2001). The NJDEP coverage characterized land use using the general Anderson Level I classification and subclasses (Anderson et al. 1976). Wetlands were classified according to Cowardin et al. (1979). Pinelands land use/land cover types within the overall snake activity range included developed land, upland agriculture, wetland agriculture, barren land, pine (*Pinus* spp.) and oak (*Quercus* spp.) upland forests (based on the dominant canopy-cover species), pine and hardwood wetland forests (based on the dominant canopy-cover species), herbaceous wetlands, and open water. Snake activity within a land use/land cover type is expressed as the percentage of an active season the snake was located in a cover type.

The 1995 land use/land cover data predated construction activities at the Sanctuary and Compass Point developments. A comparison of 1995 and 2002 aerial photography indicated that the only major landscape changes that occurred in the overall snake activity range were associated with these developments. A portion of the forested cover within the boundary of the Sanctuary and Compass Point developments was converted to developed land (houses, pavement, lawns, etc.) during that time period. Using ArcView software, snake activity within the boundary of the two developments, expressed as a percentage of the active season, was determined for each snake tracked over a complete season.

Fence and Culvert Monitoring. The effect of the fence on snake movements and the use of culverts were chiefly assessed by visual examination of plotted timber rattlesnake telemetry points relative to fence and culvert locations. Sand-track stations were established across both entrances of each of the five culverts to record tracks of snakes and to corroborate the use of culverts by timber rattlesnakes as determined with telemetry. In an effort to obtain photo vouchers of snakes passing through the culverts, motion-activated cameras (PhotoHunter 35-mm Infrared Camera System) were mounted inside the metal grates at the eastern opening (most distal to hibernacula) of the two most southerly culverts. Cameras were operational from June through mid-July, 2003, to coincide with the dispersal of rattlesnakes away from the hibernacula area. The sensitivity of the motion detector was tested by very slowly pulling a stick with a string repeatedly through the culvert mouth. The camera was activated during slightly more than half of the field trials. The entire length of fence was surveyed for timber rattlesnakes and all other species approximately once every two days in the early and latter part of the season, and less frequently at other times. Behavioral observations were recorded for all species that were encountered at the fence.

RESULTS

Snakes

Five male and four female timber rattlesnakes representing a range of sizes were radiotracked for various time periods during the study period (Table 2). Three snakes (TR7, TR9, and TR10) were tracked for two consecutive, nearly complete activity seasons. Two snakes (TR4 and TR5) were tracked in two consecutive seasons, but tracking was initiated in late spring of the first year. These two snakes were previously tracked by others in 2000 and overwintered in a laboratory prior to the 2001 season. Three snakes (TR8, TR11 and TR12) were tracked for a single, complete season. One gravid female (TR6) was tracked for over half of a single season before being lost prior to giving birth. TR4 gave birth to nine neonates in 2000 (Zappalorti, *per. comm.*) and TR5 gave birth to at least three neonates in 2002. TR5 was found dead and severely mutilated near the fence and Georgia O'Keefe Way almost two weeks after giving birth. TR5 is the only confirmed mortality during the study period among the nine snakes that were monitored. After the conclusion of the study, in July 2004, TR7 was found dead on a street near the western boundary of the Compass Point development. TR4 and TR8 were not recovered after their transmitters failed during hibernation. TR12 was determined to be gravid when transmitters were removed in June 2004.

Overall snake activity range and general snake movements

The nine transmitter-equipped snakes traversed a region encompassing 1500 ha during the study period (Figure 2). This overall snake activity range was approximately bounded by Hopewell Road to the west, Jackson Road and associated development and agricultural land to the south, cranberry bog and blueberry field complexes to the east, and a golf course and other development to the north. The density of snake locations was highest in the immediate vicinity of the Sanctuary. The two most heavily utilized areas within the Sanctuary were the forested Kettle Run corridor between the stream and residential dwellings aligned parallel to the stream and the forested area in the vicinity of Georgia O'Keefe Way. Forested lands to the east and southeast of the development were also extensively used by some of the snakes.

Snake activity parameters

Values for activity parameters varied considerably among individual timber rattlesnakes and were generally related to size, sex, and breeding status of individual snakes that were tracked for complete seasons (Tables 2 and 3, Figures 3-10). Activity range maps for snakes not tracked for complete seasons are presented in the Appendix. The two largest males (TR9 and TR10) had the largest activity ranges. Both snakes had total travel-distances of greater than 11 km and traveled over 3 km from the hibernacula in both years when they were tracked for the entire active season. The gravid female (TR5) traveled the shortest distance from the hibernaculum and was characterized by a reduced activity range compared with its movements in the previous year while in a non-gravid condition. Not including gravid snakes, the smallest activity range belonged to the smallest snake (TR12), a female. Non-gravid females exhibited values in the various activity parameters that were intermediate between males and gravid snakes. For most snakes, range-length values closely matched furthest-distance from den values because hibernacula were situated near the periphery of activity ranges. With the exception of a gravid female (TR05) and two other snakes (TR7 in 2003, and TR12), the active season movements for snakes formed round-trip loops. The snakes dispersed in a north to east bearing from hibernacula and moved in a clockwise direction. TR7 (in 2003) and TR12 exhibited more erratic movements characterized by numerous direction changes and no looping pattern. Neither snake moved beyond the boundary of the development in 2003.

Kernel analysis indicated that for all snakes tracked for complete seasons, at least a portion of their estimated core use area (50% isopleth) occurred within the Sanctuary development. Specific areas within the Sanctuary identified as core areas included the Kettle Run corridor (e.g., TR7 and TR12, Figures 5 and 10), a rookery site (basking area) used by gravid snakes (e.g., TR5 and TR6, Figure 4 and Appendix), and a forested area along Georgia O'Keefe Way (e.g., TR11, Figure 9). Other core areas located outside of the Sanctuary development included an abandoned cranberry-bog area to the east of Compass Point (TR4, Figure 3) and an area of pine-dominated uplands and lowlands to the east of the Sanctuary that was used for much of the summer by TR11 (Figure 9).

Snake movements with respect to activity ranges, the rookery site, and hibernacula were consistent between years. A visual assessment of between-year activity ranges for TR9 and TR10 indicated that the two individuals moved over nearly the same area to the northeast and east of the Sanctuary and traveled similar distances in both years (Table 3, Figures 7 and 8). Though TR7 made an extensive southerly movement in 2002, this snake occupied the Kettle Run corridor within the Sanctuary for most of both field seasons (Figure 5). Gravid snakes used the same rookery area near the hibernacula in 2001 and 2002. The activity ranges of two females (TR5 in 2001 and TR4 in 2002) in nongravid condition were similar (Figure 3 and Appendix). With one exception, all snakes returned to the same hibernacula from which they emerged in the spring. The exception, TR9, moved from a stream-bank hibernaculum late in 2001 and overwintered beneath a partially decomposed log located approximately 35 m from the stream channel. This movement coincided with elevated surface-water levels adjacent to the stream-bank den that resulted when the downstream control structure could not accommodate heavy water flows. The snake overwintered in the stream-bank hibernaculum in the following year.

Snake movements relative to land use/land cover

Forested land cover occupied nearly 90% of the overall snake activity range with about 50% as upland forest and 40% as lowland forest (Figures 11 and 12). The remaining 10% of the overall snake activity range was developed and agricultural lands, open water, and herbaceous wetlands. All but TR09 occupied upland forest habitat for more than half of the activity season (Figure 12). Pine-dominated uplands were heavily utilized by most of the snakes. Two snakes used oak-dominated uplands for nearly a quarter of the active season. Three of these snakes spent the entire active season within the development. TR9 spent more than half of the activity season for both years in lowlands. Two females (TR5 in 2001 and TR4 in 2002) occupied herbaceous wetlands associated with an abandoned cranberry-bog complex to the east of Compass Point for a considerable part of the season. On average, timber rattlesnakes tracked for complete seasons occupied upland forest cover types nearly 70% of the active season and wetland forest types and herbaceous wetlands slightly over 30% of the active season. Forest cover within the boundary of the Sanctuary and Compass Point developments was used by six snakes for over half of at least one active season (Figure 12).

Snake movements near the fence and culverts

The fence directed the early-season movements of some of the timber rattlesnakes but failed to prevent any of the snakes from entering the southern portion of the development in 2002 and 2003 when a major portion of the fence was operational. Two snakes (TR8 and TR10, Figures 6 and 8) in 2002 and two snakes (TR10 and TR11, Figures 8 and 9) in 2003 followed the fence as they moved to forested areas east of the development early in the season. A gravid snake (TR5 in 2002) moved along the fence in the spring, reversing directions several times over a period of two weeks, and eventually breached the fence before moving to a rookery site (Figure 4). The other snakes either crossed the fence early in the season (e.g., TR7 and TR12) or moved in a direction away from the fence (TR9). In both years, all snakes eventually passed into the southern section of the Sanctuary by moving around the end of the fence, passing through a gap in the fence, or moving through the permanent opening where the fence intersects Kettle Run. Gaps in the fence were created at several locations throughout the study period as a result of vandalism and fallen tree branches. After moving past the fence boundary into the development, snakes typically remained in forested cover despite the close proximity of cleared areas and structures associated with residences. Though snakes generally avoided cleared areas, TR7 and TR12 were captured in 2003 on five and four occasions, respectively, and moved to nearby forested cover because they were found on or along streets, lawns, or active construction areas. At the end of the season, most snakes passed the fence boundary again to gain access to hibernacula.

Timber rattlesnakes observed in the vicinity of the fence were usually coiled beneath shrub cover within several meters of the fence. They were less frequently found coiled alongside the fence where the shrub cover had been cleared. On the few occasions when timber rattlesnakes were observed traveling along the fence, the snakes typically poked their snout against the fence, as if seeking an opening, while they moved.

In June 2003, two snakes (TR10 and TR11) passed through the southernmost culvert nearly two weeks after first encountering the structure. After initial entry, TR10 and TR11 reemerged from the culvert on the side of entry, and occupied an area within 20 and 60 m of the entrance for 10 and 14 days, respectively. After eventually passing through the culverts within three days of each other, the snakes made large movements to the east. Sand-track stations recorded the trails of both snakes, but their movement through the culvert failed to trigger the motion-activated camera. In October, the tracks of a large-bodied snake, presumed to be a timber rattlesnake because of the width of the tracks, were noted in the sand-track station on the east end of an adjacent culvert and leading into the culvert entrance. No transmitter-equipped rattlesnakes were in the vicinity of the culvert at the time of these observations.

