MICROHABITAT PROPERTIES, USAGE, SPATIAL MOVEMENTS, AND HOME RANGES OF THE ORNATE BOX TURTLE, *Terrapene ornata*, IN THE MONAHANS SANDHILLS OF WEST TEXAS.

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ABSTRACT

This study examined microhabitat properties, spatial use patterns, and home range data of a Texas population of the ornate box turtle, *Terrapene ornata*, located in the zone of intergradation between the two recognized subspecies, *T. ornata ornata* and *T. ornata luteola*. The study site consists of 146-hectares in Monahans Sandhills State Park. A total of 124 turtles were captured 369 times during the spring, summer, and fall of 2002, of which 21 captures provided thread trail data. Thread trail data showed they are capable of moving at least 290 meters a day. Home ranges were calculated from seven turtles that were captured at least eight times each. Home ranges, calculated as minimum convex polygons, (MCP), ranged from 0.73 to 3.28 ha, with an average of 2.27 ha, and as greatest linear measure, 173 to 368 meters, with an average of 278.6 meters. These home range estimates are comparable with estimates from Wisconsin, Nebraska, Kansas, Texas, and New Mexico populations. Box turtles are non-randomly distributed in MSSP with respect to percent cover of vegetation types. They exhibited uni-modal and bi-modal daily activity patterns. Results showed that turtles restrict their active periods due to the available thermal environment across their eight-month active season.

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INTRODUCTION

Turtles and tortoises have recently drawn attention within the scientific community because of apparent declines in distribution and densities (Stickel 1989, Ernst, et al. 1994, Dodd 2001). The ornate box turtle, *Terrapene ornata*, has shown these trends in portions of its range (Dodd 2001). The ornate box turtle ranges from southern Wisconsin in the north to northern Tamaulipas, Mexico in the south. Its range extends east into Louisiana and west into southern Arizona and Colorado (Stebbins 1985, Ernst, et al. 1994, Behler and King 1996, and Conant and Collins 1998). Much of the recent box turtle population decline has been associated with habitat loss, habitat fragmentation, and hunting pressures from the pet trade (Stickel 1989, Ernst, et al. 1994, Dodd 2001).

Previous studies have examined *T. ornata* in other regions focusing on movement patterns, home range, thermal regulation and preference, demography, natural history, and reproductive biology (Legler 1960, Gatten 1974, Blair 1976, Metcalf and Metcalf 1979, Packard et. al. 1985, Rose 1988, Doroff and Keith 1990, Ellner and Karasov 1993, Nieuwolt 1996, Nieuwolt-Dacanay 1997, Curtin 1998). Only one study of *T. ornata* has been conducted on a Texas population (Blair 1976). This was conducted in the hill country of central Texas, near Austin, an area typified by oak, mesquite, mulberry trees, and moderate vegetative cover. Many other regions of Texas provide different habitats for *T. ornata*.

The Monahans Sandhills in west Texas represent a zone of contact between the two recognized subspecies, *T. ornata ornata* from the east and *T. ornata luteola* from the west.

Ecology

of ornate box turtles (Ward 1978). This is a unique habitat that is important to many organisms. The purpose of this research is to determine the spatial movements, home range size, thermal aspects of microhabitat sites, and activity patterns of the ornate box turtle, *T. ornata*, in this intergradation zone.

Box turtles are known to thermoregulate by choosing microhabitats that allow them to occupy their preferred thermal ranges (Heath 1964, Gatten 1974, Rose 1988, Ellner and Karasov 1993, Curtin 1998). Thermoregulation also allows for the reduction of water loss. The aridity of Monahans Sandhills State Park, MSSP, may influence the thermoregulatory behavior of *T. ornata* to maximize their water balance. Therefore, box turtles should display body temperatures that differ significantly from the model turtles, ambient air and soil temperatures.

High temperatures and high rates of water loss play a role in determining the microhabitat used by box turtles (Reagan 1974). Increasing temperature slows the voluntary locomotion patterns of box turtles (Adams, et al. 1989). The extreme thermal environment and low moisture levels, along with the topography of the sand hill habitat, may reduce the home range and daily movements. Box turtle home range size should be between the reported values of other populations. But, home ranges may be larger due to the distribution of resources in MSSP or home ranges may be smaller to due the extreme thermal environment, the topography of the sand dunes, and vegetative cover that may restrict daily movements.

The movements of box turtles are non-random and influenced by environmental conditions or resource distribution (Stickel 1950, Legler 1960, Schwartz and Schwartz 1974, Nieuwolt 1996). *Terrapene ornata* from the Monahans Sandhills will also show this relationship.

When the major objectives of determining home range size, describing temperature profiles of the available microhabitats, analyzing of spatial movements, and determining the daily and seasonal activity periods of the Monahans Sandhills population are ascertained, this project will increase the knowledge of *T. ornata* in Texas by supplying data on its spatial requirements, spatial movements, microhabitat characteristics, and activity patterns for administrators, conservationists, and researchers.

METHODS

Study Site. – The study site consisted of 146 hectares located in the southwest corner of Monahans Sandhills State Park, (MSSP), in Ward and Winkler counties of west Texas. The eastern boundary of the study site is State Park Road 41, the southern and western boundaries correspond to the south and west fences of the state park, with the northern boundary an arbitrary curve from the west fence to the park road 41. Monahans Sandhills State Park is located approximately 8 kilometers east of the West Texas town of Monahans and is maintained year round by Texas Parks and Wildlife (TPW). The park consists of 1554 hectares of sand dunes leased from the Sealy-Smith Foundation on a 99-year lease started in 1956. The park dune system consists of active dune fields, coppice dunes, densely vegetated dunes, blowout dunes, interdunal flats, covered sands, and ephemeral ponds (Machenberg 1984). The discontinuous sand dune system ranges approximately 320 kilometers north from Crane, Ward, Winkler, and Andrews counties of Texas to the Mescalero Sands of Eddy, Lea, Chaves, and Roosevelt counties of New Mexico (Degenhardt, et al. 1996, Dixon 2000).

Although ornate box turtles are found throughout MSSP, they are mainly found in habitats of low eolian activity, such as the vegetated dunes, coppice dunes, and level covered sands of the study site. The covered sands' dominant vegetation consists of moderate sized mesquite trees (*Prosopis glandulosa*), yuccas (*Yucca campestris*), shin oak (*Quercus havardii*), forbs (*Gaura villosa, Chamaesyce missurica, Eriogonum annuum, Croton texensis, Boerhavia spicata*, and *Heterotheca* sp.), and grasses (*Cenchrus spinifex* and *Sporobolus contractus*). The dominant vegetation of the vegetated dunes consists of shin oak (*Q. havardii*) and interspersed yuccas (*Y. campestris*), forbs (*E. annum, Monarda citriodora, C. texensis, Heliotropium convolvulaceum, C. missurica, Mentzelia strictissma*, and

Heterotheca sp.), and sticker grass (*Cenchrus spinifex*). The dominant coppice dune vegetation consists mostly of shin oak (*Q. havardii*) on the domes, with grass (*S. contractus*) and sparse, seasonal forbs (*Helianthus petiolaris* and *Oenothera rhombipetala*), occurring in the blowouts. Identification of dominant vegetation was discerned by Jeff Masters of Angelo State Natural History Collection (ASNHC) Herbarium, from literature, and specimens of the ASNHC Herbarium (Warnock 1974, Jones and Wipff, in press). An expanse of active sand dunes with sparse vegetation was located in the center of the study site, adjacent to the eastern study site boundary, park road 41.

The study site was located within the boundaries of the MSSP equestrian use area. In addition to equestrian use, cattle are periodically found grazing on the study site. Domesticated livestock potentially have a negligible or slightly positive impact on the box turtles, by providing more dung beetles for food.

Turtle Handling, Locating, and Marking. – All individuals studied in this project were handled in accordance with the 1997 guidelines for field research on amphibians and reptiles set forth by the American Society of Ichthyologists and Herpetologists (ASIH), Herpetologists' League (HL), and Society for the Study of Amphibians and Reptiles (SSAR). Turtles were located by walking the study site looking for their tracks in the sand or by opportunistic encounters. Once located, each turtle was measured and given a unique four-dot paint code, which was painted on both sides of the carapace with non-toxic acrylic paint. Each turtle was additionally given an Avid passive integrated transponder (PIT) 12 mm tag. PIT tags were permanently affixed to one of the first pleural scutes on the carapace with a fast-dry epoxy. PIT tags were placed on the anterior end of the carapaces so they would not interfere with reproductive positions or the turtle's movements through the environment. Internally inserted PIT tags do not interfere with normal activities or have adverse health effects on box turtles (Camper and Dixon 1988), thus external PIT tags should have no effect on box turtle activities or health. Careful placement was used to not cover scute sutures that would affect normal growth patterns. Several parameters were recorded each capture including weight, plastron length (PL), plastron width at the bridge (PW), carapace height (CH), sex, age class, eye color, location, date, time of day, paint code, and PIT tag number.

Turtle weight was taken with a 500 by 5 gram Pesola Light Line model 10500 scale. Plastron length was measured along the central seam from gular region to the anal region to the nearest millimeter. Plastron width was measured along the hinge seam to the nearest millimeter. Carapace height was measured at the hinge of the plastron to the highest point on the carapace to the nearest millimeter. Sex was determined by examining the plastron for a depression, an inward facing hind toe, eye color, and the amount of flaring of the posterior marginal scutes on males. Age was determined from the number of growth rings per scute. Turtle age classes were categorized as reproductive adults, juveniles, or hatchlings based on PL and weight. Individuals less than 100 mm in PL, less than 200 grams, and less than 10 years old were designated as juvenile turtles. No hatchlings were encountered during the study. Location was taken with a Garmin eTrex Venture model Global Positioning System, (GPS), in degrees/minutes/seconds. PIT tags were read with an Avid mini-tracker.

Handling time per observation was approximately 15 minutes for new turtles and less than 10 minutes for previously marked turtles. When thread trailing was performed, an additional five minutes of handing was necessary to attach the thread bobbin.

Microhabitat Properties. – Microhabitat properties measured included temperature of the sand (Ts), air (Ta), and body (Tb) as well as relative humidity (Rh), percent cover, degree of cover, distance to nearest vegetation or distance to nearest shade vegetation, vegetation type, and turtle behavior. Models of turtles with data loggers were placed at specific locations on the study site to provide corresponding model temperatures (Tm) based on environmental thermal factors.

Sand temperatures were taken with a Reotemp soil probe, (-40 to 160 °F), placed five to 10 centimeters into the sand. Readings were converted to Celsius for analysis. Air temperature and relative humidity were taken at ground level at the position of the turtle with a hand-held thermo-hygrometer, (0 to 50 °C ± 1 °C, 2 to 98% ± 5 % RH). Body temperatures were taken with a Miller and Weber model T-600 cloacal temperature probe, (0 to 50 °C with 0.2 markings). The probe was tightly placed in a rear inguinal cavity touching the body wall and leg. This method was used because most turtles did not allow cloacal readings by completely closing their shell. Percent cover was estimated by visual inspection of the surrounding few meters. Degree of cover was classified as either open, shade, or burrow. Distance to nearest vegetation was measured by ruler to the nearest centimeter, and vegetation type was classified as mesquite, yucca, shrub, cactus, tall and low forbs, grass, ground cover, or shin oak. From 6 April through 16 July and 15 October through 6 November 2002, distance was measured to nearest vegetation and from 17 July to 14 October 2002, distance was measured to nearest vegetation sufficient to provide shade. The reason for the switches between closest vegetation and closest shade vegetation was to assess if turtles were using shade to thermoregulate their body temperature (Tb). Turtle behavior was classified as walking, feeding, resting, or social. Feeding was only designated when a turtle was eating and not foraging. Social behavior included male to male, male to female, and female to female encounters.

Models of turtles were constructed from empty ornate box turtle shells, aluminum foil, and data loggers (Claussen, et. al. 1997). Empty shells were first lined with aluminum foil, and then a foil wrapped data logger was placed inside. Hobo data loggers (model H01-001-01) were set to take a temperature reading in Celsius every half hour. Data loggers reached capacity after 36 days. When the models were weathered, it was necessary to draw the carapace pattern on the shell with a black permanent marker to simulate radiant energy uptake. At least one model was always recording. Models were placed on the surface in captured turtle locations. From May through November, models were also placed in vacant burrows to take burrow temperatures. Data was downloaded from the data loggers with the program "BoxCar for Windows" (Onset 2001).

Spatial Use. – The use of space by individual box turtles was determined by attaching thread trails to the rear of the carapace (Stickel 1950, Schwartz and Schwartz 1974, and Claussen, et al. 1997). Thread trailing provides detailed information on the orientation of movement, distance covered, and displacement (Claussen, et al. 1997). Thread trailing devices have been employed for a variety of organisms, such as armadillos and rats, to determine microhabitat usage and to map daily movements (Greegor 1980, Key and Woods 1996).

Nine males and nine females were thread trailed a total of 21 times. Bobbins of approximately 300 meters of white nylon from Imperial Threads Inc. in Northbrook, Illinois were used to obtain thread trail data. Bobbins measured 38 mm by 15 mm and weighed four grams. Bobbins were affixed with a drop of glue and then covered with a duct tape strap across the bobbin. A second piece of duct tape was placed at the rear to keep the bobbin from being pulled free and to provide an opening for the string to dispense. A third strap, placed at the top of the carapace, was used to keep the bobbin and the first strap from being caught in vegetation or in burrows. The loose end of nylon was tied to a marking flag and the turtle was repositioned in the same spot and direction in which it was headed.

Turtles were only thread trailed within the first hour after sunrise. On the following morning, the trail was recorded by heading and distance traveled between turns. The duct tape and bobbin were removed when the turtle was relocated. Only heading changes greater than 15 degrees were recorded. Headings were determined to the nearest degree with a hand-held sighting compass from Suunto. Distances were measured to the nearest tenth of a meter with a measuring wheel from Rolatape (model MM-30M).

Vegetation Transects. – Three randomly placed transects were measured to assess percent cover of vegetation types in the study site. Vegetational types included mesquite, yucca, shrub, shin oak, grass, ground cover, cactus, tall forbs, and low forbs. Tall forbs are large enough to provide full shade to a turtle and low forbs do not provide shade. The first two transects consisted of 500 meter lines with 100-meter arms alternating left and right at 90 degrees every 100 meters starting from the origin, for a total of six 100-meter arms per transect. The third transect was 200 meters long with three 100-meter arms. Distances were measured with a 50-meter measuring tape and headings read with a Suunto hand-held sighting compass. Initial headings were randomly determined by spinning a pencil. Percent cover for each type was determined by laying the measuring tape on the ground and recording the distance covered by each vegetation type. All 15 arms were averaged together to provide a percent cover estimate for each vegetation type on the study site. Starting and ending points for each transect were recorded with a GPS unit.