Animals near fence and culverts

Nine other animal species were observed at or moving along the fence (Table 4). The behavior of black racers moving next to the fence was similar to that observed for the timber rattlesnakes (i.e., poking their heads against the fence). Several box turtles and painted turtles were observed at the base of the fence attempting to climb it. A moderately sized snapping turtle was found dead and hanging from the top of the fence by the skin of its rear leg. The turtle appeared to have been snagged by the sharp edges of the hardware mesh as it attempted to climb over the fence and down the other side. Another snapping turtle was observed attempting to burrow beneath the fence. Woodchucks also repeatedly burrowed beneath the fence. Deer tracks were frequently noted near and running parallel to the fence. People were also occasionally seen walking or riding horseback in the vicinity of the fence. The motion-activated camera recorded nine species of vertebrates in the two southernmost culverts during a six-week period, with northern fence lizards, woodchucks, striped skunks, and house cats accounting for most of the records (Table 5).

DISCUSSION

The orientation of all transmitter-equipped snakes away from major roads and historically established developed and agricultural areas suggests a negative association between timber rattlesnake movements and these features. The results of this study suggest they generally do not spend time in cleared areas such as fields or yards. Timber rattlesnakes are considered to be morphologically and behaviorally adapted to forested habitat and, with the exception of gravid snakes, do not spend appreciable amounts of time in open-canopy settings (Reinert and Zappalorti 1988). The occurrence of this species is negatively associated with road density elsewhere in its range and its distribution is thought to be largely determined by road mortality (Rudolph et al. 1998, 1999). Although a single example of timber rattlesnake mortality on a road was recorded in the Pinelands-wide portion of this study, dead specimens on roads elsewhere in the Pinelands have been reported. From 1988-2002, sixteen out of 106 location records for timber rattlesnakes in the Pinelands (Natural Heritage Database) were for snakes reported as dead on roads. An additional four records were for snakes intentionally killed on roadsides after the snakes were discovered by onlookers. Snakes from the Sanctuary that moved to the west across the major roadway may have suffered higher mortality rates over the years with the result that few, if any, snakes currently travel to those areas. Sampling bias may affect these results because all snakes were found and most researcher time was spent in areas within the Sanctuary development and to the east of the road. However, because several snakes were obtained in response to residents within the study area who reported snakes, and no reports were received from residents in the more densely developed region to the west of the road, the observed directional orientation of snake movements is not considered to be an artifact of sampling bias.

The looped seasonal movement pattern exhibited by most snakes in this study was described by Reinert and Zappalorti (1988) as typical for most snakes in another Pinelands timber rattlesnake population. Spring dispersal toward the northeast and a clockwise direction of travel was also apparent for all but one of the snakes that were monitored for complete seasons by Reinert and Zappalorti (1988). They observed that the exception, which was a male, did not follow a looped pathway and the presence of females in the area during the breeding season was thought to have influenced the snake's movements. In an investigation of timber rattlesnake movements between translocated and resident snakes, Reinert and Rupert (1999) described the looping pattern as typical for resident snakes. More erratic, extensive, and frequent movements characterized translocated timber rattlesnakes and translocated individuals suffered higher mortality. Translocated snakes that survived eventually settled into a more repeated and smaller activity range over a period of several seasons. The similar year-to-year movements of TR9 and TR10 and the looping round-trip movements of these and other individuals tracked in single seasons resemble movements described for resident snakes by Reinert and Rupert (1999). Notably, these snakes moved to forested areas beyond the development boundary relatively early in the activity season. In contrast, TR7 and TR12 resembled translocated snakes with respect to erratic movements, frequent direction changes, and no round-trip looping pattern. Because TR12 was determined to be gravid in the spring of the following year, breeding activities may have affected the movements of these two snakes in 2003. Other factors, such as changes to landscape features in the vicinity of the hibernacula and more frequent handling may have contributed to the uncharacteristic movements of these two snakes. Because these snakes remained within the boundary of the development, they encountered fence, structures, paved streets, cleared lots, and active construction sites more frequently and, as a consequence, were handled and moved more frequently than other snakes. Reinert (1992) cautioned that snake movements may be altered by handling, surgery, constant disturbance through frequent observation, and the burden of transmitters. With the exception of a higher frequency of handling and relocating for TR7 and TR12, these factors were experienced equally by snakes in this study.

A trend of increasing activity-range size and travel-distance values for gravid, non-gravid females, and males was generally consistent with those described for timber rattlesnakes in the Pinelands (Reinert and Zappalorti 1988) and elsewhere (Brown 1993). Values for total distance traveled (5.38 and 7.29 km) and activity range size (101.4 and 123.5 ha) for the two most wide-ranging snakes reported by Reinert and Zappalorti (1988) were lower than most of the males tracked at the Sanctuary development. Although Reinert and Zappalorti (1988) did not report snake measurements, these contrasting values may represent differences in snake sizes between the two studies. The apparent low number of females at the Sanctuary may also have affected the movements of males, resulting in greater travel distances as males search for receptive females. Reinert and Zappalorti (1988) monitored nine females whereas only four were tracked at the Sanctuary, and of those four, one was killed and two were lost.

The use of upland and wetland forest types by individual snakes could not be compared with other Pinelands colonies. Though Reinert and Zappalorti (1988) indicated that several snakes had an affinity for the vicinity of a stream, they did not quantify the amount of time spent in different forest types. General habitat descriptions summarized by Brown (1993) for timber rattlesnakes from mountainous areas in the northeast typically include dry forested ridges, rocky outcrops, and deciduous and coniferous forests. Southern populations may utilize swamps and wet pine flatwoods (Brown 1993). Though snakes at the Sanctuary included both pine- and oak-dominated uplands and pine- and hardwood-dominated wetland forest in their activity areas, most snakes occupied upland forest types for the majority of the active season.

With few exceptions, most of the core snake activity areas identified were situated within the boundary of the Sanctuary development or on land which could be developed in the future. The area in the southern section of the development near Georgia O'Keefe Way that was identified as core activity area for several snakes is slated for residential development. This area was also used as a travel pathway for other transmitter-equipped timber rattlesnakes. Though a conservation easement protects core use areas in the Kettle Run corridor, this critical area will be entirely surrounded by a county road and residential streets after construction of Georgia O'Keefe Way. The residential streets will likely have less traffic volume than nearby county roads, but even low volume roadways (100 vehicles/day) may have a considerable impact on large snake species such as timber rattlesnakes (Rudolph et al. 1999). Core activity areas associated with abandoned bogs to the east of Compass Point are situated in an area where development may be permitted. A portion of a single snake's (TR11) core area was located in a zone designated as Preservation Area District.

The core area used as a rookery by gravid snakes in 2001 and 2002 was considered particularly vulnerable. This site, comprised of a lot with open-canopied forest and an open lot with brush and other debris piles, is surrounded on three sides by houses and a street. Although the area has already been considerably disturbed, the scheduled development of this site may change the conditions that attracted the gravid snakes to this site and cause the snakes to seek another area. Gravid snakes may continue to attempt to use the existing rookery site after it is developed because an attempt to establish an alternate rookery by relocating gravid TR6 to an open canopy area nearly 0.6 km away failed when the snake immediately returned to the original rookery site. Continued use of the site may place gravid snakes at a higher level of risk because areas of high human activity are associated with accidental mortality, deliberate killing, or illegal collecting of snakes (Reinert and Zappalorti 1988). In either case, changes to the rookery may have an impact on the successful reproduction of this population.

The failure of the fence to prevent any of the snakes from entering the southern portion of the development may be attributed to the materials used to construct the fence, the large movements of timber rattlesnakes, and the configuration of the fence. The fence material used (hardware cloth) was vulnerable to cutting, crushing by off-road vehicles, or collapse under the weight of fallen tree branches. All of these situations occurred numerous times during the study period and, despite vigilant efforts to maintain the fence in an operational condition, some of these gaps may have been used by snakes. The permanent gap in the fence at the stream is suspected to have been used by several snakes to enter the development. Despite the extensive length of fence (2.7 km) constructed at the Sanctuary, the large movements characteristic of this species allowed several snakes to routinely enter the development by passing around the end of the fence. The fence did not form a completely closed area but extended only partially around the development. The successful use of fences in herpetological applications elsewhere contrast with that used at the Sanctuary. Brown (1993) reported the apparent success of a hardware cloth fence erected to exclude timber rattlesnakes over a period of several years from a vacation camp in New York. The fence was erected around the camp and was 250 m long. Though this strategy may merit consideration for excluding snakes from comparatively small areas such as an individual yard or lot, preventing snakes from using a large area at the Sanctuary by encircling the entire development would be nearly impossible given the number of streets and residences the barrier would have to cross. For conservation purposes fences have been used to direct animals under or over busy roadways. The fences associated with successful examples may be more appropriately termed barriers and are typically permanent, linear features constructed of durable materials such as concrete (e.g., Dodd et al. 2004). In this case, the purpose of the barrier is to direct animals to a culvert to allow safe passage to the other side of a roadway and not to exclude them from a large area. For at least two snakes, the fence along Georgia O'Keefe Way was successful in directing the snakes to culverts beneath the street.

Other than the failure to exclude snakes from the development, the extensive length of fence at the Sanctuary may be problematic for other reasons. The fence may serve as a focal point for unauthorized collecting or harassment of timber rattlesnakes and other species that may be discovered along the fence. Though no deliberate killing or illegal collecting of snakes was observed during the study, the mutilation of TR5 near Georgia O'Keefe Way and the fence and the loss of gravid TR6 at its rookery alongside a street aroused suspicion that these activities may have occurred. The fence may also stress the snakes by increasing travel distances as suggested by the telemetry data. Though the effect of the fence on predation rates on timber rattlesnakes, particularly on smaller size classes, was not examined, predation rates may increase as a result of greater visibility and more frequent encounters with predators that travel along the fence. Disruption of the normal activity movements of other species by the fence, as inferred from the number of individuals of several species recorded at the fence as well as behavioral observations, is of concern.

This study represents the first documented use of culverts by timber rattlesnakes to travel beneath a roadway. Other snake species have used culverts in association with barriers to move beneath roadways in coastal plain systems (Dodd et al. 2004) and the use of culverts or tunnels is a recommended strategy for reducing the impacts of roadways on wildlife (Forman 2000). The initial, apparent reluctance of both snakes to pass through the culvert has not been described for other snake species in the presence of culverts. This behavior may be due to several factors including a tentativeness associated with the first encounter with an unknown landscape feature, darkness toward the center of the culvert, chemosensory cues left by other animals that passed through the culverts, a change in microclimate (temperature and humidity), and substrate differences (concrete versus sand and leaf litter). Some of these factors may be alleviated by using larger culverts which would allow for increased air movement inside and greater light penetration into the entrances. Substrate differences could be mollified by distributing sand and leaf litter along the entire length of the passage. While use of culverts by the snakes offers initial optimism, it should be noted that mammals, some of which depredate small snakes, also used the culverts. Though the impact of culverts on predation was not examined here, and has received limited attention elsewhere (Dodd et al. 2004), the use of culverts by potential predators raises the possibility that higher predation rates on snakes may occur in the vicinity of culverts.