Home Ranges. – Home range is defined as the area an animal transverses daily in foraging, mating and sheltering activities (Burt 1943). Home ranges were estimated for turtles that had at least eight locations each. A total of seven home ranges were estimated. Six of the turtles were adult males and one was an adult female. Home ranges were estimated with Minimum Convex Polygons (MCP) from Universal Transverse Mercator (UTM) locations using the program "CALHOME" (Kie, et al. 1994). Home ranges were also estimated by determining the longest linear distance between two locations with the program "Terrain Navigator" (Maptech 2001).

Voucher Specimen. – One adult male box turtle, *Terrapene ornata*, was taken as a voucher specimen from the southeast corner of MSSP on 11 June 2003 (ASNHC # 14011). This specimen was deposited in the Angelo State Natural History Collection (ASNHC) of Amphibians and Reptiles at Angelo State University (ASU) in San Angelo, Texas. The specimen was fixed in 10 percent formalin solution for two days, soaked in tap water overnight, and placed in 70 percent ethanol for preservation. Deposition in the ASNHC will provide a specimen for other researchers, improve the museum database for online referencing, provide documentation of their range in the western region of Texas, and provide a definitive and referable example the study subject.

Statistical Analysis. – Statistical analyses were performed with the program "SYSTAT 9" (SPSS 1999). Analysis of variance (ANOVA) was used to discern significant differences in Tb between males and females for each month's activity periods. ANOVAs were run to assess the differences in means across months for both AM and PM Tb. Significant differences in Tb between AM and PM active periods of the same month were analyzed with an ANOVA. The same analysis was used to find differences in Tb of individuals depending on degree of cover, shaded or open, across active periods.

For thread trail data, ANOVAs were also employed to analyze differences between male and female means for the absolute value of the average turn, average leg distance, total distance, total displacement, and the ratio of distance/ displacement. For four variables with no significant difference between the sexes: average leg distance, total distance, total displacement, and the ratio of distance/ displacement, ANOVAs were performed to determine significant differences between months.

ANOVAs were used to test differences in relative humidity for both AM and PM active periods across months. For differences in relative humidity between males and females in April through June, one-way ANOVAs were employed. For July through October, two-way ANOVAs were used to discern significant differences in relative humidity between males and females and AM and PM active periods.

Chi-squared tests were employed to determine if the vegetation type nearest to the turtle fit the expected percent cover of the vegetation types from the vegetation transect data. This was performed for closest vegetation, from 6 April to 16 July, and for closest shade vegetation, from 17 July to 14 October.

Males and females were compared within each month from April through July for significant differences in distance to vegetation using t-tests. Then for April through July, males and females were compared to each other with an ANOVA for a significant difference in distance to cover. Males and females were compared within each active period from July through October for significant differences in distance to shade vegetation using t-tests. Then a two-way ANOVA was run on distance to shade vegetation and active period for each month from July through October.

Male versus female percent cover means for each active period were compared with t-tests. ANOVAs were used to elucidate significant relationships of percent cover between AM and PM active periods in the months of July through October. ANOVAs were also used to compare percent cover of both AM and PM active periods across months.

For all active observations, paired t-tests were employed to discern significant differences for Tb, Tm, Ta, and Ts, within months and grouped by time of day (AM/PM). Differences between the means of Tb, Tm, Ta, and Ts were also assessed based on all active captures using t-tests. Bonferroni adjustments were used to support an overall experimental α value of 0.05. Normality of data sets was checked with probability plots. All data sets were approximately normally distributed.

RESULTS

Population Demographics. – A total of 124 turtles were located 369 times (Table 1), of which 365 were active locations. The four non-active locations consisted of three resting burrow locations and one mortality location. More individual females were captured (67) than individual males (57). Fourteen juveniles were marked, of which eight were female, and six were male, with 22 and 17 active captures, respectively. Juvenile turtles are classified as weighing less than 200 grams, less than 100 millimeters in PL, and/or less than eight years old. Size and age at sexual maturity differ by geographic region due to environmental factors (St. Clair 1998). Therefore, the characteristics of juveniles are based on published ranges (Legler 1960, Doroff and Keith 1990, St. Clair 1998). The 110 adult turtles marked accounted for 326 active captures. The average number of captures per individual for all groups was approximately three. The density estimate for the study site is 0.849 turtles per hectare. Using the same density estimate for the rest of the state park, there are an estimated 1320 turtles on MSSP.

Activity Patterns. – Box turtles exhibited both uni-modal and bi-modal daily activity patterns. From April through June, box turtles were only located in the morning. In May and June, AM activity started at sunrise and turtles remained active for approximately four to five hours. In April, turtles were not found immediately active at sunrise, but one to two hours after sunrise. Afternoon and evening captures were only recorded from July through November. No turtles were seen during afternoon searches in April or May, and none were encountered in the afternoon until late July. The bimodal daily activity pattern consisted of two periods, one for

Table 1. Total number of individuals marked, total numbers of captures, average number of captures for all observations, active turtles, and various subgroups.

Grouping	Individuals	Captures	Average # Captures
All captures	124	369	2.98
Active captures	124	365	2.94
Males	57	177	3.11
Females	67	189	2.82
Adult	110	326	2.96
Juveniles	14	39	2.79
Adult males	51	159	3.12
Adult females	59	167	2.83
Juvenile males	6	17	2.83
Juvenile females	8	22	2.75

four or five hours beginning at sunrise and one in the early evening for two to three hours until sunset. This pattern was observed from July through September. In October, the turtles exhibited a bimodal activity pattern consisting of a five hour AM active period starting at sunrise and a six hour PM active period ending at sunset. Overall, box turtles were rarely encountered more than 30 minutes after sunset.

Total daily activity ranged from three hours in April to eleven hours in October. During October, lower daily temperatures allowed activity to occur all day, although no turtles were captured during the noon hour. In November only one capture was recorded, which was at 2:03 PM. The AM activity period produced a higher capture rate, 1.577 turtles per man-hour, than the PM activity period of 1.267 turtles per man-hour (Table 2). The hour of the day with the highest capture rate was 5:00 PM (2.198), but all these captures came in the month of October. The hour of the morning with the highest capture rate and with a capture in more than one month was 8:00 AM from May through October, with 2.000 turtles per man-hour. AM capture rates increased from 6:00 AM to 8:00 AM and then declined in each subsequent hour. During the evening hours, the highest capture rate with a capture in more than one month was 8:00 PM from July to September, with 1.923 turtles per man-hour. This is the last hour of the day in which turtles were found active. The least productive hour, but one that still had captures in more than one month, was 11:00 AM with 0.925 turtles per man-hour.

Seasonal activity was from 6 April through 6 November. No individuals or tracks were located during searches before 6 April or after 6 November. Capture rates ranged from 0.200 turtles per man-hour in November to 1.792 turtles per man-hour in August. The overall capture rate was 1.487 turtles per man-hour. Monthly and hourly capture rates are presented

Table 2. Total capture rates (captures / search hour) for every active hour, monthly capture rate for both AM and PM activity periods, overall capture rates for AM and PM activity periods, and the overall capture rate of all active turtles.

TIME	Captures	Capture Rate
6:00 AM	9	1.286
7:00 AM	49	1.678
8:00 AM	91	2.000
9:00 AM	78	1.600
10:00 AM	39	1.256
11:00 AM	8	0.925
1:00 PM	2 *	0.444
2:00 PM	3	1.200
3:00 PM	1 *	1.000
4:00 PM	2 *	0.741
5:00 PM	10 *	2.198
6:00 PM	15	0.997
7:00 PM	33	1.158
8:00 PM	25	1.923

Month	Captures	Capture Rate
April	10	1.053
May	26	1.190
June	67	1.787
July	72	1.767
August	63	1.792
September	59	1.355
October	67	1.284
November	1	0.200

AM average	274	1.577
PM average	91	1.267

Overall	365	1.487

*- Only captures from October

in Table 2. Peak capture rates occurred during June, July, and August. Capture rates increase from spring to summer months and taper from summer to fall months. The month with the most reduction in activity was November. No turtles were found active in March.

Microhabitat Properties. – Body temperatures (Tb) followed the daily and seasonal environmental temperature cycles (Table 3). There was not a significant difference in Tb between males and females during any activity period of any month. Therefore, males and females were combined for all Tb analyses. There was not a significant difference in Tb between turtles in shade versus turtles in the open ($p > 0.2608$) in any month and the interaction between month and cover type was not significant ($p > 0.06648$). Body temperature was only significant by month ($p < 0.001$). Therefore, shaded and open turtle locations were combined for Tb analysis. Since there were low numbers of juveniles caught, 14, and juvenile captures, 39, during activity periods, no analyses of adults versus juveniles were performed.

Peak seasonal body temperatures occurred in August for both AM and PM activity. Body temperature for the AM and PM activity periods differed significantly across months ($p < 0.001$). Body temperature differed significantly between AM and PM activity periods within each bimodal month: July = $p < 0.05$, August = $p < 0.001$, September = $p < 0.001$, October = $p < 0.001$.

Within some monthly activity periods, significant differences between air (Ta), body (Tb), model (Tm), and sand (Ts) temperatures were found. Table 4 shows relationships between Ta, Tb, Tm, and Ts during each activity period for each month. For relationships that are not significantly different within an active period, those variables and corresponding

Table 3. Monthly averages of Tb, Ta, Ts, Tm (°C), relative humidity, and the number of captures per activity period. Seasonal maximum values for AM and PM active periods are noted with and asterisk (*).

Month	Time	Tb	Ta	Ts	Tm	Relative Humidity	Captures
April	AM	25.7	28.1	21.3	32.0*	38.1	10
May	AM	23.1	24.8	20.8	25.4	51.3	26
June	AM	25.9	27.0	24.9	25.8	55.0	67*
July	AM	25.2	25.9	24.1	24.9	67.2*	62
August	AM	27.4*	28.9*	26.3*	26.5	54.0	24
September	AM	23.8	24.6	21.6	21.8	52.4	51
October	AM	22.3	23.6	19.5	21.9	64.0	32
July	PM	28.3	27.8	27.8	26.2	58.9*	8
August	PM	30.4*	30.5*	30.7	30.7	50.3	39*
September	PM	30.2	29.5	32.5*	33.9*	35.8	8
October	PM	26.9	25.2	23.0	27.9	47.9	35
November	PM	27.6	25.2	19.4	18.6	29.0	1

Table 4. Non-significant relationships between Tb, Tm, Ta, and Ts (°C), for all monthly activity periods are underlined. Averages of each variable for each active period are in parenthesis. Significant differences are based on p-values < 0.05 and are Bonferroni adjusted to maintain an overall experimental $\alpha < 0.05$.

Month	**Time**					**df**
April	AM	Tm (32.0)	Ta (28.1)	Tb (25.7)	Ts (21.3)	9
May	AM	Tm (25.4)	Ta (24.8)	Tb (23.9)	Ts (20.8)	25
June	AM	Ta (27.0)	Tb (25.9)	Tm (25.8)	Ts (24.9)	66
July	AM	Ta (25.9)	Tb (25.2)	Tm (24.9)	Ts (24.1)	61
August	AM	Ta (28.9)	Tb (27.4)	Tm (26.5)	Ts (26.3)	23
September	AM	Ta (24.6)	Tb (23.8)	Tm (21.8)	Ts (21.6)	50
October	AM	Ta (23.6)	Tb (22.3)	Tm (21.9)	Ts (19.5)	31
July	PM	Tb (28.3)	Ta (27.8)	Ts (27.8)	Tm (26.2)	7
August	PM	Ts (30.7)	Tm (30.7)	Ta (30.5)	Tb (30.4)	38
September	PM	Tm (33.9)	Ts (32.5)	Tb (30.2)	Ta (29.5)	7
October	PM	Tm (27.9)	Tb (26.9)	Ta (25.2)	Ts (23.0)	34

values are underlined. For all seven AM activity periods, Ta was significantly warmer than Ts. In four of the seven months (May, June, August, October), AM Ta was significantly warmer than Tb. For the other months (April, July, September), there was no significant difference between AM air and body temperatures. In two of the seven months (April and May), there was no significant difference in AM Ta and Tm. From June through October, AM Ta was significantly warmer than Tm. In April and May, AM Tm was significantly warmer than Tb. But in August and September, AM Tb was significantly warmer than Tm. In the other three months (June, July, October), there was no significant difference between AM Tm and Tb. For four of the seven months (April, May, June, October), AM Tm was significantly warmer than Ts. In the other three months, there was no significant difference between AM Tm and Ts. For all seven months, AM Tb was significantly warmer than Ts. Three of the five months (July, August, November), had no significant differences between Ta, Tb, Tm, or Ts during the PM activity period. In September, PM Ts was significantly warmer than Ta ($p < 0.05$), but in October, PM Ta was significantly warmer than Ts ($p < 0.00001$). In both September ($p < 0.01$) and October ($p < 0.005$), PM Tm was significantly warmer than Ta. In September, PM Tm was significantly warmer than Tb ($p < 0.05$), but in October there was no significant difference between PM Tm and Tb. In October, both PM Tb and Tm were significantly warmer than Ta and Ts.

When comparing all active captures, there was no significant difference between Tb and Tm. Air temperature was significantly warmer than Tb ($p < 0.00001$), Tm ($p < 0.001$), and Ts ($p < 0.00001$). Both Tb ($p < 0.00001$), and Tm ($p < 0.00001$), were significantly warmer than Ts. All p-values are Bonferroni adjusted to maintain an overall experimental $\alpha < 0.05$.

Relative humidity (RH) peaked for both AM and PM activity periods in July (Table 3). When comparing RH between males and females in the AM active periods of April through June, only May had a significant relationship. In May, readings for males were significantly more humid than for females ($p < 0.05$). There was no significant difference between males and females in their RH readings for either AM or PM active periods for July through October. The only significant difference occurred between the time of day of the active period, AM or PM, within the months of July ($p < 0.05$), September ($p < 0.005$), and October ($p < 0.0001$). In all three cases, AM periods were significantly more humid than PM periods. The ANOVA for AM active periods showed that RH is significantly different across months ($p < 0.00001$). For the PM active periods, RH is also significantly different across months ($p < 0.05$).

There was no significant difference in any active period of any month between males and females for percent cover. Therefore males and females were combined for percent cover analysis. For July through October, only October had a significant difference between AM and PM percent cover ($p < 0.05$). Analysis of percent cover for AM active periods showed a significant difference across months ($p < 0.0005$). Analysis of percent cover for PM active periods also showed a significant difference across months ($p < 0.0005$).

The distance to vegetation did not differ significantly between males and females for April (61.2 cm, 72.0 cm), May (6.6 cm, 7.6 cm), June (8.2 cm, 7.4 cm), or July (9.7 cm, 9.0 cm). Therefore, males and females were combined for the distance to vegetation analysis across months from 6 April through 16 July. The distance to vegetation differed significantly from April to July ($p < 0.00001$). April captures were approximately six to ten times farther away from vegetation as May, June, or July captures. In October, there was no significant difference between males and females in distance to vegetation and no significant difference between AM or PM active periods.