The encroachment of housing developments on critical habitat is considered one of the major present-day threats to timber rattlesnake populations throughout much of its geographical range (Brown 1993). Brown (1993) suggested that land protection (including the den and areas of habitat around the den) was critical to maintaining a viable timber rattlesnake population. A protected area of 1.5 miles (2.4 km) in radius around the den was recommended as adequate to protect most females and many of the males with the caveat that this area may not protect the whole population. In the Pinelands, protection of habitat has been primarily accomplished through regional management area designations (zoning). These types of regional land-use planning decisions are considered to have greater, long-term positive effects on the protection of threatened snake species habitat when compared with various mitigation techniques performed at a site-specific scale (Zampella 1986). Similarly, previous regional management-area designations in the Sanctuary area allowed for the development to occur and provided the framework for future development both within the Sanctuary and surrounding areas. Comparatively little area near the hibernacula is designated Preservation Area District, the most restrictive management zone with respect to permitted development. Because snake activity primarily occurred in management areas where development has already occurred and may occur in the future, and the exclusion fence was largely ineffective in maintaining a separation between snakes and development, impacts to this snake population are expected to intensify as additional development occurs. Because the nearest known Pinelands hibernacula are distant (> 20 km away), with major roadways and a large agricultural region present in the intervening area, any impacts to the Sanctuary timber rattlesnake colony would be difficult to offset. In the absence of more restrictive regional planning decisions, the application of Brown's (1993) criteria suggests that an inadequate area has been protected to maintain the long-term viability of this population. This assessment of the timber rattlesnake colony at the Sanctuary must be considered preliminary because the total number of snakes in the colony is unknown and a significant portion of the development remains to be completed. The analysis of snake movements from this study may provide a benchmark against which future assessments of snake movements and the integrity of this timber rattlesnake colony can be made.

CONCLUSIONS

1. Telemetry data for nine timber rattlesnakes over a three-year period indicated that rattlesnakes used extensive areas of forested uplands and wetlands within a 1500-ha area in and around the Sanctuary development.

2. Core activity areas for several timber rattlesnakes, including a rookery used by gravid snakes, were located on portions of the Sanctuary that may be developed in the future.

3. The fences did not prevent any of the transmitter-equipped timber rattlesnakes from entering constructed portions of the development.

4. Two timber rattlesnakes used culverts to move beneath Georgia O'Keefe Way to forested lands east of the development.

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Table 1. Information on eleven timber rattlesnakes captured as part of the Pinelands-wide study during 2001-2003.

Snake Number	Date Captured	Gender	Hibernaculum Number	Township of Hibernaculum
PL0101	7/30/2001	M	1	Bass River
PL0102	8/7/2001	M	-	-
PL0103	8/14/2001	M	2	Bass River
PL0204	7/22/2002	F	3	Bass River
PL0205	7/18/2002	F	-	-
PL0206	8/16/2002	M	4	Bass River
PL0207	8/5/2002	M	5	Bass River
PL0208	8/27/2002	M	6	Washington
PL0309	8/3/2003	M	1	Bass River
PL0310	8/1/2003	M	7	Lacey
TR2003.52	10/9/2003	M	-	-

Table 2. Characteristics of nine timber rattlesnakes radiotracked at the Sanctuary, Evesham Township, Burlington County, NJ, during 2001-2003. TR4 was gravid when weighed. An "H" refers to hibernaculum.

Snake Number	Sex	Initial Weight (g)	Initial Total Length (cm)	Years Tracked	Start Date	End Date	Tracking Period (days)	Year-end Status
TR4	F	976	91.4	2001	1-Jun	28-Sep	120	H
				2002	15-Apr	21-Oct	190	H
				2003	-	-	-	Lost
TR5	F	650	95.2	2001	1-Jun	26-Sep	118	H
				2002	8-Apr	20-Sep	166	Dead
TR6	F	775	93.0	2001	5-Jun	11-Sep	99	Lost
TR7	M	875	112.3	2001	28-Jun	26-Jul	29	Lost
				2002	29-May	28-Oct	153	H
				2003	16-May	15-Oct	153	H
TR8	M	1100	114.4	2001	1-Aug	1-Oct	62	H
				2002	15-Apr	7-Oct	176	H
				2003	-	-	-	Lost
TR9	M	1550	116.5	2001	8-Aug	5-Nov	90	H
				2002	17-Apr	7-Oct	174	H
				2003	30-Apr	11-Oct	165	H
TR10	M	1175	114.5	2002	8-May	17-Oct	163	H
				2003	30-Apr	17-Oct	171	H
TR11	M	675	110.5	2003	20-May	20-Oct	154	H
TR12	F	400	84.1	2003	19-May	17-Oct	152	H

Table 3. Activity parameters for nine timber rattlesnakes radiotracked at the Sanctuary, Evesham Township, Burlington County, NJ, during 2001-2003. Activity range represents the area of a minimum convex polygon. Range length refers to the distance between the most distant points in an activity range. Values for the gravid snake (TR5) and snakes not tracked for a complete activity season (*) were not included in summary values. TR6 (gravid) was released 0.6 km from capture site.

Snake Number	Year	Activity Range (ha)	Total Distance Traveled (km)	Mean Distance Moved per Day (m)	Mean Distance per Move (m)	Number of Moves	Furthest Distance from Den (km)	Range Length (km)
TR4*	2001	1.5	1.43	11.9	35.7	40	0.17	0.22
TR4	2002	42.1	3.62	19.0	69.5	52	1.24	1.24
TR5*	2001	69.5	5.79	49.1	118.1	49	1.46	1.54
TR5	2002	6.4	1.43	8.6	42.0	34	0.52	0.52
TR6*	2001	13.5	1.67	16.9	66.7	25	0.71	0.71
TR7*	2001	14.5	2.39	82.4	199.0	12	0.74	1.02
TR7	2002	105.1	7.33	47.9	170.5	43	1.58	1.60
TR7	2003	69.8	5.56	36.4	146.4	38	0.94	1.47
TR8*	2001	9.4	2.14	34.5	118.9	18	0.49	0.54
TR8	2002	58.4	5.57	31.7	92.8	60	2.29	2.29
TR9*	2001	4.7	1.35	15.0	96.5	14	0.41	0.48
TR9	2002	706.6	13.66	78.5	253.0	54	5.22	5.24
TR9	2003	722.2	11.80	71.5	294.9	40	4.63	4.63
TR10	2002	346.3	12.11	74.3	198.5	61	3.48	4.31
TR10	2003	426.2	11.72	68.6	229.9	51	3.51	3.86
TR11	2003	165.1	7.08	46.0	168.6	42	2.52	2.54
TR12	2003	25.5	3.75	24.7	110.2	34	0.77	0.93
	Median	135.1	7.21	47.0	169.6	47.0	2.41	2.42
	Mean	266.7	8.22	49.8	173.4	47.5	2.62	2.81
	SD	270.8	3.76	22.0	72.3	9.38	1.55	1.57

Table 4. Animals other than timber rattlesnakes observed near fence while conducting radiotelemetry study at the Sanctuary, Evesham Township, Burlington County, NJ. Number refers to the number of separate days in which a species was observed at the fence. No attempt was made to distinguish between individuals of a species.

Common Name	Species Name	Number
Eastern box turtle	*Terrapene c. carolina*	15
Northern black racer	*Coluber c. constrictor*	6
Eastern painted turtle	*Chrysemys p. picta*	4
Fowlers toad	*Bufo woodhousii fowleri*	3
Common snapping turtle	*Chelydra s. serpentina*	2
Northern fence lizard	*Sceloporus undulatus hyacinthinus*	2
Spotted turtle	*Clemmys guttata*	2
Green frog	*Rana clamitans melanota*	1
Woodchuck	*Marmota monax*	1

Table 5. Animals recorded in two culverts by motion-activated cameras at the Sanctuary, Evesham Township, Burlington County, NJ. Cameras were operational from June to mid July, 2003. Culvert 1 was the southernmost culvert along Georgia O'Keefe Way. Culvert 2 was the next culvert along that street. Animals moving through the culverts to the east were heading in the direction away from the development. No attempt was made to distinguish between individuals of a species.

Common Name	Species Name	Culvert 1: abundance & direction	Culvert 2: abundance & direction	Total
Northern Fence Lizard	*Sceloporus undulatus hyacinthinus*	4 (east), 7 (west)	1 (east)	12
Woodchuck	*Marmota monax*	2 (west), 1 (east)	3 (east), 3 (west)	9
Domestic Cat	*Felis sylvestris catus*	2 (east)	2 (east), 2 (west)	6
Striped Skunk	*Mephitis mephitis*	2 (east)	1 (east), 3 (west)	6
White-footed Mouse	*Peromyscus leucopus*	1 (east), 2 (west)	1 (west)	4
Vole	*Microtus sp.* or *Pitymys pineorum*	1 (west)	2 (east)	3
Black Snake	*Coluber c. constrictor* or *Elaphe o. obsolete*	-	1 (east)	1
Opossum	*Didelphis marsupialis*	-	1 (west)	1
Raccoon	*Procyon lotor*	1 (east)	-	1

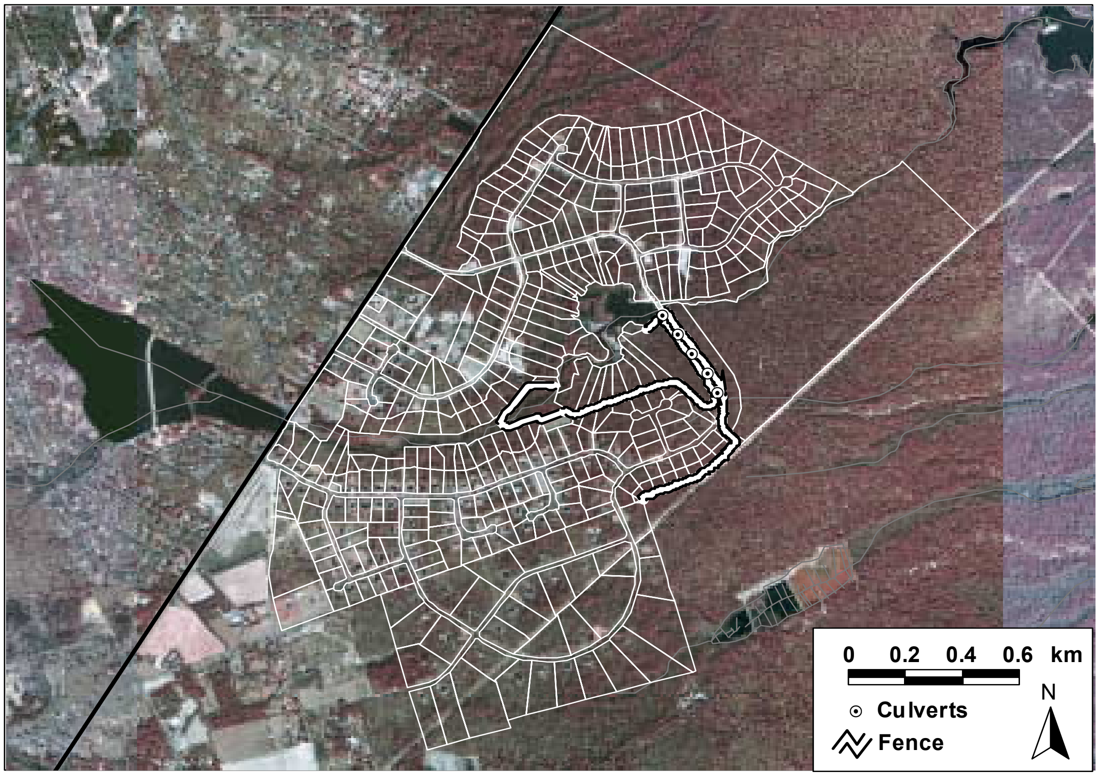


Figure 1. Subdivision plan of Sanctuary development to the north and the adjacent Compass Point development (larger lots) to the south superimposed on digital aerial photography from 2002 (BAE Systems ADR for New Jersey Office of GIS). Completed houses are visible throughout Compass Point and the southern portion of the Sanctuary. The culverts are located on Georgia O'Keefe Way. Hopewell Road is represented by the dark line to the west. Kettle Run bisects the Sanctuary.

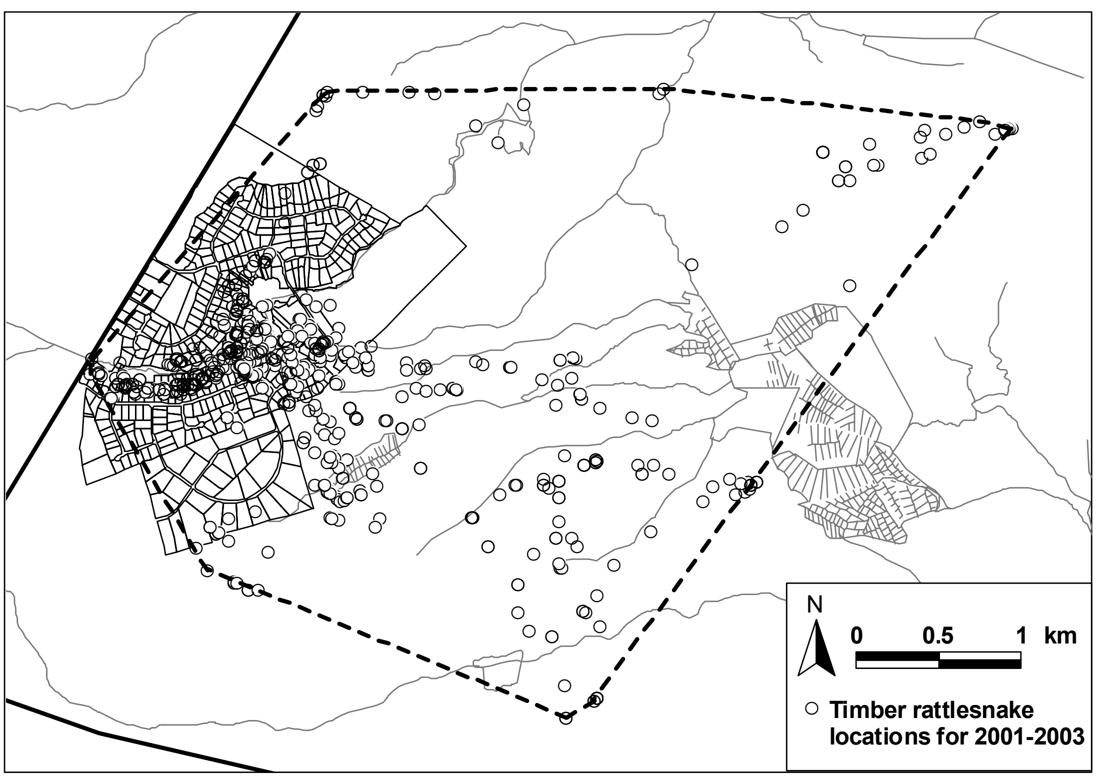


Figure 2. Radiotelemetry locations for nine timber rattlesnakes during 2001-2003. The dashed line represents the overall snake activity range.

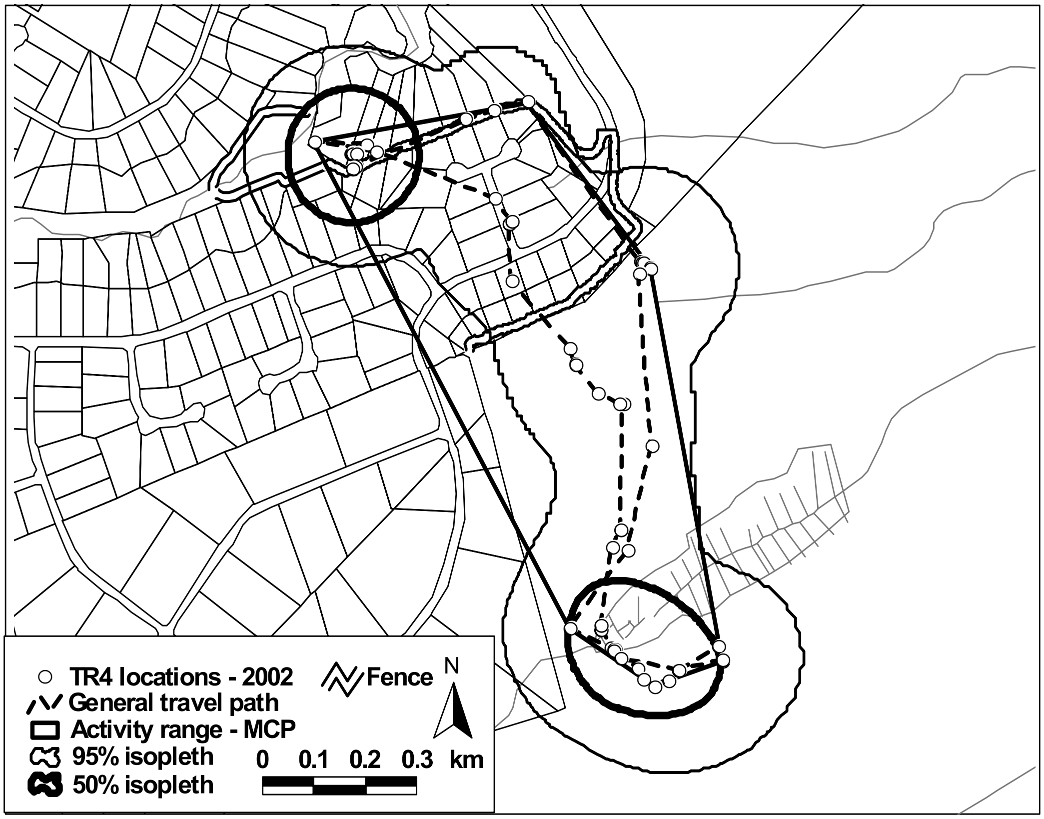


Figure 3. TR4 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for 04/15/02 through 10/21/02.

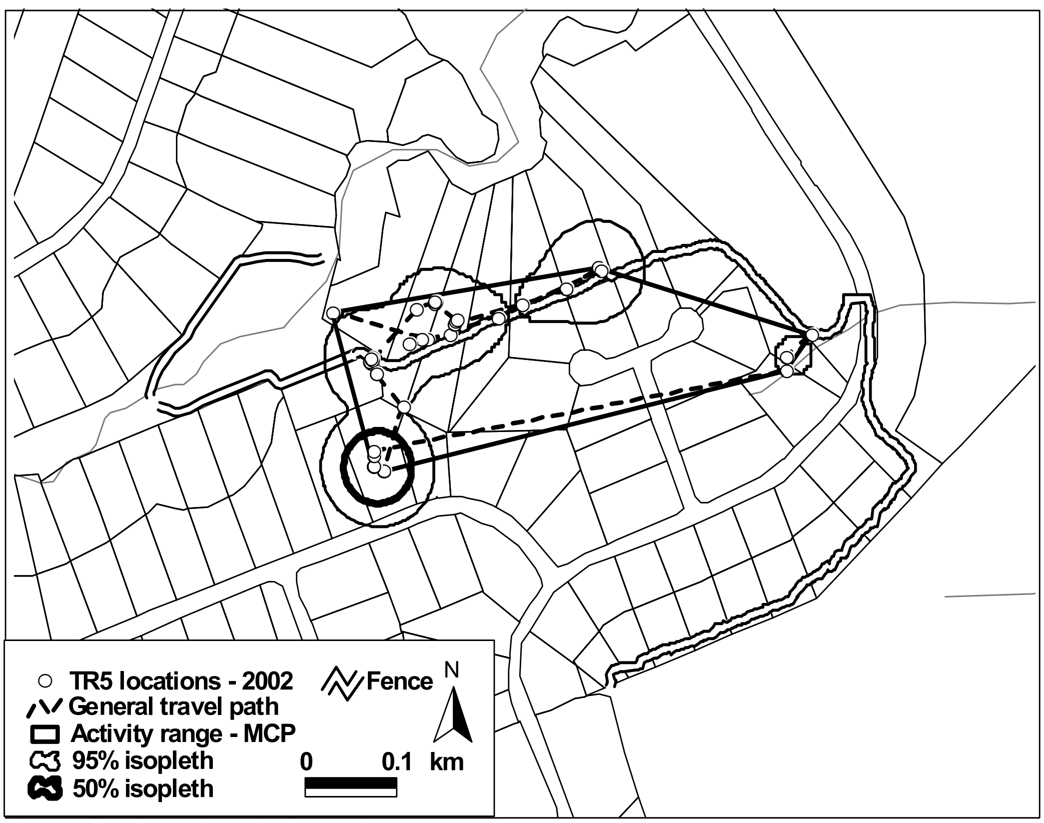


Figure 4. TR5 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for 04/08/02 through 09/20/02.