For males and females from 17 July to 14 October, there was no significant difference in distance to shade vegetation within any active period. There was no significant difference in any month between active periods, AM or PM, for distance to shade vegetation. There was a significant difference in distance to shade vegetation between months ($p < 0.00001$). October (59.0 cm) and September (47.3 cm) were approximately twice as far as July (12.9 cm) or August (31.3 cm).

Spatial Use. – A total of 18 individual turtles were thread trailed 21 times from 6 April to 25 October. Only one turtle thread trailed was a juvenile, the other 17 were adults. Nine of the adults were male, eight were female, and the juvenile was a female. Turtle b-b-b-y was thread trailed on consecutive days, 18 and 19 June. This adult female was missing her entire right rear leg and did not travel as far as other turtles. Two months later, her shell was found only 25 meters from her last location. Data from each thread trail is displayed in Table 5. Each thread trail is graphically represented in Appendix A.

Analyses of variables between months were not run due to small sample sizes per month. There was a significant difference between males and females in absolute value of the average turn in degrees ($p < 0.05$). Females (71.64 °) had a greater turning average than males (54.37 °). There was no significant difference between male and female average leg length, total distance moved, total displacement, or in the ratio of displacement/ distance.

Table 5. Data table for each thread trail showing paint color code, sex, age class (A = adult, J = juvenile), start date, AM start time of day, spool result (Off = spool dislodged, EOS = End Of Spool, Burrow = thread lead to burrow), distance moved, absolute value of average heading change, displacement, ratio of displacement divided by distance, and average leg length between heading changes. Column maximums and minimums for trails of at least 50 meters or ended in burrows have an asterisk (*). The last three rows are column averages for all, male, and female trails. Significant differences between males and females have an asterisk (*). Paint color codes in italics have multiple trails per individual.

#	Paint Color Code	Sex	Age	Start Date	AM Start Time	Spool Result	Total Distance (m)	Average Turn (degrees)	Total Displace ment (m)	Dsplc. / Dist.	Average Length (m)
1	r-r-r-r	F	A	6-April	8:27	Off	91.8	67.75	62.03	0.68	2.78
2	o-b-o-o	F	A	10-May	7:50	EOS	206.5	84.09	35.17	0.17	4.49
3	o-o-b-b	M	A	10-May	8:15	Off	167.6	63.39	40.42	0.24	4.53*
4	b-b-o-o	F	A	10-May	8:57	Off	102.5	84.50	56.22	0.55	3.31
5	r-y-r-r	F	A	17-May	9:03	Burrow	51.7	72.25	39.19	0.76	3.04
6	o-r-r-o	F	A	17-May	9:34	Burrow	123.0	86.85	38.66	0.31	3.00
7	y-b-y-b	M	A	10-June	6:45	Off	25.5	82.50	16.57	0.65	2.32
8	b-b-b-y	F	A	18-June	6:44	Burrow	55.8	61.21	34.88	0.63	2.23
9	b-b-b-y	F	A	19-June	7:30	Burrow	44.2	92.36*	23.35	0.53	1.92
10	g-g-y-g	M	A	21-June	6:50	Burrow	172.8	63.81	53.97	0.31	2.19
11	w-g-w-g	F	J	25-June	7:00	Burrow	195.9	53.24	42.79	0.22	1.98
12	o-o-b-o	M	A	2-July	6:49	EOS	273.7	59.20	37.75	0.14	1.61*
13	w-g-g-w	M	A	10-July	6:40	EOS	293.2*	52.90	59.29	0.20	1.88
14	r-r-w-w	F	A	15-July	7:00	EOS	293.0	53.80	113.30*	0.39	2.01
15	g-w-w-w	M	A	29-July	6:57	Off	207.3	48.88	7.62*	0.04*	1.96
16	b-o-o-b	M	A	19-Aug.	7:40	EOS	273.3	48.04	94.85	0.35	1.99
17	o-g-o-g	M	A	28-Aug.	7:40	Burrow	164.1	65.53	51.58	0.31	2.25
18	g-w-w-w	M	A	6-Sept.	7:00	Burrow	144.0	50.58	17.50	0.12	2.12
19	o-g-o-g	M	A	25-Sept.	7:46	Burrow	16.7*	26.14*	15.76	0.94*	2.09
20	y-y-o-o	F	A	15-Oct.	9:25	EOS	286.3	60.36	42.44	0.15	2.03
21	b-b-b-b	M	A	25-Oct.	9:15	EOS	282.5	46.55	74.58	0.26	2.62
All		18					165.30	63.04	45.62	0.38	2.49
M		9					184.79	54.37*	41.59	0.33	2.34
F		9					145.07	71.64*	48.80	0.44	2.68

The ratio of displacement divided by distance gives an index between 1 and 0. Values closer to 1 indicate a straighter path, while values closer to 0 indicate a more curved path. Displacement to distance ratios ranged from 0.12 to 0.94, with an average of 0.38. Females tended to have a straighter path (0.44) than males (0.33), although this trend was not significant. Females also tended to travel further per leg length (2.68 m) and have a farther displacement (48.80 m) than males (2.34 m and 41.59 m, respectively), but these relationships were not significant. Males tended to have a farther total distance (184.19 m) than females (145.07 m), but this trend was not significant.

The maximum distance traveled was 293.2 meters. Since this trail continued on and exceeded the bobbin length, no maximum daily distance can be determined. The minimum daily distance was 16.7 meters, from a cold morning and day. This thread trail also had the highest displacement to distance ratio (0.94), meaning it was the straightest recorded trail. This trail also had the smallest heading change average of 26.14 degrees. The average total distance traveled was 165.3 meters. The maximum displacement was 113.30 meters from the site of bobbin attachment. The average displacement was 45.62 meters. The minimum displacement recorded was 7.62 meters. This turtle thread trail also had the lowest displacement to distance ratio (0.04) and had traveled 207.3 meters, but was only 7.62 meters from the bobbin attachment site when the bobbin was dislodged. The trail with highest average turn, 92.36°, was the three-legged female that died. The average heading change was 63.04 degrees.

Vegetation Transects. – Three random transects provided 15 100-meter arms for analysis of percent cover by vegetation types. The vegetation types used were grass, tall forbs, low forbs, shin oak (*Q. havardii*), mesquite trees (*P. glandulosa*), yucca (*Y. campestris*), woody shrubs, low profile ground cover, and cactus (*Opuntia engelmannii* and *O. leptocaulis*). Forbs were classed as tall or low on the basis of ability to provide shade. Percent cover by vegetation type, total percent vegetated, and total percent open are listed in Table 6.

Vegetation only covers an average of 33.51 % of the surface on the study site, leaving 66.49 % of the surface as open sand. Grasses (23.67 %), tall forbs (19.67 %), shin oak (18.16 %), mesquite (14.76 %), and low forbs (13.79 %), are the dominant vegetation types based on percent of total vegetation. Overall, grasses account for only 7.93 % of the surface area. Cactus only accounts for 0.10 % of the total vegetation and 0.03% of the surface area.

Chi-squared tests showed that box turtles are not randomly distributed between 6 April and 16 July, in relation the closest vegetation, ($x^2 = 109.926$, $df = 7$, $\alpha = 0.05$). Turtles used forbs (100 observations) and mesquites (39) less frequently than expected (122 and 54, respectively). Turtles used shrubs (47 observations), ground cover (9), and cactus (4) more frequently than expected (15.3, 5.1, and 0.4, respectively).

From 17 July to 14 October, box turtles were not randomly distributed based on expected values for a chi-squared test ($x^2 = 23.522$, $df = 7$, $\alpha = 0.05$), in relation to closest shade vegetation. Turtles used yuccas (3 observations) less frequently than expected (6.4) and used grasses (39.5 observations) and cacti (1.5) more frequently than expected (35.1, 0.1, respectively).

Table 6. Percent cover averages for each vegetation type, total vegetation, and open sand. Vegetation type as a percent of total vegetation is given in the third row.

Vegetation Type	**Grass**	**Tall Forbs**	**Shin oak**	**Mesquite**	**Low Forbs**	**Yucca**	**Shrubs**	**Ground Cover**	**Cactus**	**Vegetated**	**Open**
Mean %	7.93	6.59	6.09	4.95	4.62	1.43	1.40	0.47	0.03	33.51	66.49
% Total Vegetation	23.67	19.67	18.16	14.76	13.79	4.26	4.18	1.41	0.10	100.00	

Home Ranges. – For seven turtles with at least eight captures each, home ranges were calculated by Minimum Convex Polygons (MCP) and by direct measure between the two farthest location points (Table 7). The maximum number of captures was twelve. Locations used to calculate home ranges include active and resting locations. Six of the turtles were males and one was a female. All home ranges represented adult turtles. Home range size varied from 0.73 ha to 3.28 ha, with an average of 2.27 ha for MCP. Direct linear measure of home range size ranged from 173 to 368 meters, with an average of 278.6 meters.

Table 7. Home range for each turtle with at least eight captures: paint color code, number of captures, range of dates of captures, sex, age class, and home range size by MCP and direct linear measure. Averages are noted with and asterisk (*).

Paint Color Code	**Number of Captures**	**Range of Dates**	**Sex**	**Age Class**	**Home Range MCP (ha)**	**Home Range Linear Measure (m)**
b-b-b-b	8	7 April - 25 Oct.	M	Adult	2.21	283
o-o-b-b	11	7 April - 11 Oct.	M	Adult	3.28	368
b-o-o-b	12	7 April - 16 Oct.	M	Adult	3.11	329
o-b-o-o	8	21 April - 22 Oct.	F	Adult	2.48	276
o-o-b-o	9	21 April - 6 Nov.	M	Adult	0.73	173
y-y-g-g	8	28 May - 9 Oct.	M	Adult	1.13	249
g-g-y-g	10	3 June – 3 Oct.	M	Adult	2.93	272
Average	9.4*				2.27*	278.6*

DISCUSSION

The box turtle population demographics of Monahans Sandhills State Park appear to be consistent with other studies on box turtle populations (Allard 1935, Stickel 1950, Legler 1960, Blair 1976, Murphy 1976, Doroff and Keith 1990). A female skewed sex ratio in both age classes (Table 1) can be attributed to four different potential factors. First, the duration of the study was only one summer. A multiple year project would provide a more complete view of the demographic structure of the Monahans sandhill's population. Secondly, new individuals were captured and marked in every month that had more than one capture (Table 8). This indicates that not all individuals in the study site were marked. Therefore, one of the sexes could be under or over represented by incomplete sampling of study site. Also box turtles exhibit temperature dependant sex determination in the nest (Dodd 2001). At warmer temperatures (at or above 29° Celsius) all females are produced, whereas at 22.5° to 25° Celsius all males are produced (Packard et al. 1985, Ewert and Nelson 1991). Based on average monthly burrow temperatures from models in burrows, temperatures exceeded 26° Celsius from May through September, during which mating, nesting, incubation, and hatching likely occurred (Legler 1960). Therefore, shallow nests will be warmer and produce mostly females. Finally, in case of the juvenile sex ratio, the low number of individuals captured (14) is problematic. Marking more juveniles would provide a more precise estimate of juvenile sex ratios.

The MSSP density of 0.849 turtles per hectare is much lower than a published estimate of *T. ornata* at a Kansas site of 2.18 turtles per ha (Legler 1960), or at a Texas site recalculated as a range of 9.6 to 12.3 turtles per ha (Blair 1976), or at a Wisconsin site of 2.9

Table 8. Active captures for each month, cumulative total captures, new individuals marked in every month, total number of marked individuals, and percent of monthly captures that were new individuals.

Month	Monthly Captures	Total Captures	New Individuals Marked	Total Marked	% Of Captures New
April	10	10	10	10	100%
May	26	36	15	25	58%
June	67	103	35	60	52%
July	72	175	25	85	35%
August	63	238	11	96	17%
September	59	297	13	109	22%
October	67	364	15	124	22%
November	1	365	0	124	0%

to 5.0 turtles per ha (Doroff and Keith 1990). The Monahans sandhills density estimate is also much lower than reported densities for the eastern box turtle, *T. carolina*, (Stickel 1950, Schwartz and Schwartz 1974, Dodd 2001). This low density estimate may be influenced by many factors of the Monahans sandhills. Habitat quantity and quality affect individual home range size (Dodd 2001). The sparseness of vegetation on the study site and the non-random distribution of box turtles in relation to vegetation types may play a role in determining home range size. Size of the home range may be reflected in a relatively low density estimate, although Madden (1975) noted no studies have correlated home range size to box turtle density estimates. The density estimate may also be conservatively low, because not all potential turtles on the study site were marked during the study.

The MSSP home range size estimates (Table 7) are comparable to other ornate box turtle home ranges calculated by MCP. The Monahans sandhills home range estimates (0.73 to 3.28 ha, mean = 2.27 ha, n = 7) are smaller than Nebraska populations (9.5 to 15.8 ha, mean = 13.2 ha, n = 6) but are consistent with New Mexico populations (0.03 to 4.1 ha, mean = 1.64 ha, n = 15) of ornate box turtles (Holy 1995, Nieuwolt 1996). Ornate box turtle home range size estimates from MSSP are also similar to all reported home ranges (0.02 to 9.9 ha) of the eastern box turtle, *T. carolina*, calculated by MCP (Dodd 2001). Home range estimates by direct linear measure for MSSP, 173 to 368 meters with a mean of 279 meters, are comparable with a New Mexico study, 32 to 526 meters with a mean of 276 meters (Nieuwolt 1996). But it is longer than studies from eastern regions: from three Kansas studies (167 meters from Fitch 1958, 44 to 556 meters with a mean of 170 meters from Legler 1960, and 73 to 270 meters with a mean of 182 meters from Metcalf and Metcalf 1970) and a Texas study (67 to 137meters with a mean of 103 meters from Blair 1976). Ornate box turtle home range estimates from MSSP are also greater than all reported direct linear measurements for eastern box turtles, *T. carolina* (Dodd 2001).

The daily distance covered by box turtles on MSSP ranged from 16.7 meters to greater than 293.2 meters, with an average of 165.30 meters. This daily distance is greater than all other studies for ornate and eastern box turtles which reported daily distances (Dodd 2001). This could be related to the distribution of resources: mates, food, shelter, and competition. The MSSP daily displacement of the box turtles ranged from 7.62 to 113.30 meters, with an average of 45.6 +/- 25.9 meters. The daily displacement range and average are greater than reported values from New Mexico populations, with an average of 13.4 +/- 32 meters (Nieuwolt 1996).