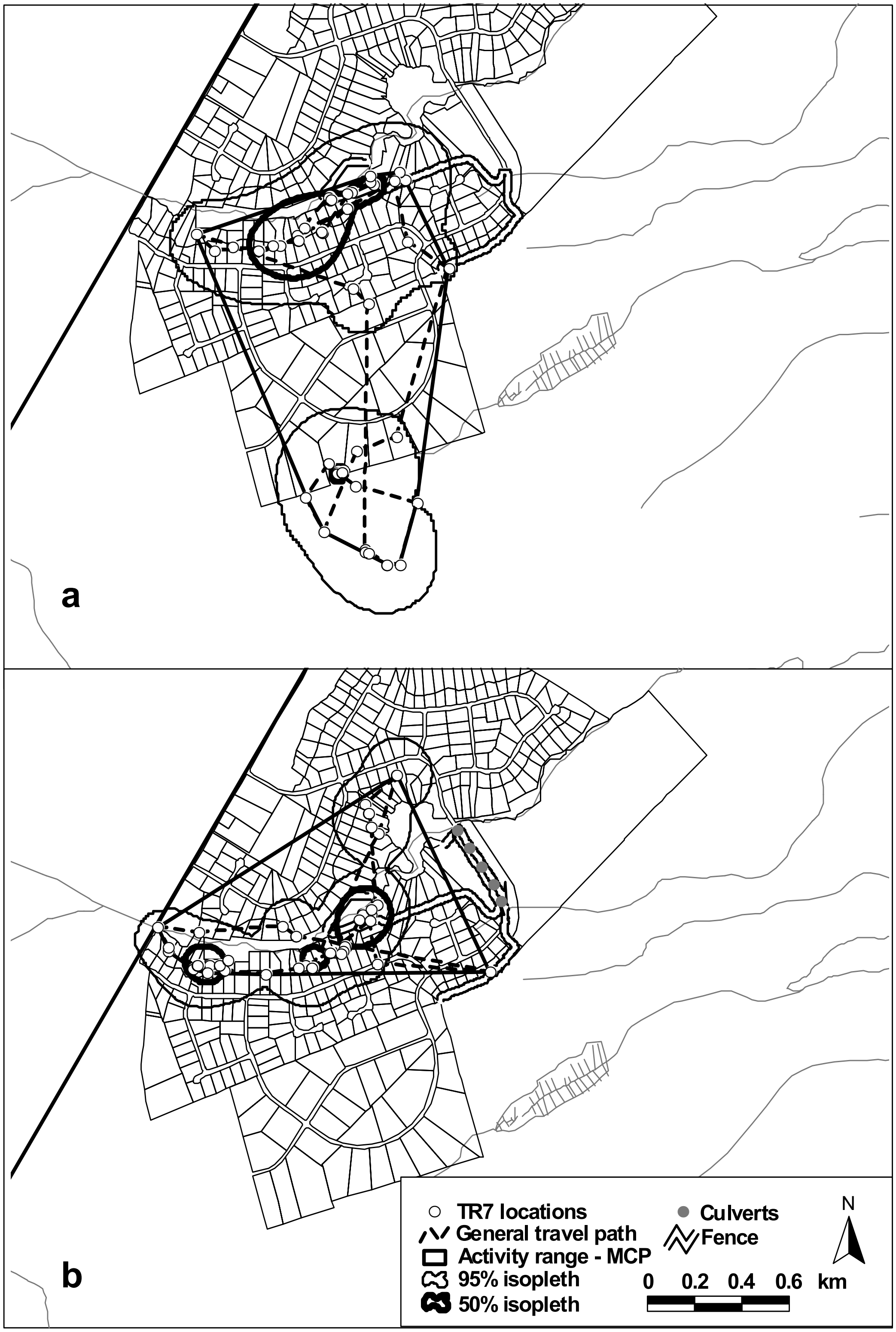


Figure 5. TR7 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for (a) 05/29/02 through 10/28/02 and (b) 05/16/03 through 10/15/03. Culverts and the fence along the connector street were not installed in 2002.

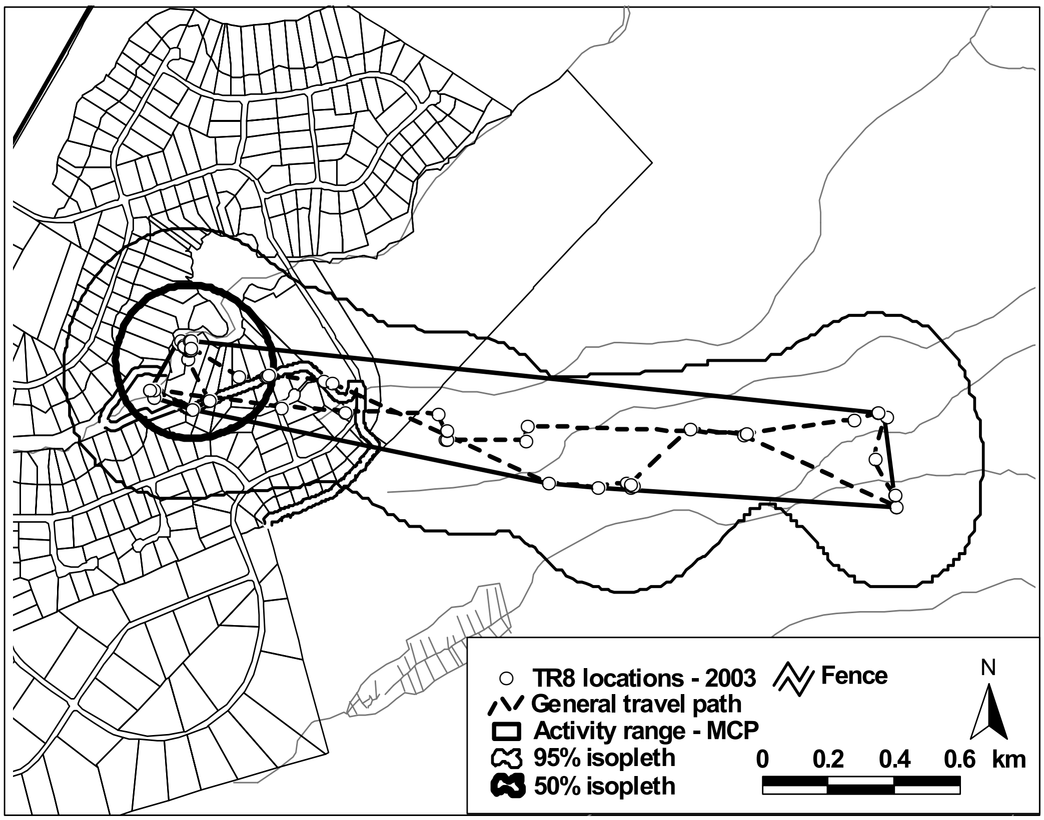


Figure 6. TR8 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for 04/15/02 through 10/07/02.

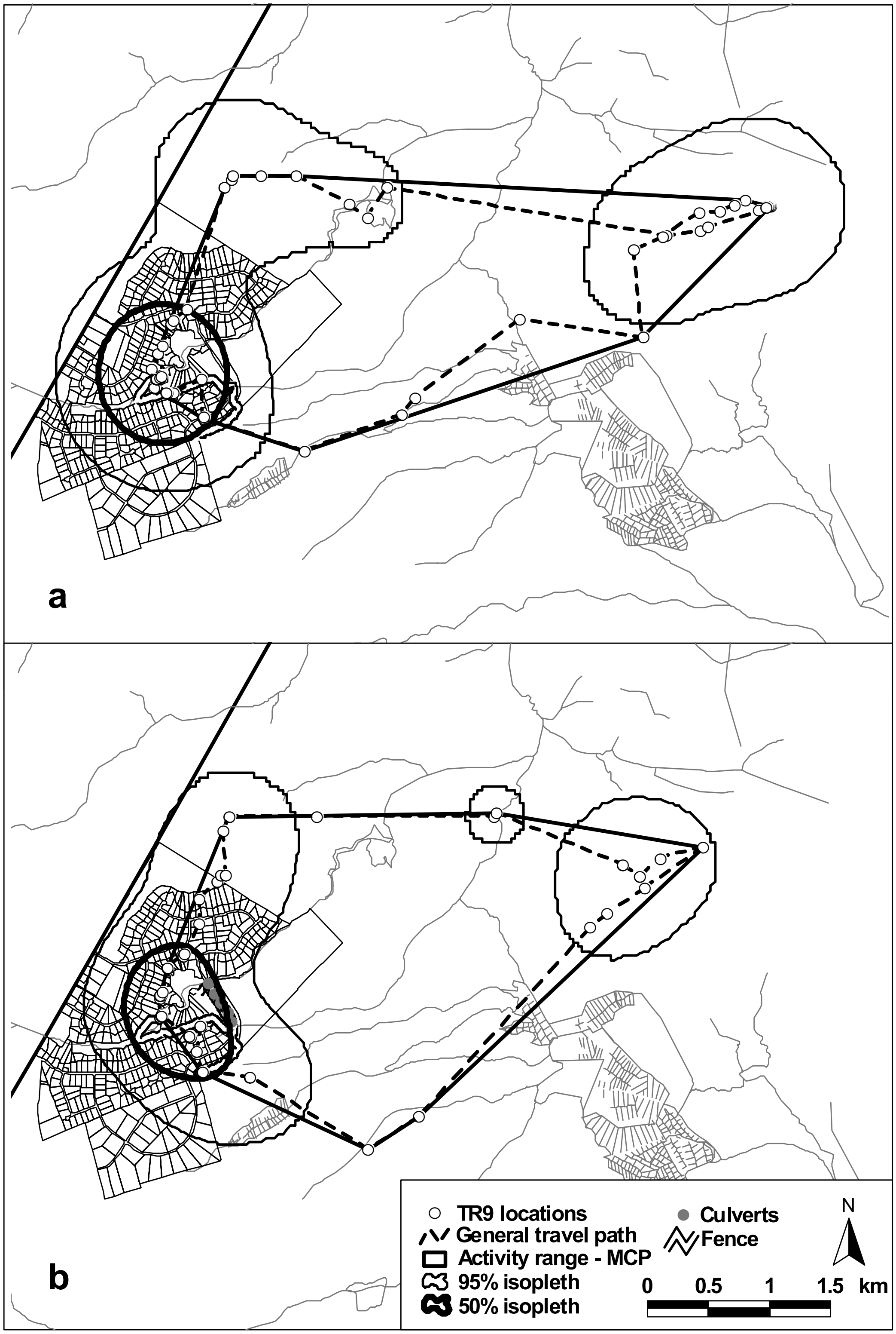


Figure 7. TR9 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for (a) 04/17/02 through 10/07/02 and (b) 04/30/03 through 10/11/03. Culverts and the fence along the connector street were not installed in 2002.