An examination of the significant difference between average turn angles for males versus females (Table 5) along with the trend of males having a farther daily distance indicates males travel a straighter path than females. This relationship is hypothesized to occur because males traveling straighter paths increase the probability of encountering females (Duvall and Schuett 1997). Unfortunately, there was no significant difference between males and females in the ratio of displacement to distance, which gives an index of amount of sinuosity of the path. Males and females also had no significant difference between average daily displacements or in average leg length, although females tended to have a less sinuous path, longer path legs, and greater displacement. These five variables do not support the hypothesis that male turtles travel a longer and straighter path to increase likelihood of encountering more females. A larger data set, including only complete trails and using longer bobbin lengths may refute this assessment.

Based on percent cover by vegetation type, the observed versus expected values of box turtle distribution in relation to vegetation type was significantly different. The difference was significant for both distance to spring vegetation and for distance to summer shade vegetation. This indicates that turtles are using the measured vegetation types non-randomly, either for thermoregulation, social interactions, foraging, or concealment. During the spring, forbs and mesquites were used less than expected, while shrubs, ground cover, and cacti were used more than expected. When examined from a foraging and concealment need perspective, thin forbs and large mesquites do not provide as much cover or food as denser, lower shrubs, ground cover, and cactus for the turtles and their arthropod prey. The main observed use of mesquites was for burrows and the occasional surface resting site. Cacti also provide an additional food source in their fruit. For the summer shade vegetation analysis, yuccas were used less frequently, while grasses and cacti were used more than expected. Of these three vegetation types, none were used primarily for shade. Yuccas are used mostly for burrows, while cacti and grasses appeared to be used mainly for foraging and concealment.

The vegetation on MSSP is considerably less dense (more than 66 % of the surface is open sand) than habitats in Wisconsin, Nebraska, Kansas, and other locations in Texas which consisted of farm fields, prairie grasslands, wooded forests, mesquite grasslands, and some natural drainage sites (Fitch 1958, Legler 1960, Blair 1976, Doroff and Keith 1990, and Dodd 2001). Vegetational dynamics of New Mexican sand dune and creosote flat habitats were similar to vegetation types found on MSSP (Degenhardt, et al. 1996 and Nieuwolt 1996).

The topography of the Monahans sandhills did not provide a substantial obstacle to the daily activity of box turtles. Turtles were observed in every habitat type on the state park and trails traversed the slopes of many dunes. On multiple occasions, trails would ascend straight up dune faces, regardless of the lack of vegetation. Many burrows were located near the peaks of coppice dunes in shin oak patches that had substantial slopes. The angle of repose at which the Monahans sand hill slopes lose their stability is 34° (Machenburg 1984). Box turtles have no reduction in ability to climb slopes below 40° (Muegel and Claussen 1994). Therefore, the topography and substrate do not provide limitations to daily travel distances, home range size, or ability to maneuver in this habitat.

Taking into account the comparable home range estimates, lower density estimates, the non-random distribution of box turtles in relation to vegetation types, the sparseness of vegetation characterized on MSSP, and the topography when compared to other studies of ornate box turtles from Wisconsin, Nebraska, Kansas, Texas, and New Mexico, the Monahans sandhills population appears to represent the habitat nearest to the arid end of the spectrum for ornate box turtles.

This assessment is further supported by microhabitat characteristics. Examinations of the microhabitat variables within each activity period show significant relationships. In three of the eleven monthly active periods, April AM, May AM, and September PM, Tm was significantly greater than Tb. In the afternoon September period, this significance can be explained by the fact that the models are exposed to solar radiation during the entire day, while the turtles are resting in their burrows. In September, the temperature profile from the burrow models, Appendix B, indicates a drop of 3 to 4° C from August burrow temperatures in average monthly burrow temperature and afternoon burrow temperature readings. These cooler afternoon burrow temperatures in September explain this significant relationship. During the AM of April and May, Tm exceeds Tb because by the time turtles have warmed up from basking, 8:00 to 9:00 AM, and are active, the surface model profiles (Appendix B) have a higher temperature than the burrow models by 1° C to 6° C for May. No burrow profile is available for April. Similar active surface profiles for April and May, lead to the assumption that they would show similar burrow readings.

For two of the eleven active periods, Tb was warmer than Tm. Both of these occurred during the AM of two consecutive summer months, August and September. This is due to the warm burrow temperatures that turtles experience overnight in these months. Turtles are 1° C to 10° C warmer than the surface models when they emerge from the burrows between 7:00 and 9:00 AM for both August and September. Their thermal inertia allows them to be active in the early morning. The same pattern is exhibited in June, July, and October, even though the relationship is not significant. For the other six of the eleven active periods, there was no significant difference between model and body temperatures. This indicates that for more than 54 percent of the active periods, body temperature is similar to the model temperatures determined by the physical environment.

For all seven AM active periods, Ta was significantly warmer than Ts. This would be expected because gases heat faster than solids. This same pattern was seen in the October PM active period. This significant relationship is due to a cold front that moved through in mid-October for four days. After this event, October temperatures remained cool for the remainder of the study. Again the air warms faster than sand during this phenomenon. During the September PM active period Ts was significantly warmer than Ta. During this active period, Tm was 3° C warmer than Tm in August (Table 3). The sand retains heat longer than the air during the late afternoon and evening hours, thus maintaining a higher Tm and Ts longer than Ta. This relationship can be seen in the heating and cooling rates of the surface and burrow model profiles. Models on the surface heated faster, earlier, and to higher temperatures than burrow models. Surface models also cooled faster, earlier, and to lower temperatures than burrow models.

Maximum average daily burrow temperatures are 15° C to 18 ° C cooler than average daily surface models from June to September. The burrow maximums also occur one to four hours after the surface models peak. Therefore turtles are cooler than the air and model temperatures in the afternoon and evening when they emerge. By this time, evening model temperatures are quickly cooling 4° C to 8° C per hour.

The minimum average daily burrow temperatures are typically 5° C to 9° C warmer than the minimum average daily surface temperatures from May to October. These are also offset by one to two hours monthly, with the surface reading occurring between 6:00 and 7:00 AM, while the burrow reading occurs from 7:00 to 9:00 AM. Again this shows turtles are 5 to 9 ° Celsius warmer than their environment when they emerge in the AM. This pattern plays a crucial role in box turtles maintaining a daily and seasonal suitable body temperature by retreating to their burrows during the hot mid day and then not freezing during the cold winter months.

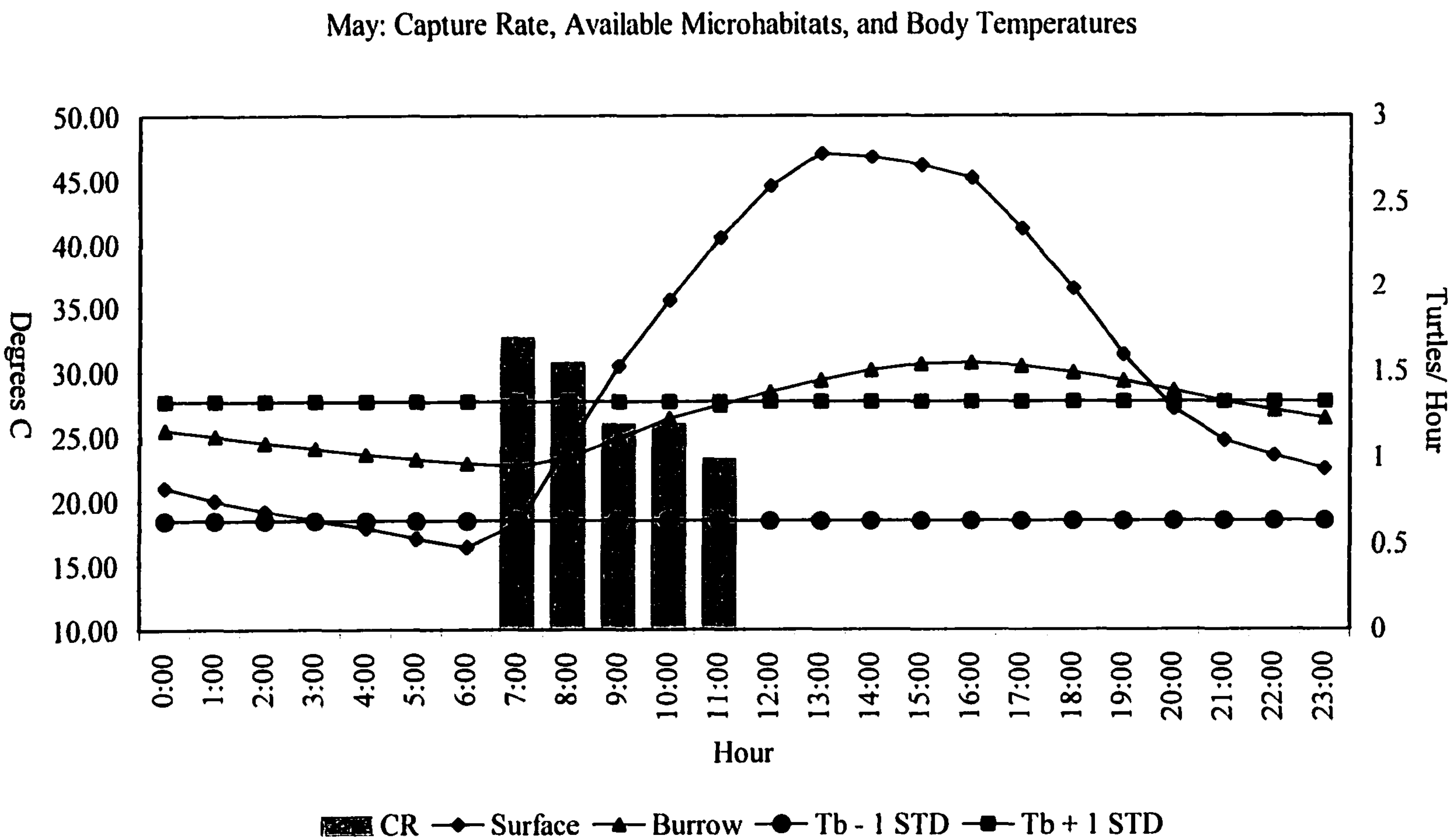
For all AM active periods, the average Tb fell between the averages of Ta and Ts. Body temperature was significantly cooler than Ta and significantly warmer than Ts in four of the seven AM months: May, June, August, and October (Table 4). In April, July, and September, Ta was not significantly warmer than Tb, but Tb was still significantly warmer than Ts. The lack of difference between Ta and Tb in April can be attributed to a low sample size of only 10 turtles. The lack of significant difference between Ta and Tb in July and September may be reflected in capture rate per AM hour.

During the evening, the average for Tb was higher than the averages for Ta and Ts for all months except August, when Ta was higher by one tenth of a degree, and September, when Ts was higher by 2.3° C. None of the relationships were significant for Tb versus Ta and Ts in the PM active periods, except during October when Tb was significantly warmer than both Ta and Ts. This is due to the almost day long active period in October where turtles were exposed to solar heating and sand conduction all day.

The relationship during activity periods between Tb and available surface and burrow microhabitats, can best be seen by a monthly graph. The graph for May (Figure 1), which has only one active period in the morning, has four lines representing the surface model profile for May (diamonds), burrow model profile for May (triangles), the average body temperature for all May active captures plus one standard deviation (squares), and minus one standard deviation (circles). The range between the two Tb lines encompasses 65 percent of all recorded body temperatures for May. A bar graph of capture rates for each hour of the day is presented on the graph. Peak capture rates occur at 7:00 and 8:00 AM, and decline towards 11:00 AM. The peak capture rates occur when the surface model line (diamonds), is between the two Tb lines (squares and circles). As the surface models heat above this range, turtles becoming increasingly less active. By 12:00 PM, all turtles had returned to their burrows. This shows box turtle activity is dependent on available microhabitat temperatures. When surface temperatures approach body temperatures turtles are the most active, and as available temperatures deviate from suitable Tb, turtles decrease in activity.

For months that had two active periods, one morning and one late afternoon, the same

Figure 1. Spring activity and temperature relationships as shown in the month of May.



pattern can be seen by the graph for August (Figure 2). In the AM active period, peak activity corresponds to the hours of the day when the surface model profile (diamonds) is between the two AM body temperature lines (squares and circles) at 8:00 and 9:00 AM. During the PM active period from 6:00 to 8:00 PM, peak activity occurs when surface model temperatures are between the two PM body temperature lines at 7:00 and 8:00 PM. The same pattern seen in the spring activity is seen in the summer. Box turtles are most active when available surface thermal microhabitats are within active Tb ranges. In the fall month of October, box turtles exhibit a wider daily activity pattern (Figure 3).

In October, box turtle activity ranges from 7:00 AM through 7:00 PM, although no turtles were seen during the noon hour. Fall activity does not fit the same pattern as well as the spring and summer months. Fall temperatures were cooler than spring or summer throughout the day (Table 3 and Appendix B). The lower daily temperatures allow them to have an almost day long active period. This is also supported by the presence of the surface model line (diamonds) between the AM and PM Tb lines (squares and circles) from 10:00 AM to 2:00 PM and again from 5:00 to 6:00 PM. The early peak of activity at 7:00 AM is a function of many turtles being located in the first two weeks of October when temperatures were still similar to summer temperatures. During mid-October, a cold front came through for three to four days, during which very few turtles were active at all. After the weather passed, turtles were active again but daily temperatures remained cool for the rest of the season.

One trend seen in each of the figures is the burrow model temperature profile line (triangles) lying between or within a few degrees of the active Tb lines (squares and circles).

Figure 2. Summer activity and temperature relationships as shown in the month of August.