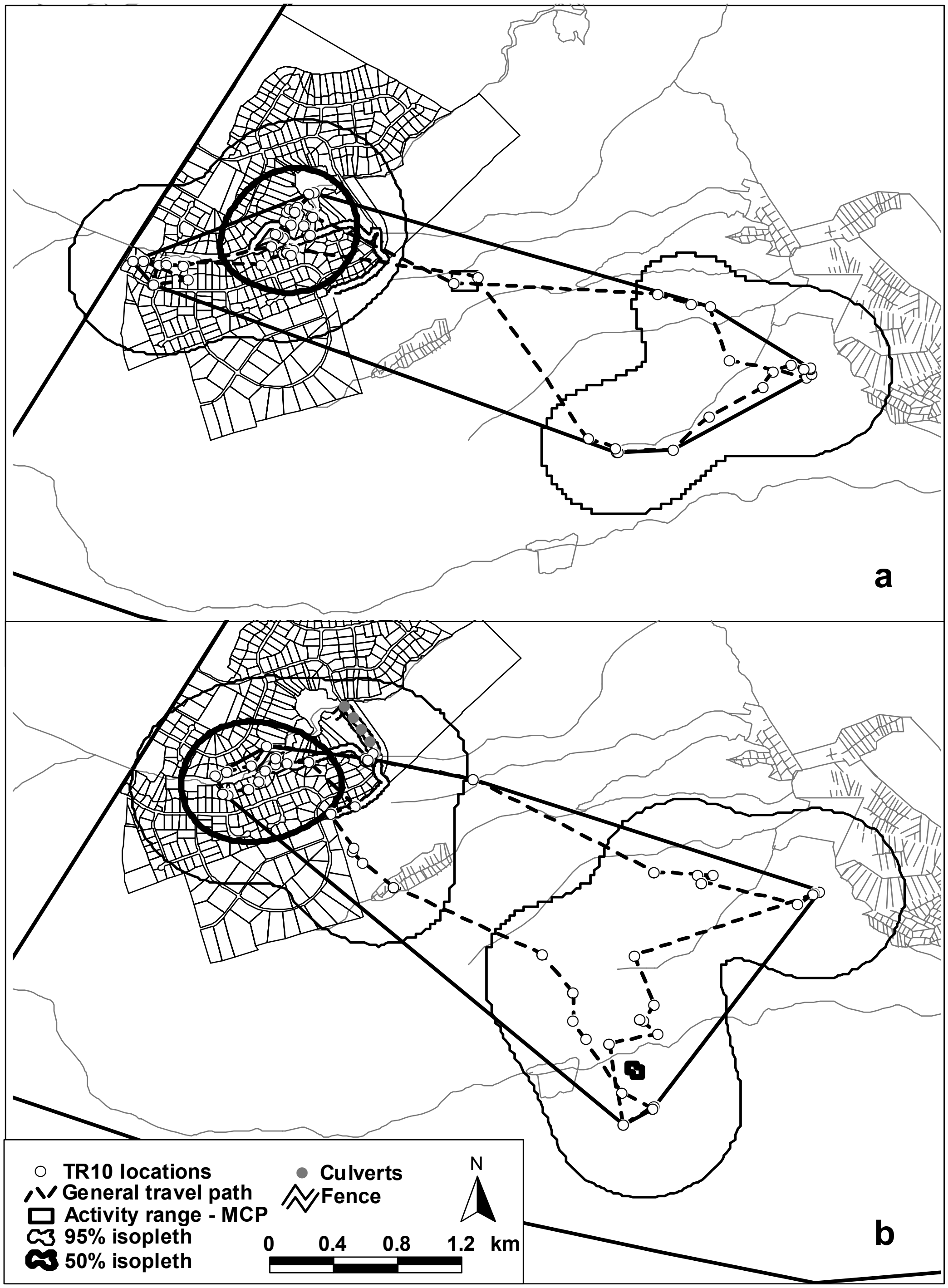


Figure 8. TR10 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for (a) 05/08/02 through 10/17/02 and (b) 04/30/03 through 10/17/03. Culverts and the fence along the connector street were not installed in 2002.

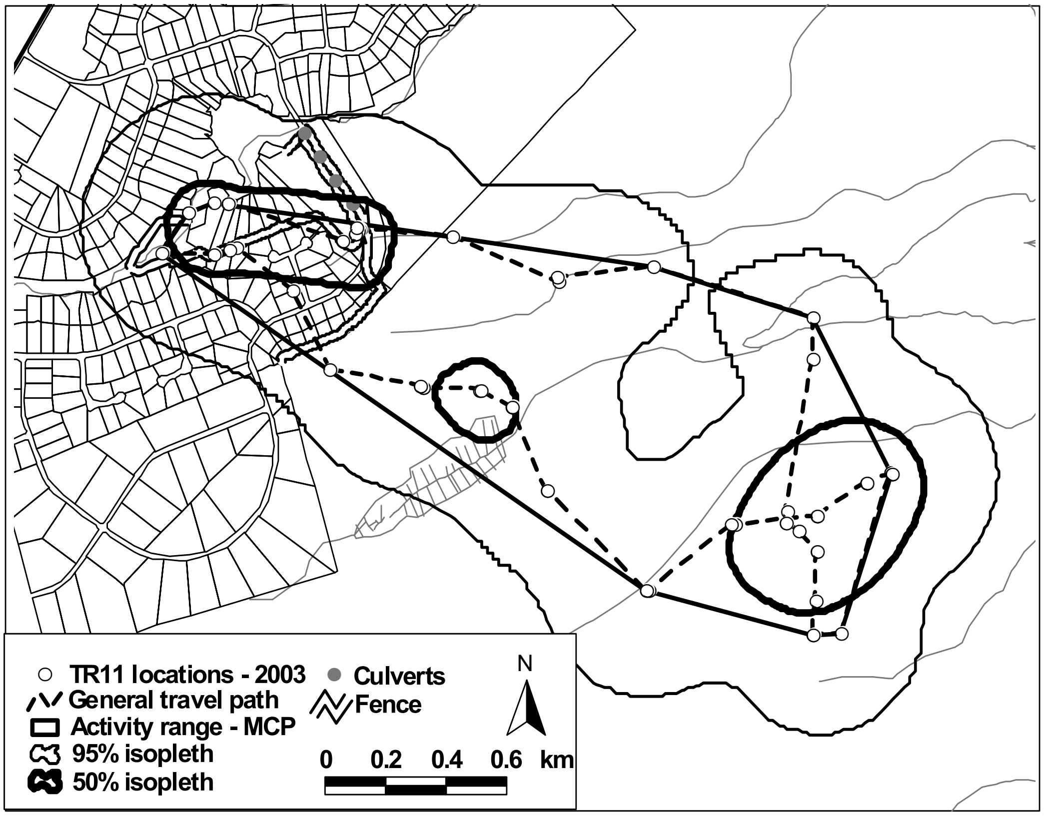


Figure 9. TR11 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for 05/20/03 through 10/20/03.

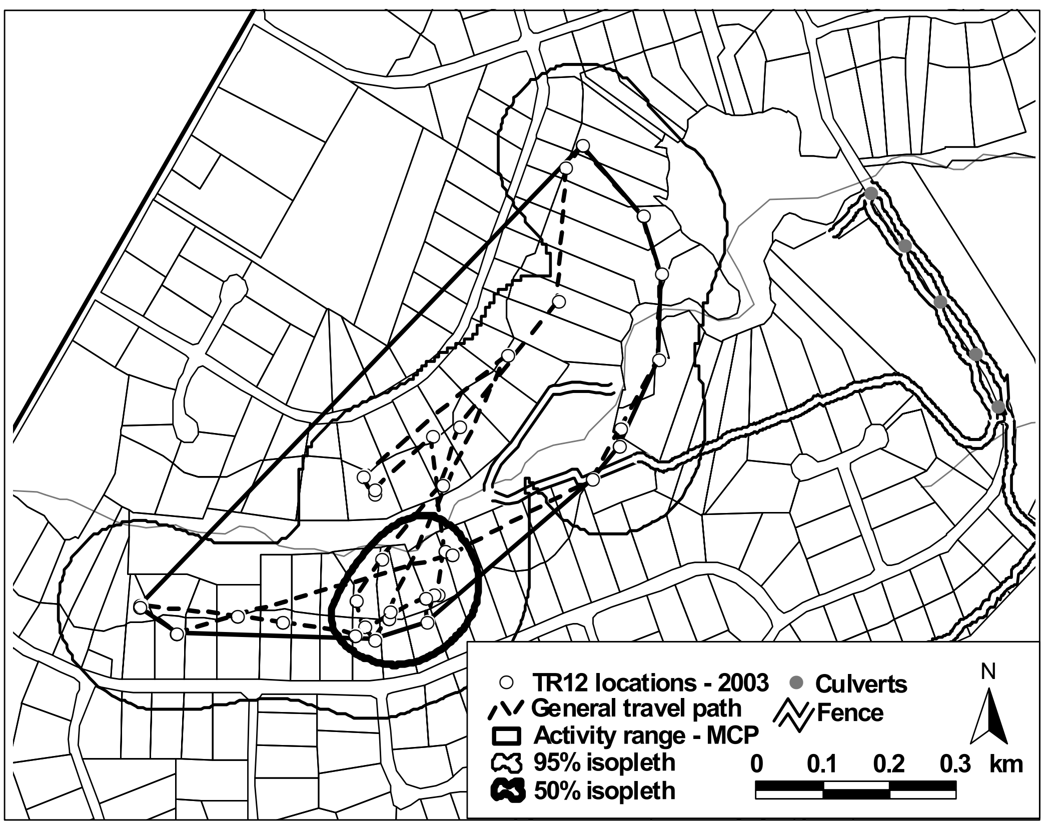


Figure 10. TR12 radiotelemetry locations, general travel path, and activity range (minimum convex polygon, and 50% and 95% isopleths) for 05/19/03 through 10/17/03.