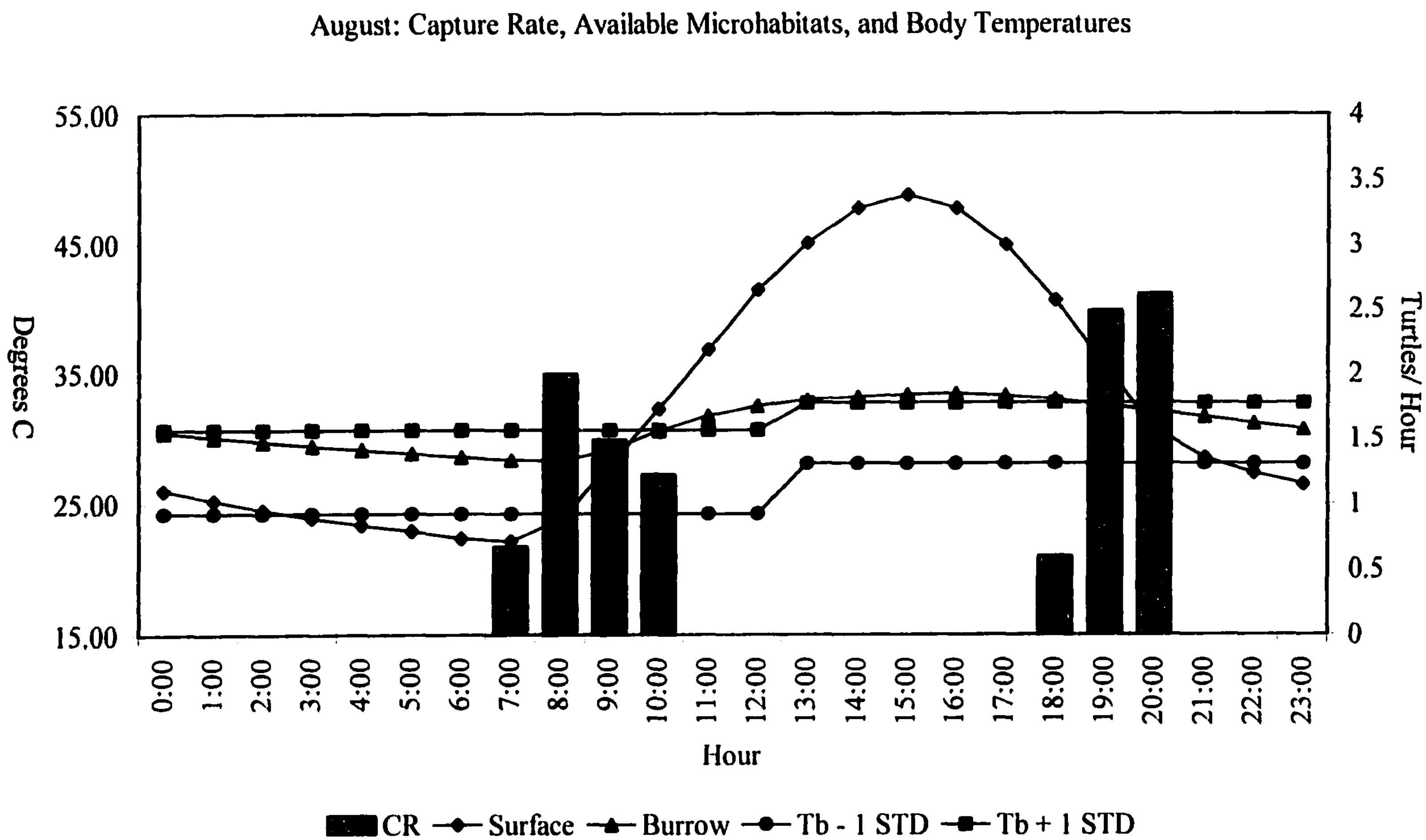
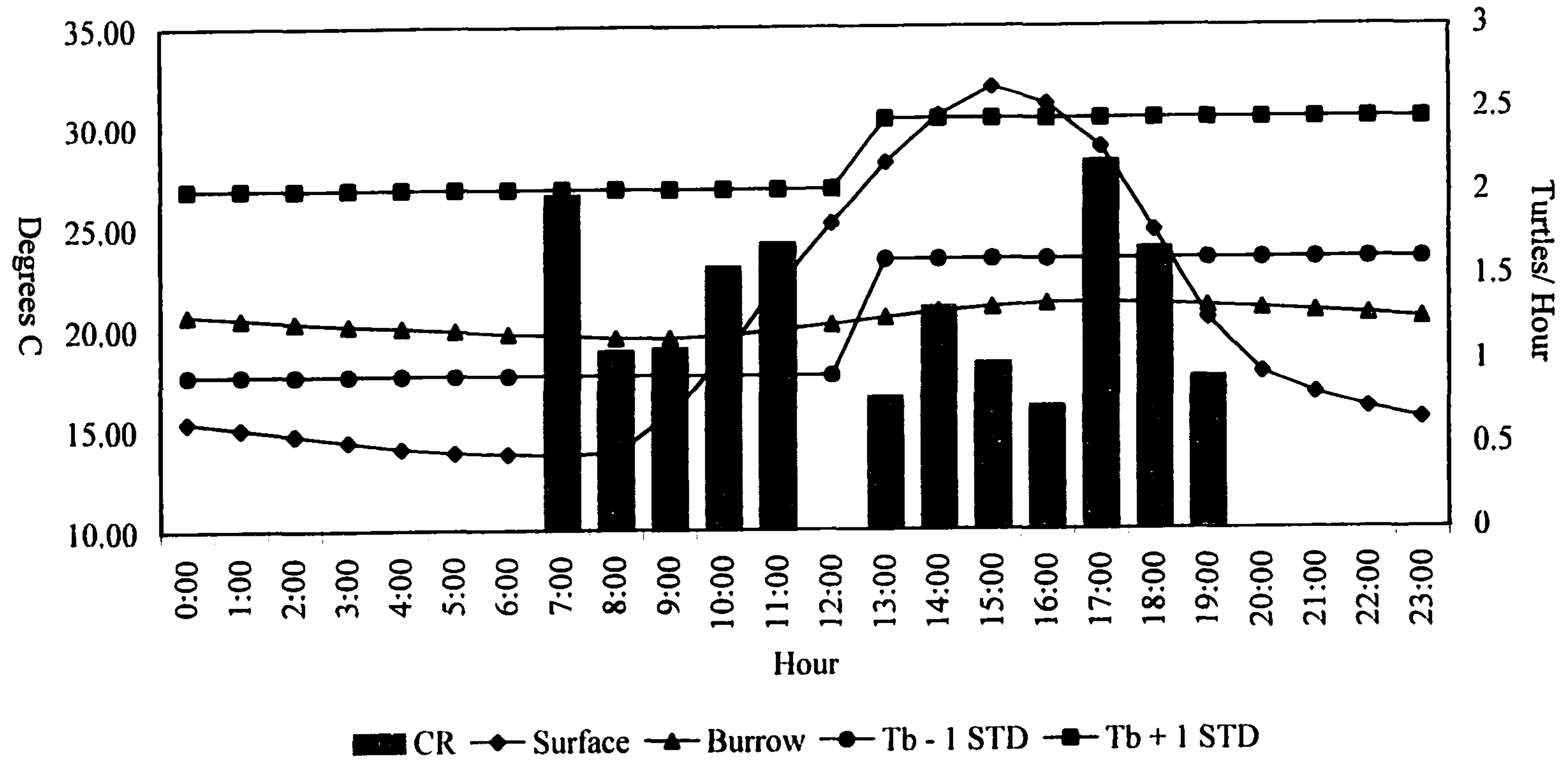


Figure 3. Fall activity and temperature relationships as shown in the month of October.

October: Capture Rate, Available Microhabitats, and Body Temperatures



This explains early morning activity morning activity when surface models are cooler than the Tb lines, because when turtles emerge they are warmer than the surface microhabitats.

The shift from uni-modal to bi-modal daily activity patterns from spring to summer and then back from summer to fall is a product of available microhabitats in terms of thermal environment, food sources, and access to mates. During the spring months, turtles are active only once daily because burrows still provide relatively cool microhabitats during the day. This is a less energetically expensive strategy to stay cool and maintain a lower body temperature, thus having a lower metabolism. When burrows become warm during the summer months, their metabolism is already high due to a high Tb, so it is beneficial to come out again in the late afternoon and early evening. There is also a potential difference between available prey in the spring and summer. More types of prey have become active and reproduced in the summer than the spring. Also most vegetative growth and production of fruit does not take place until early to mid summer in MSSP. Since box turtles mate through out the entire active season, no particular emphasis is placed on which months provide the best mating opportunities. However, the peak activity of the summer months should provide more opportunities for encountering a mate.

The shift back to an apparent uni-modal activity pattern in the fall is an extension of the active hours of the bi-modal summer months. The uni-modal spring active period consisted of four to five hours, while the fall uni-modal activity was almost twelve hours long in October. During the fall, cool daily surface temperatures allow long daily activity to increase foraging time, with no consequence of increased metabolism.

Seasonal activity of box turtles from the Monahans sandhills is typical for most populations of ornate box turtles (Legler 1960, Blair 1976, Doroff and Keith 1990, Nieuwolt

1996, and Dodd 2001). In more northern locales, activity ranges from May to October, while in southern populations activity can range from March to December. Box turtles from MSSP were active from early April to early November. For the Monahans sandhills, activity peaks and is constant throughout the summer months, whereas New Mexico populations show relatively low summer activity that is heavily influenced by precipitation (Norris and Zweifel 1950, Degenhardt, et al. 1996, Nieuwolt 1996).

Other noteworthy aspects of ornate box turtle life history on MSSP can be categorized as behavioral, burrow-related, or dietary assessments. Of the 369 observations, 365 were active turtles. Three of the four non-active observations were resting turtles, while the fourth was a mortality location. Two of the resting turtles were dug out of their burrows and measured, while the third was resting near the entrance to a burrow under a large mesquite. Burrows dug by turtles in dune faces rarely exceeded 1.0 meter in depth. Burrows dug by other animals, but used by box turtles, were highly variable in depth and size. No turtles were seen excavating any burrows. Burrows appeared to be the main sites of aestivation and hibernation for the majority of the year. In the early fall, some turtles were discovered to be using forms under or besides shrubs and tall forbs overnight. Forms are shallow depressions in either the substrate or leaf litter that are used as one-time resting sites. Forms are prominently used by box turtles in more mesic habitats (Stickel 1950, Schwartz and Schwartz 1974, Dodd 2001). The use of forms by box turtles was not recorded during other times of the year on MSSP. There was one observation of a box turtle climbing vegetation. On 19 August, after a short rainstorm, a small female (g-w-g-w) was located 25 centimeters off the sand in a tall forb (*Guara vilosa*).

A total of five social interactions were recorded. Three of these were courtship and copulation between a male and female. The other two involved male to male interaction. In the three mating encounters, three different males mated with two females. One female (o-o-g-g) was mounted by two different males (g-g-b-b and o-y-y-o). The male was larger than the female in only one of the three instances. The three mating observations were recorded between 28 August and 2 October. In each of the two male to male interactions, a dominant and submissive turtle was determined. On 7 April, a large male (b-o-o-b) had flipped a smaller male (o-o-b-b) over on to its back. This was the position in which the turtles were found. On 14 October, two males were in the copulatory position. The smaller male (y-r-r-y) was mounted on the rear carapace of the larger male (r-y-y-r). This behavior is a show of dominance between males (Legler 1960 and Dodd 2001). Usually the larger turtle is the dominant turtle (Dodd 2001).

Of the 365 active observations, 20 were observed feeding. Of the twenty feeding observations, eight were turtles digging and eating dung beetles out of cow dung piles. Box turtles use their fore limbs, head, and neck to dig in the dung. Many box turtles had dried dung on their shells when located, showing cow dung to be an important and frequent food source. One turtle was observed eating a prickly pear cactus fruit on 17 May. Several other turtles were observed to have the red cactus fruit juice, pulp, or spines on the mouth and head during the late spring and summer. Five turtles were observed eating black beetles through visual location, pursuit, and consumption. One feeding observation each was recorded of mesquite bean pods, small forbs, a shiny iridescent green beetle, and a centipede (*Scolependra*). This is the first time a box turtle has been reported to eat centipedes. In the last two feeding observations the arthropod prey item was unidentifiable.

CONCLUSIONS

The ornate box turtle population on Monahans Sandhills State Park represents a unique pattern of life for this species. These turtles exhibit the ability to travel farther per day, which corresponds to longer individual home range direct linear measurements when compared to other populations of ornate and eastern box turtles. The sparseness of vegetation and low density estimates support these differences. The available microhabitats for box turtles allow for multiple daily and seasonal activity strategies. The results from this study indicate this population does not exhibit ecological dynamics based on its location in a zone of intergradation of two subspecies, but due to the abiotic and biotic environmental constraints of the existing habitat.

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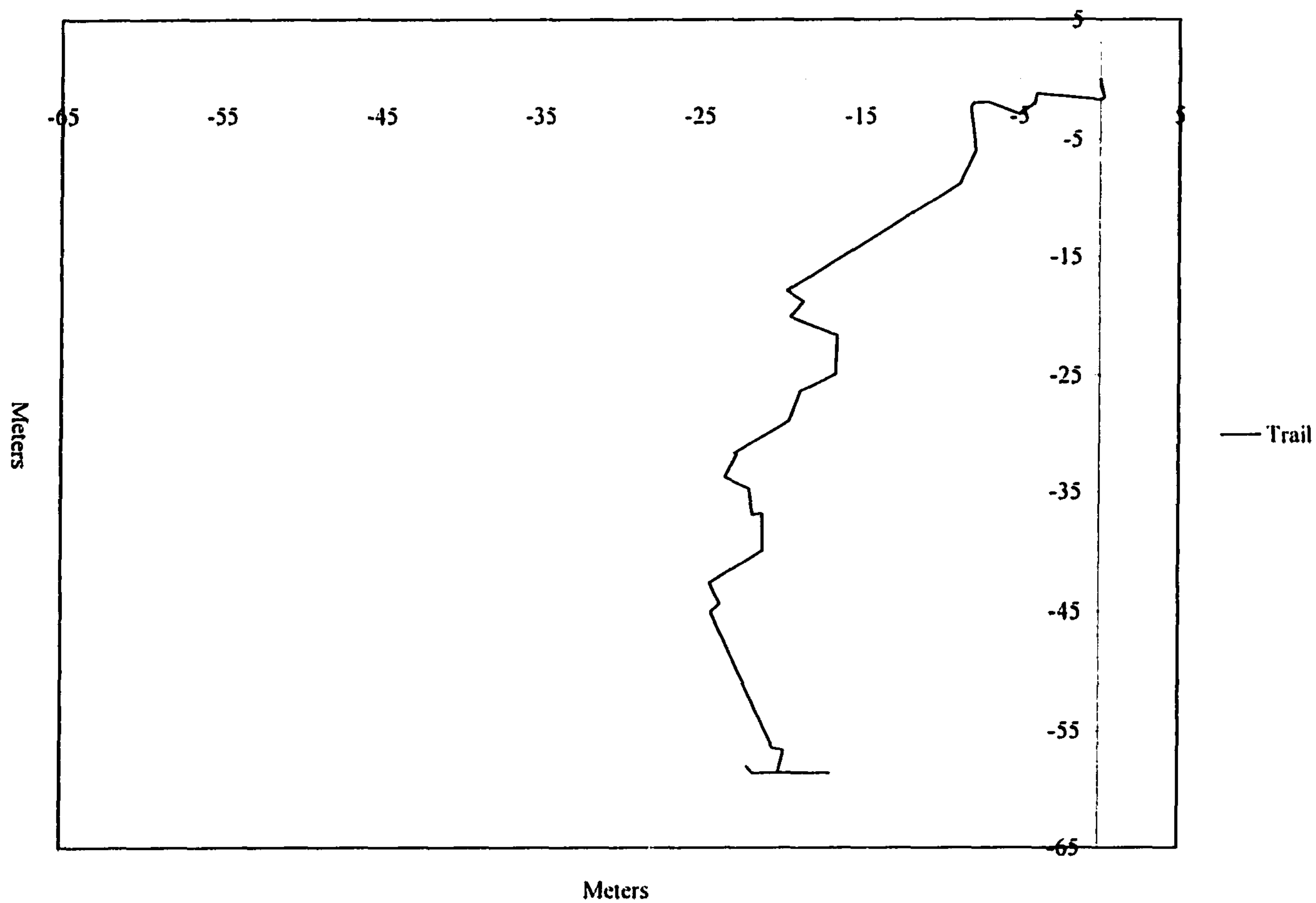
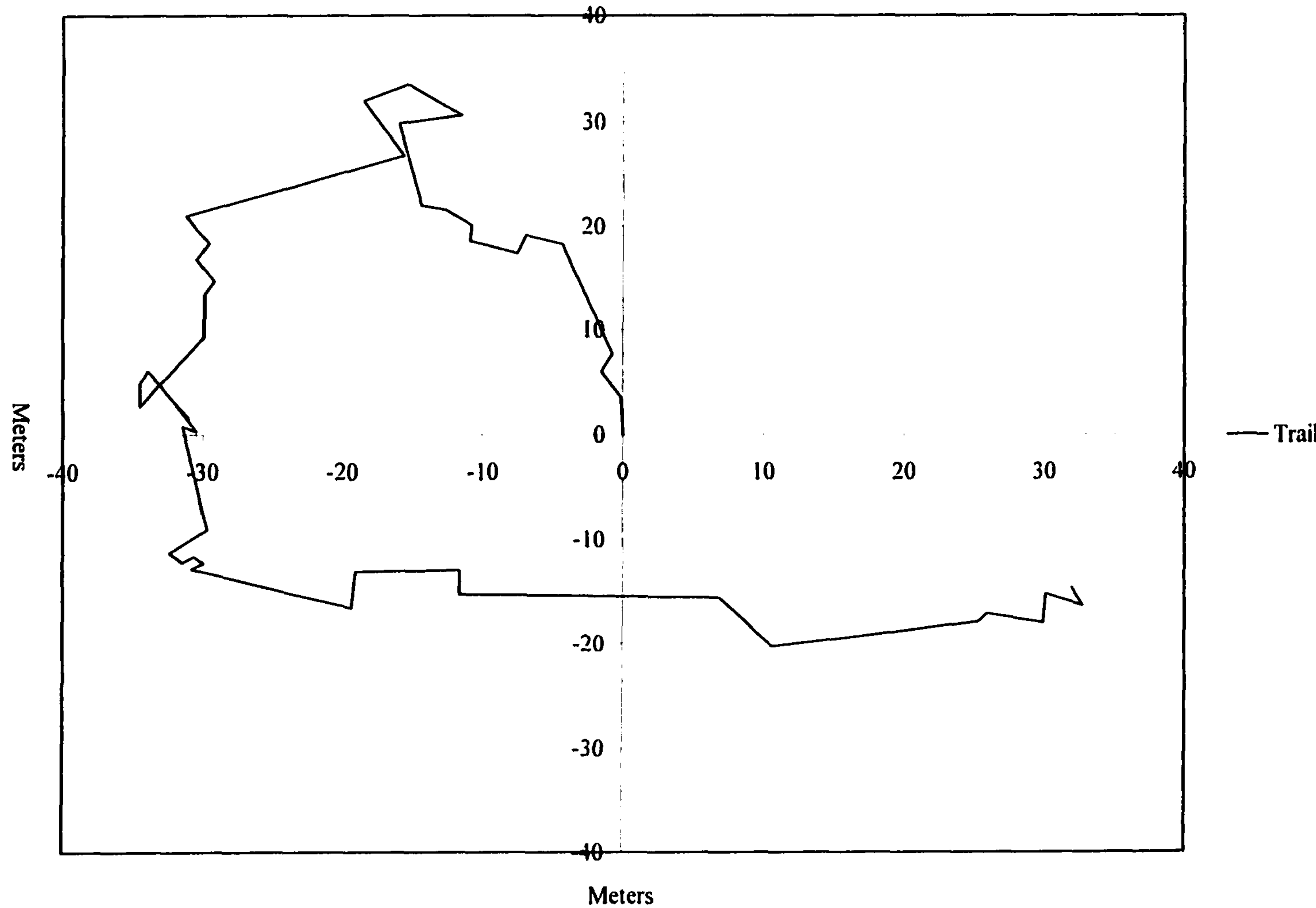
APPENDIX A

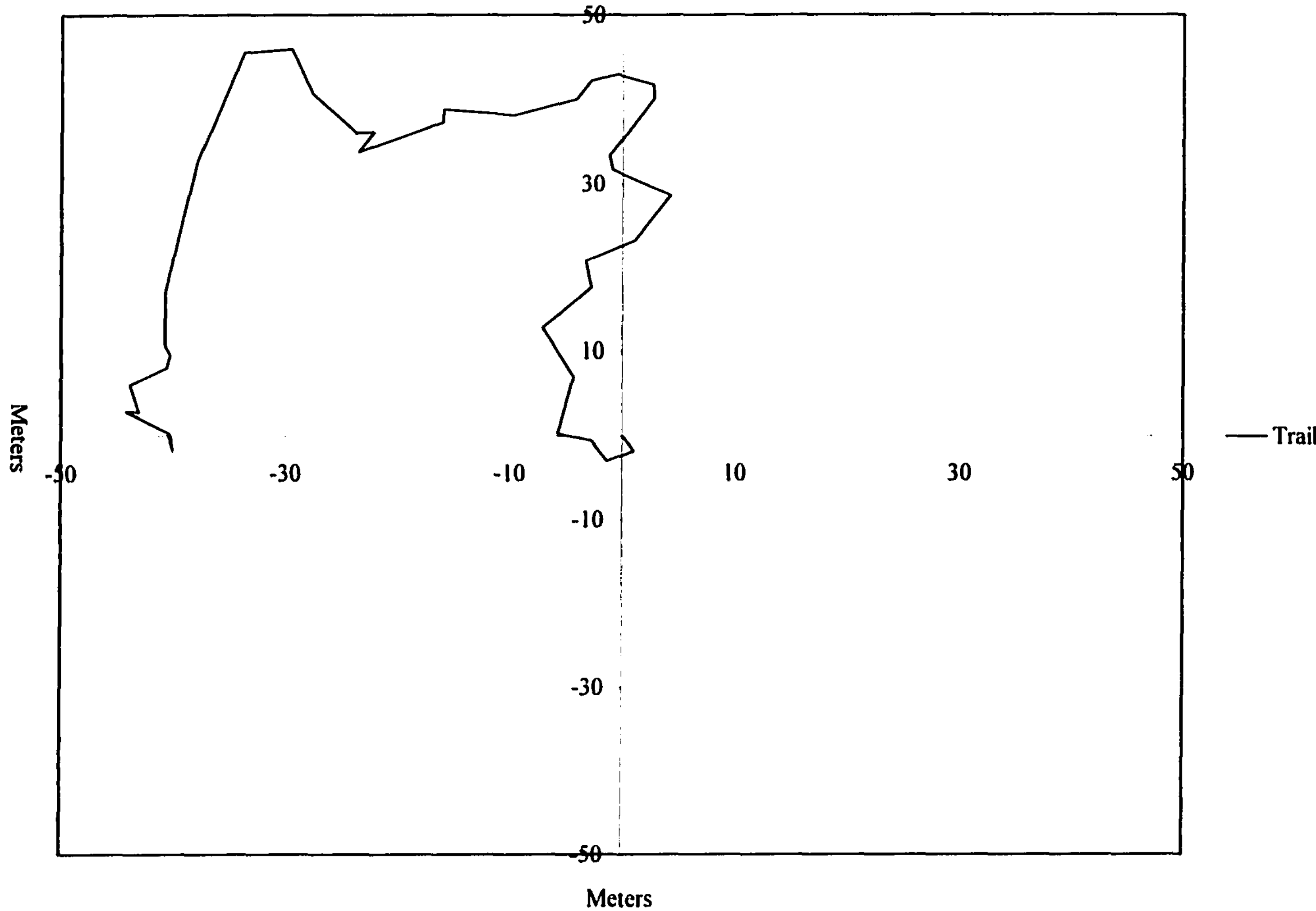
Trail 1: r-r-r-r, 6 April, adult female, total distance = 91.8 meters, average turn = 67.75 degrees, total displacement = 62.03 meters, ratio = 0.68, average leg length = 2.78 meters.



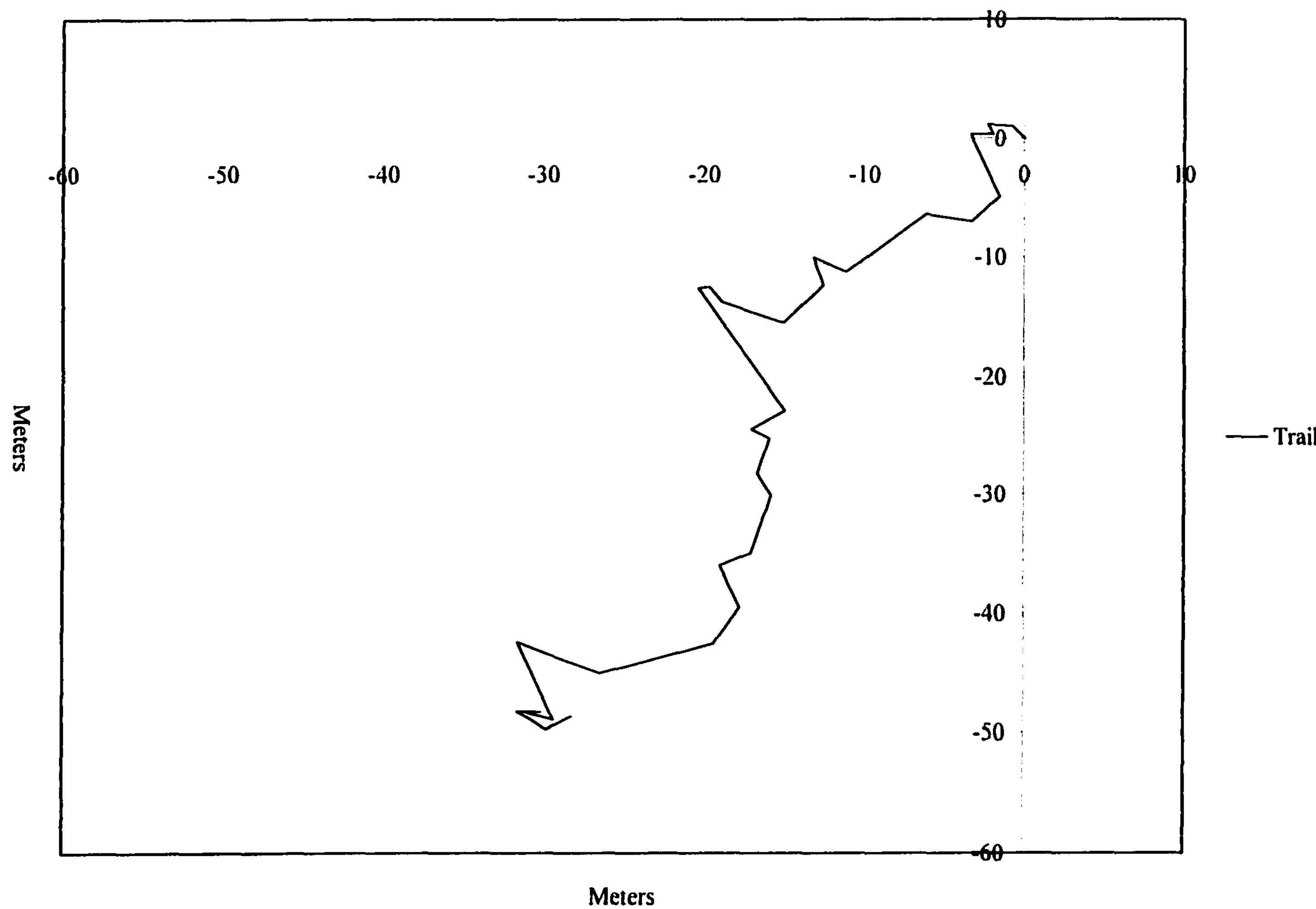
Trail 2: o-b-o-o, 10 May, adult female, total distance = 206.5 meters, average turn = 84.09 degrees, total displacement = 35.27 meters, ratio = 0.17, average leg length = 4.49 meters.



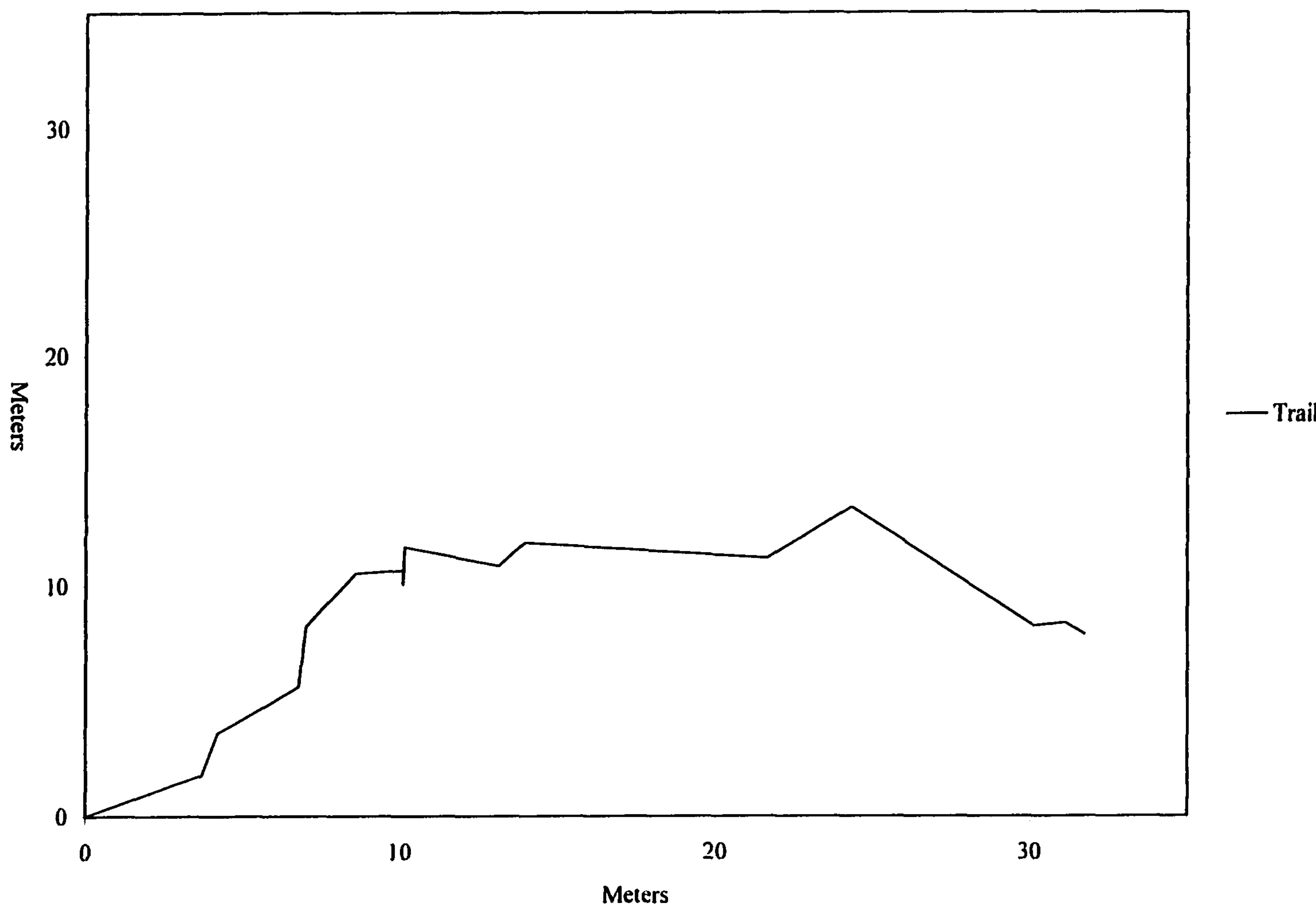
Trail 3: o-o-b-b, 10 May, adult male, total distance = 167.6 meters, average turn = 63.39 degrees, total displacement = 40.42 meters, ratio = 0.24, average leg length = 4.53 meters.