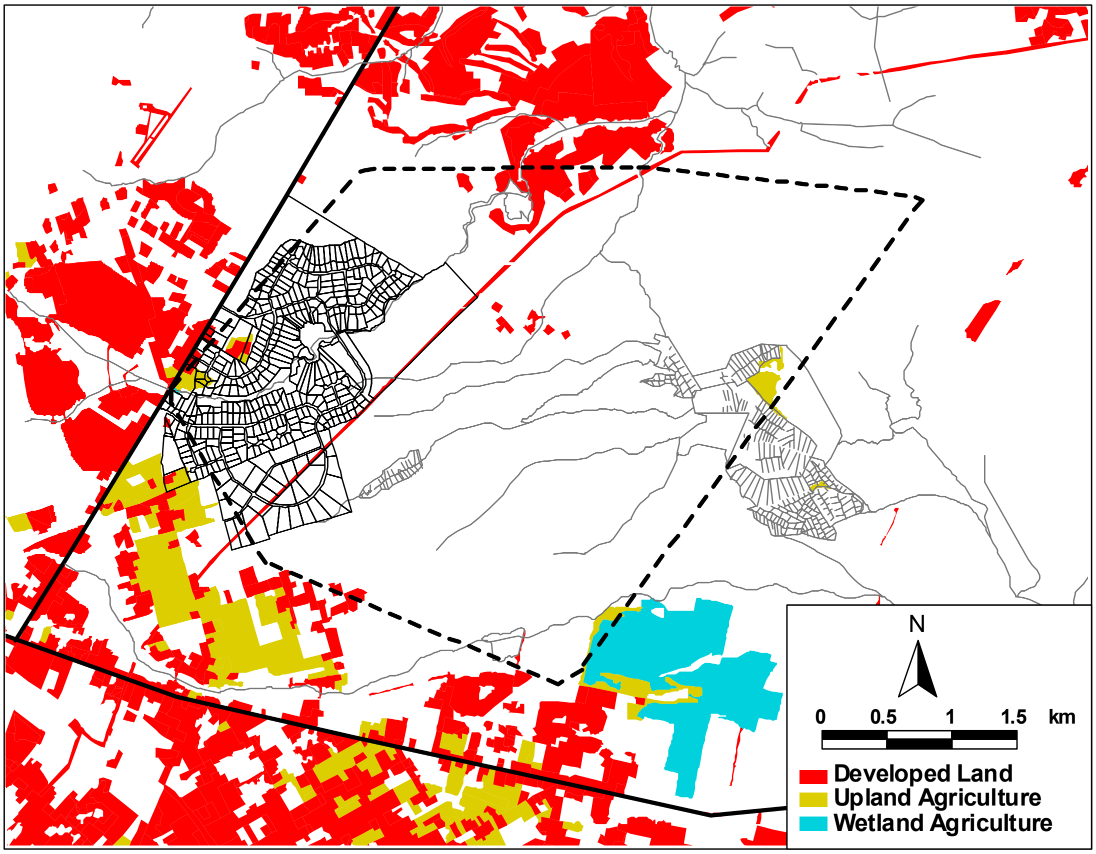


Figure 11. Developed land, upland agriculture, and wetland agriculture in the vicinity of the Sanctuary development and the overall snake activity range (dashed line). Unshaded areas represent forest land (uplands, wetlands, and water) and barren land.

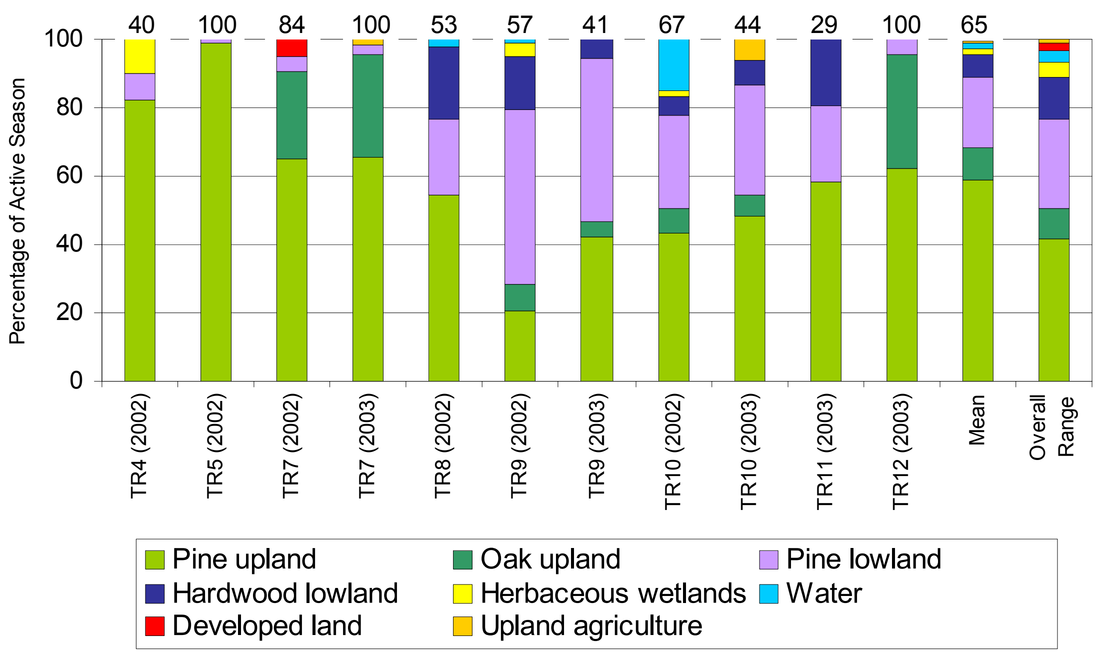
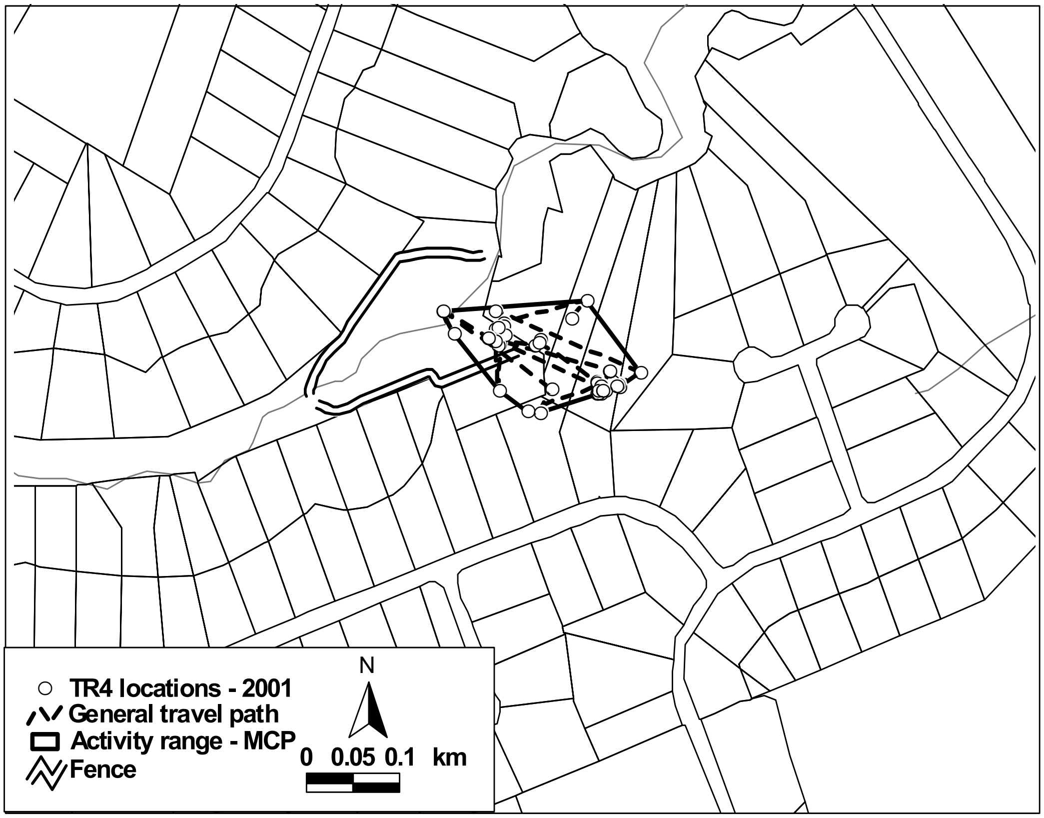
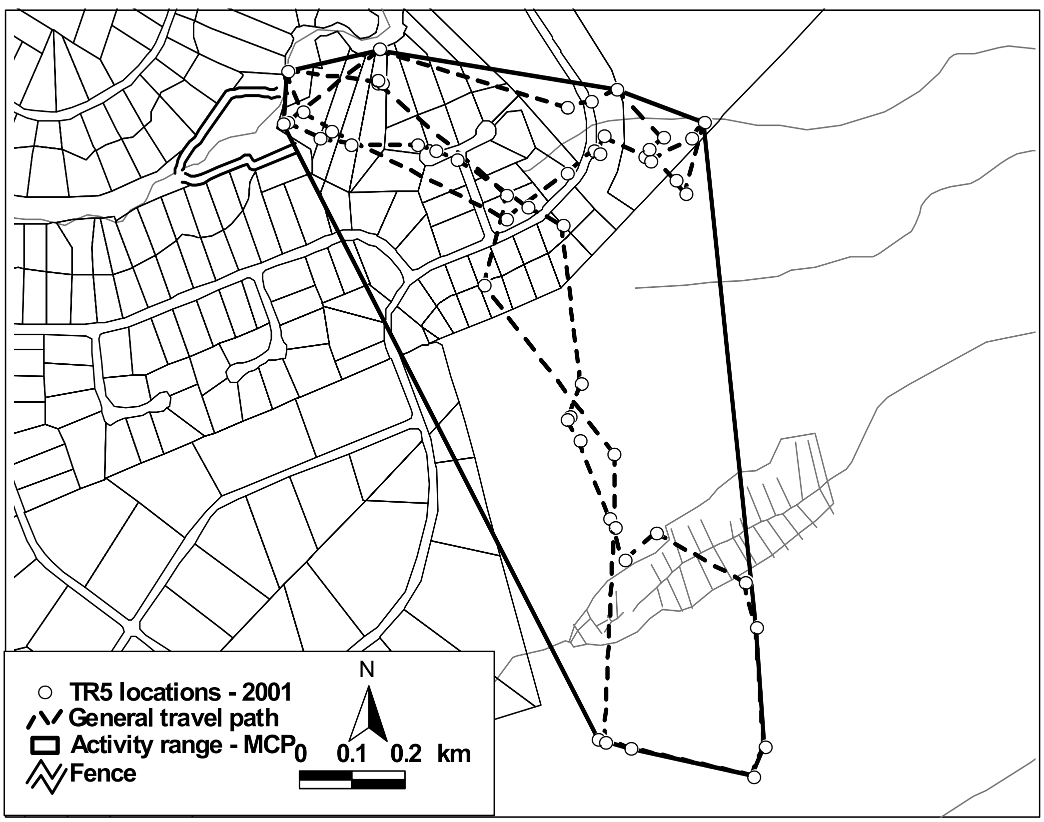


Figure 12. Land use/land cover profiles for snakes tracked during complete activity seasons. Snake activity in a cover type is expressed as a percentage of activity season. The amount of cover types present in the overall snake-activity range are expressed as a percentage of the 1500-ha area. Numbers above bars represent the percentage of activity season that a snake was located within the boundary of the Sanctuary and Compass Point developments.