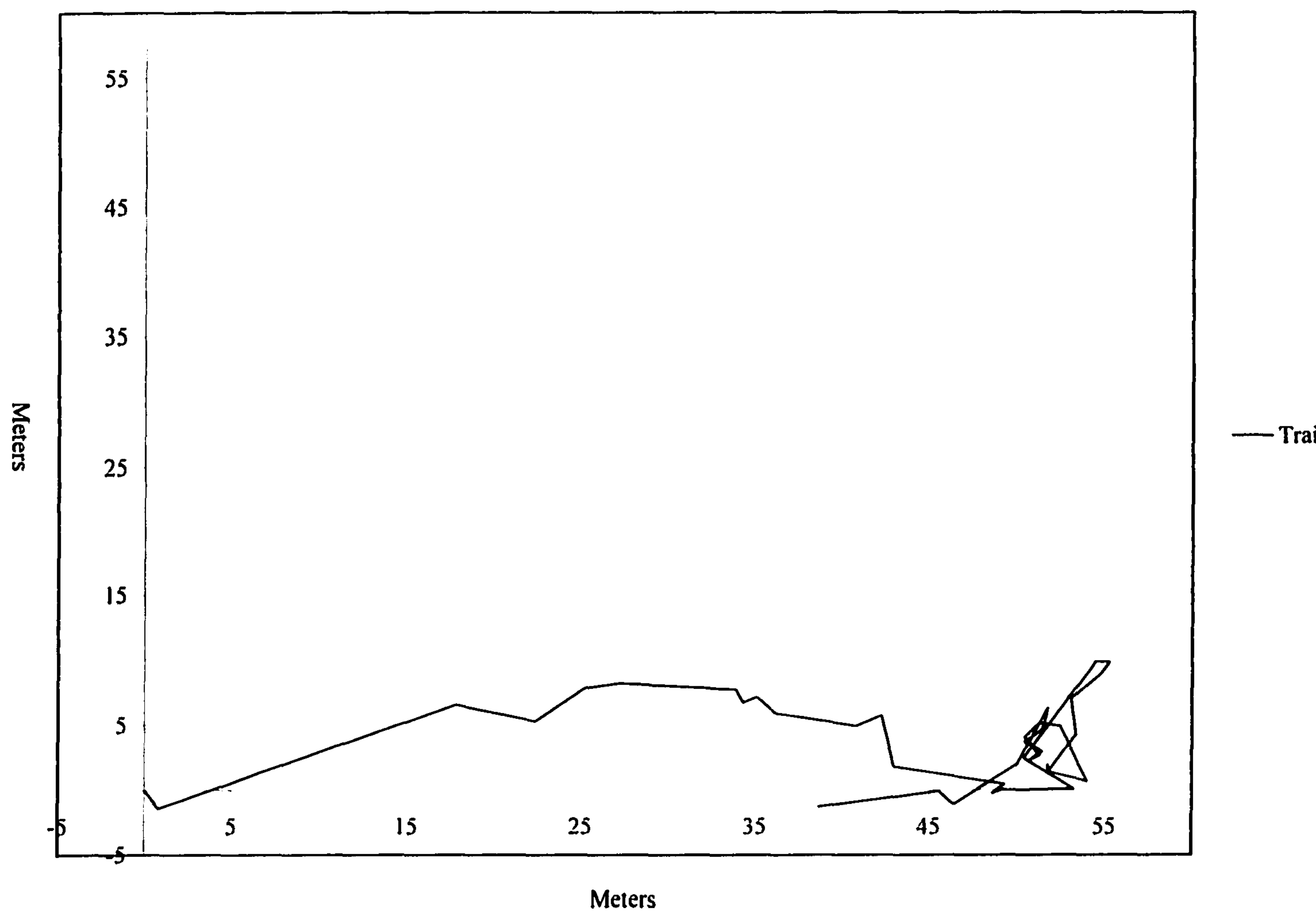
Trail 4: b-b-o-o, 10 May, adult female, total distance = 102.5 meters, average turn = 84.50 degrees, total displacement = 56.22 meters, ratio = 0.55, average leg length = 3.31 meters.



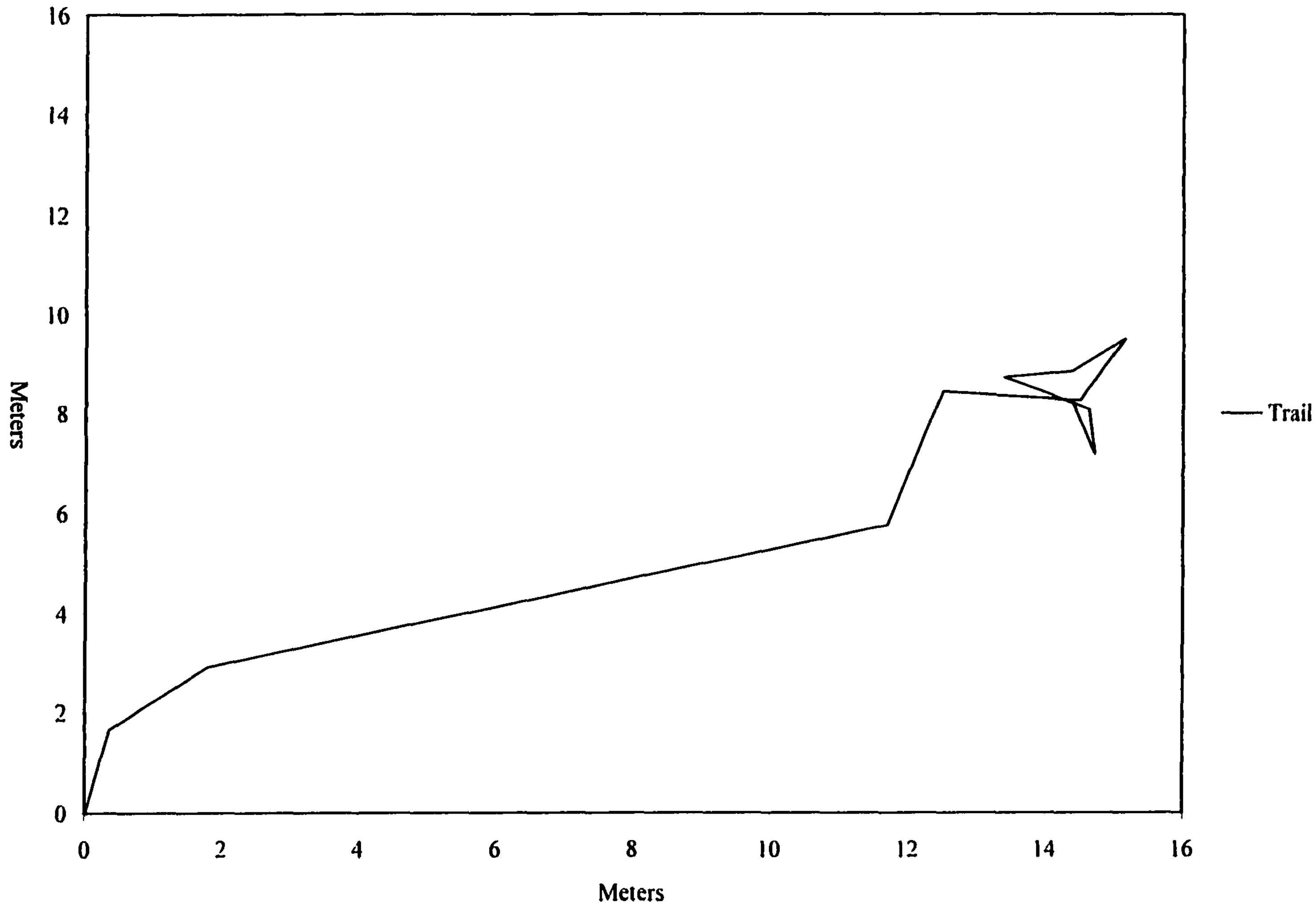
Trail 5: r-y-r-r, 17 May, adult female, total distance = 51.7 meters, average turn = 72.25 degrees, total displacement = 39.19 meters, ratio = 0.76, average leg length = 3.04 meters.



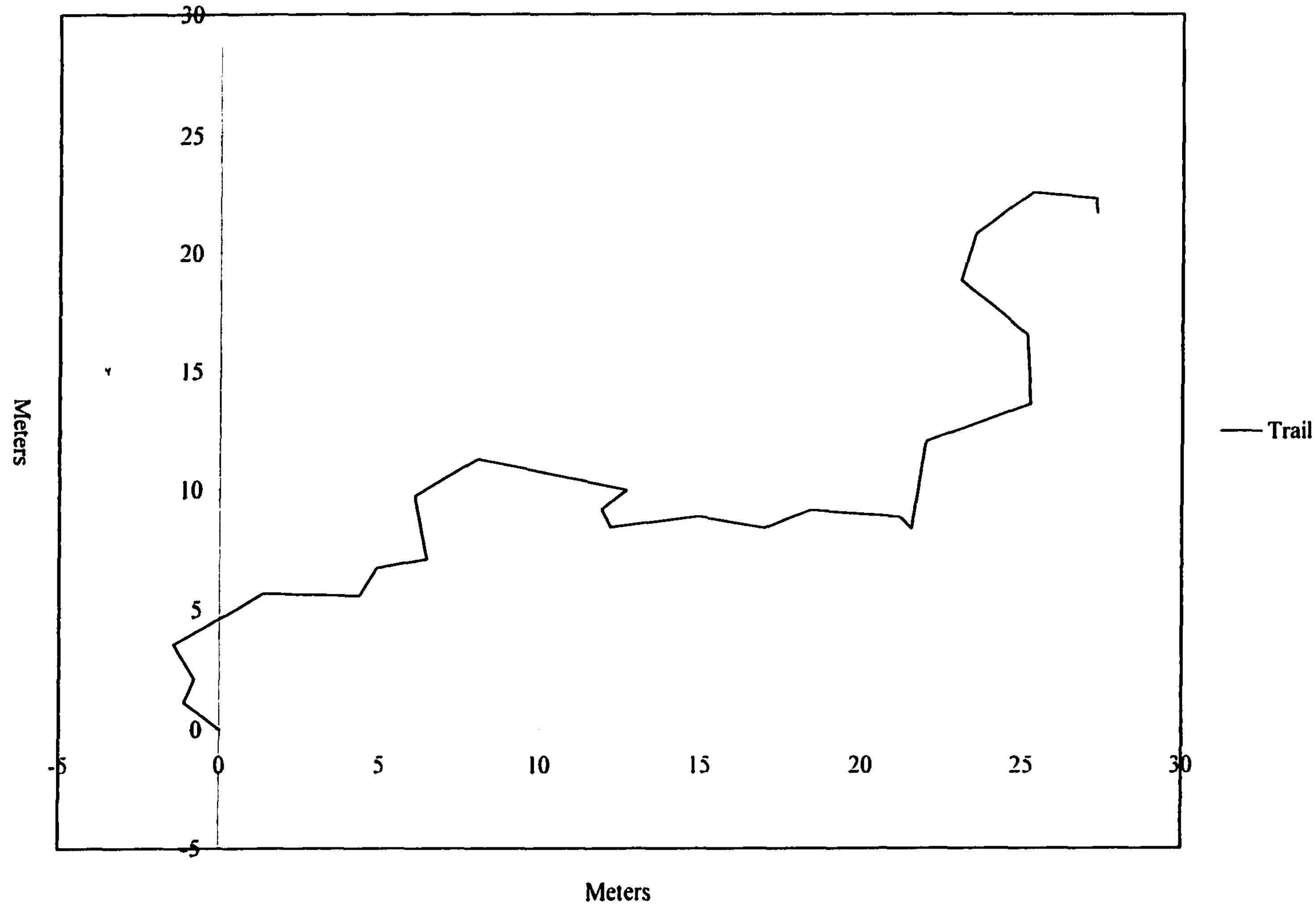
Trail 6: o-r-r-o, 17 May, adult female, total distance = 123.0 meters, average turn = 86.85 degrees, total displacement = 38.66 meters, ratio = 0.31, average leg length = 3.00 meters.