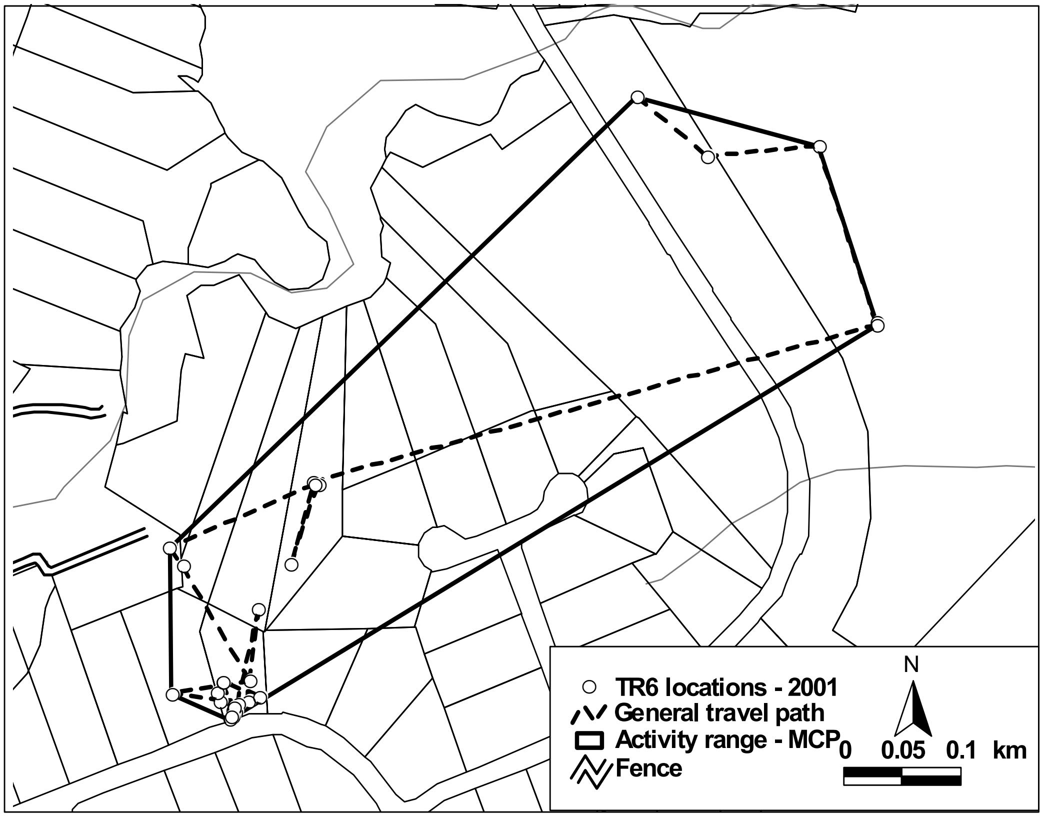
APPENDIX



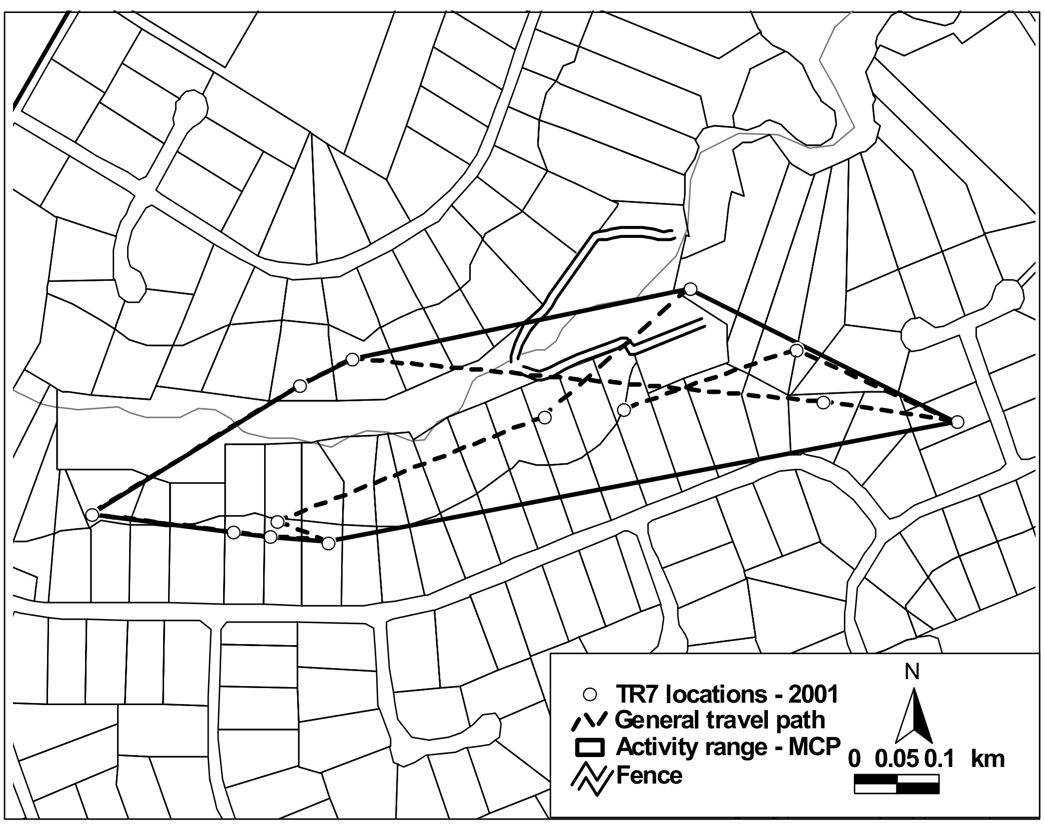
TR4 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 06/01/01 through 09/28/01.



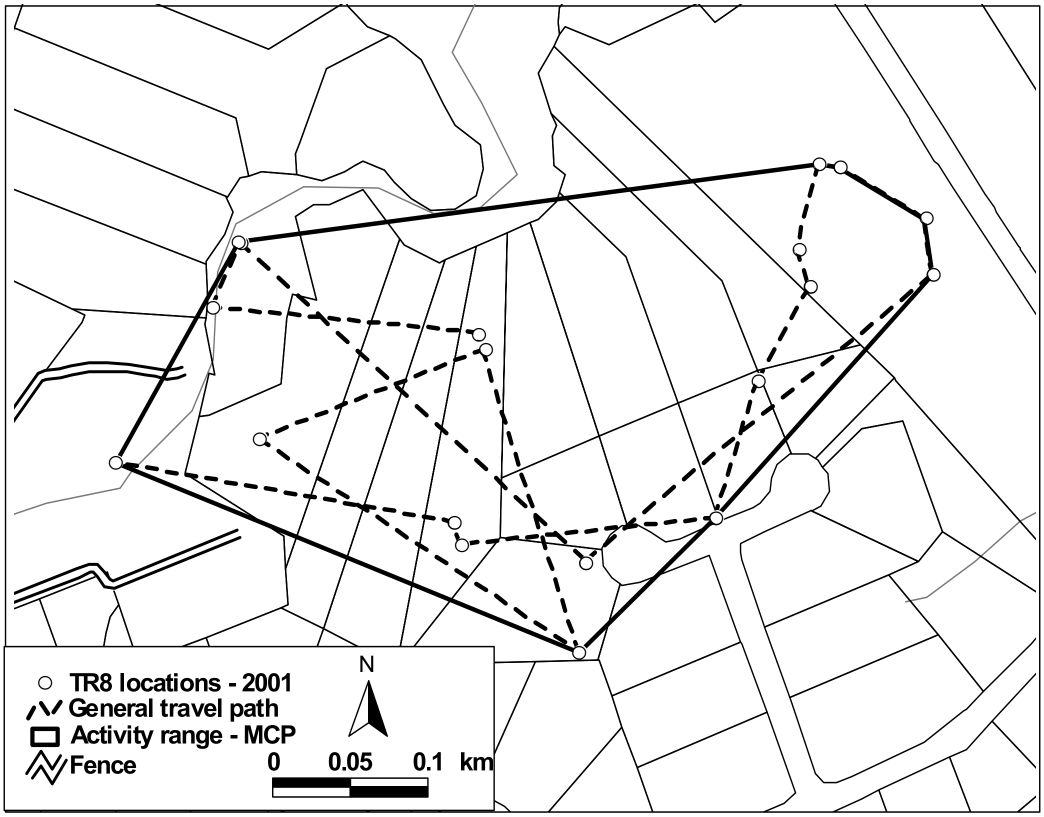
TR5 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 06/01/01 through 09/26/01.



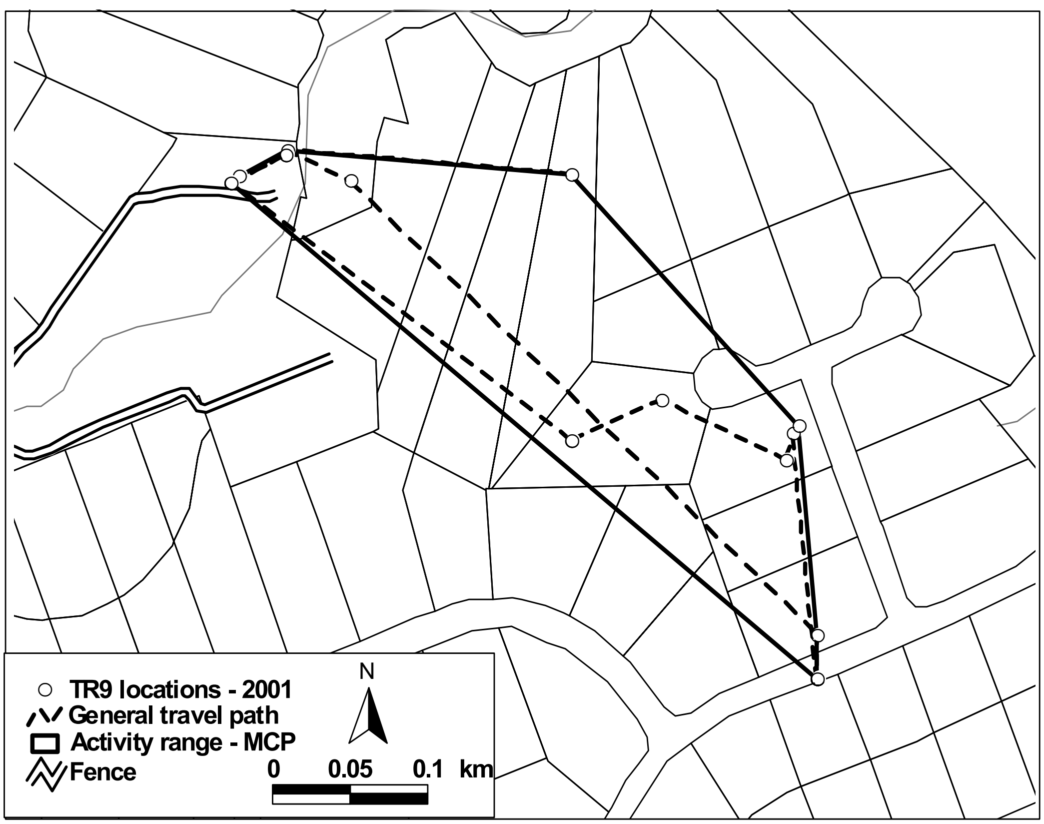
TR6 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 06/05/01 through 09/11/01.



TR7 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 06/28/01 through 07/26/01.



TR8 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 08/01/01 through 10/01/01.



TR9 radiotelemetry locations, general travel path, and activity range (minimum convex polygon) for 08/08/01 through 11/05/01.