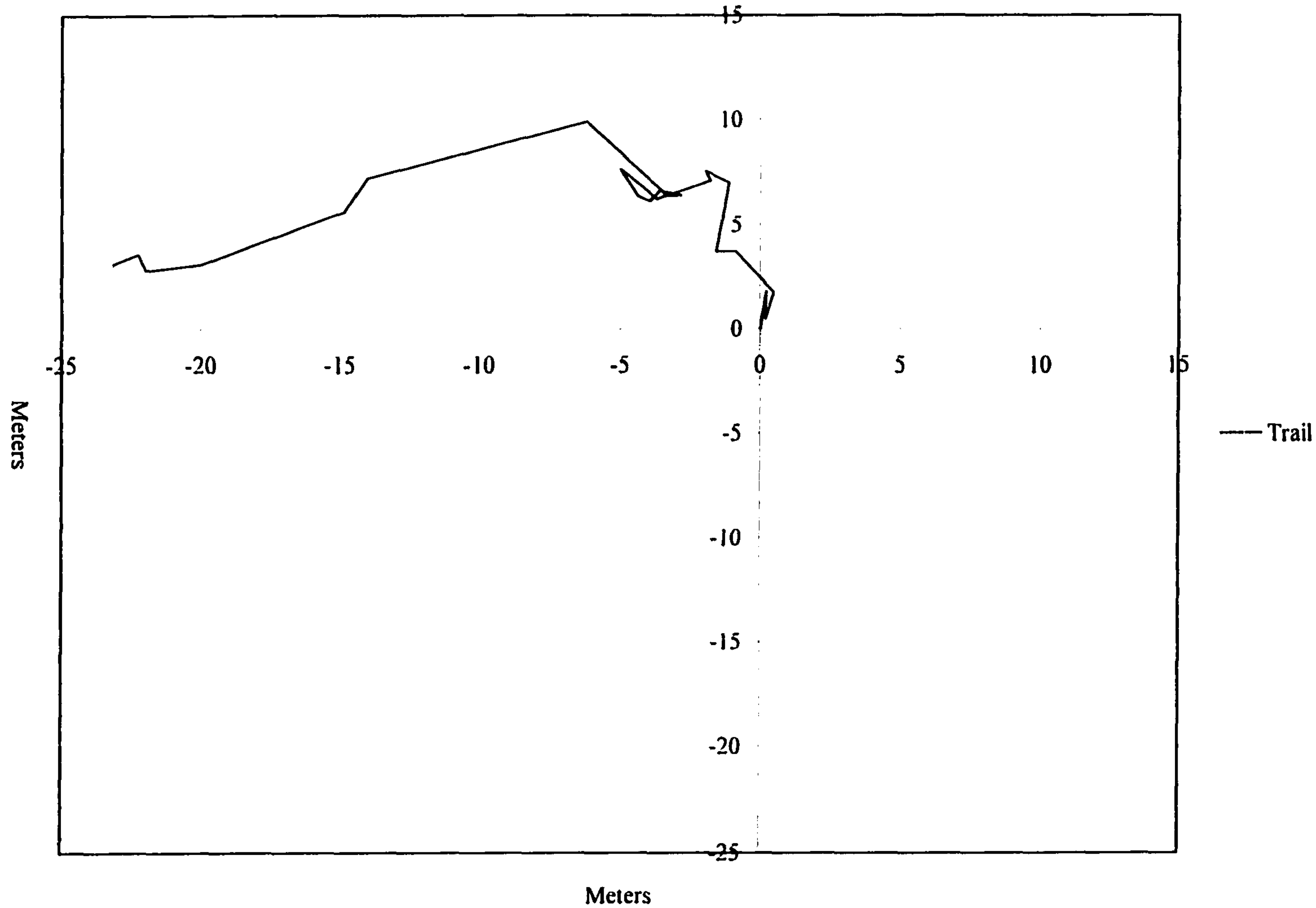
Trail 7: y-b-y-b, 10 June, adult male, total distance = 25.5 meters, average turn = 82.50 degrees, total displacement = 16.57 meters, ratio = 0.65, average leg length = 2.32 meters.



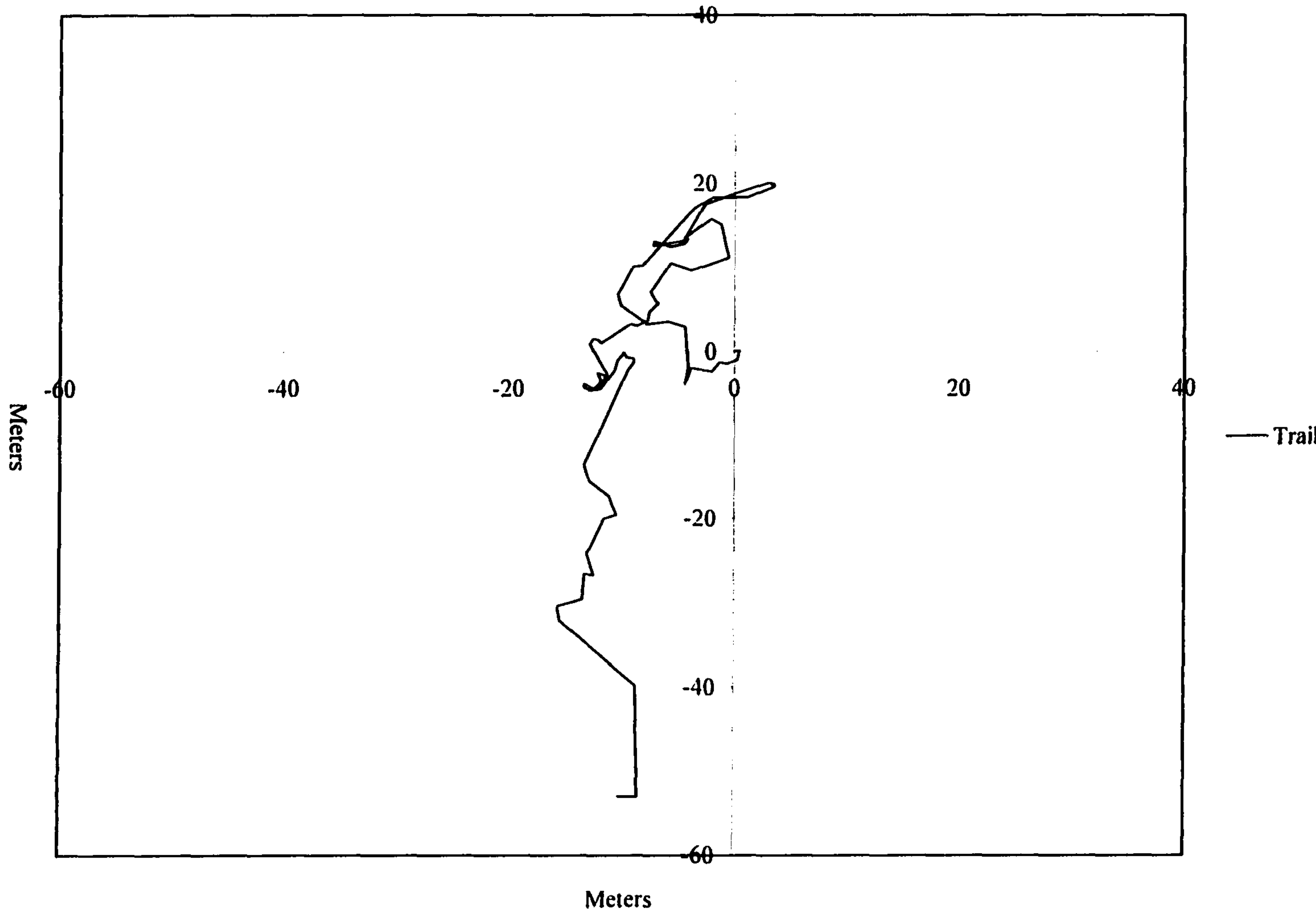
Trail 8: b-b-b-y, 18 June, adult female, total distance = 55.8 meters, average turn = 61.21 degrees, total displacement = 34.88 meters, ratio = 0.63, average leg length = 2.23 meters.



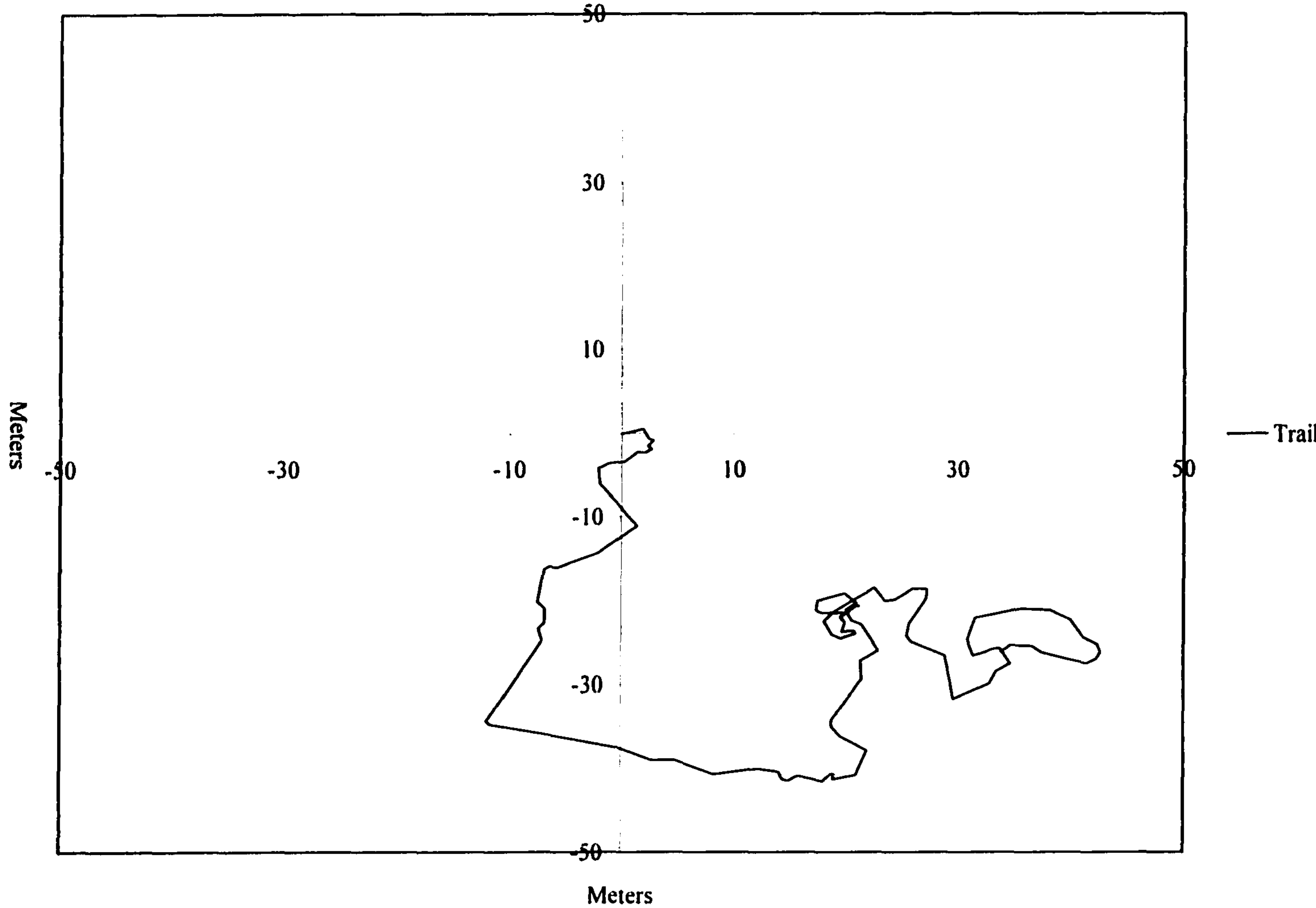
Trail 9: b-b-b-y, 19 June, adult female, total distance = 44.2 meters, average turn = 92.36 degrees, total displacement = 23.35 meters, ratio = 0.53, average leg length = 1.92 meters.



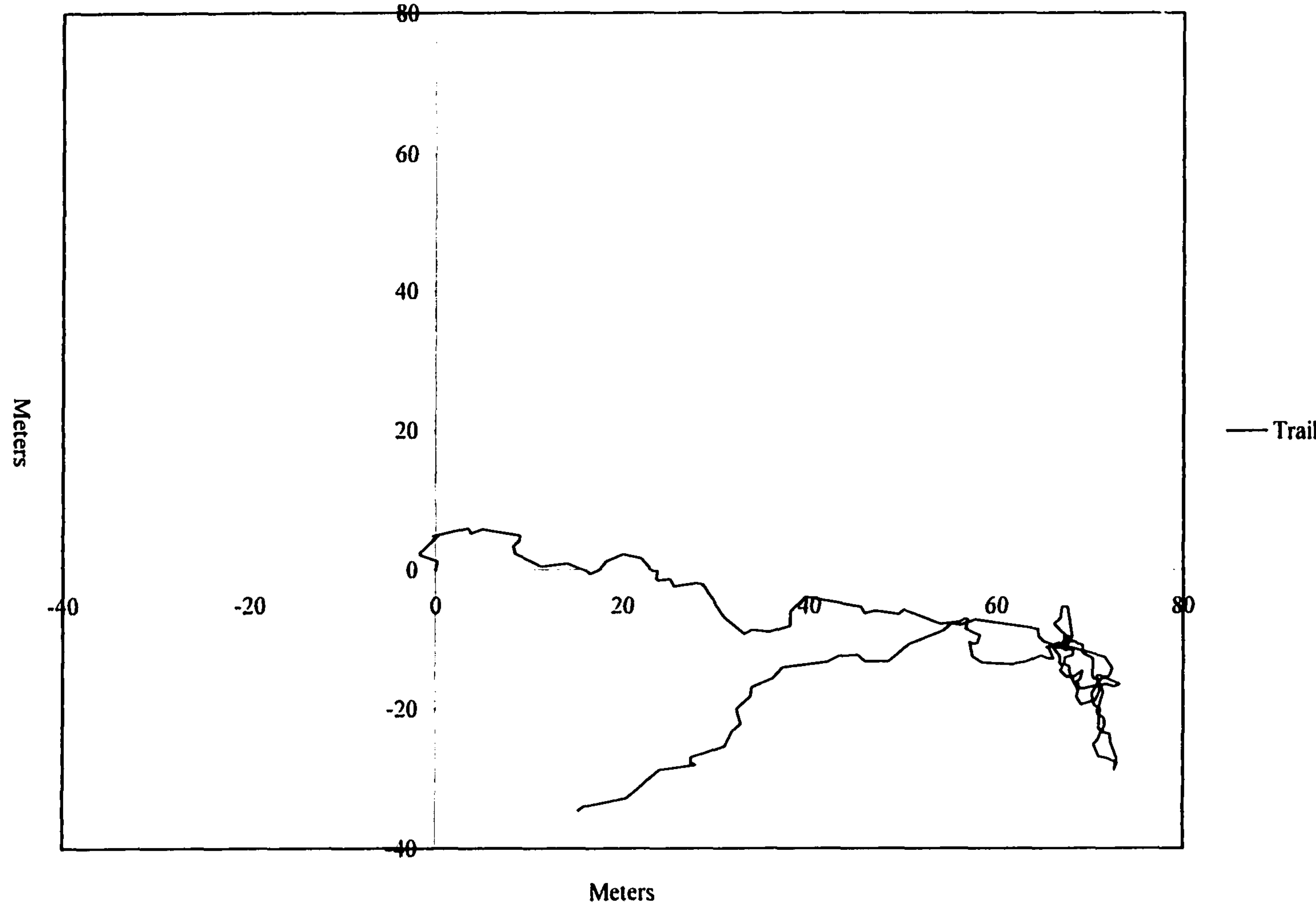
Trail 10: g-g-y-g, 21 June, adult male, total distance = 172.8 meters, average turn = 63.81 degrees, total displacement = 53.97 meters, ratio = 0.31, average leg length = 2.19 meters.



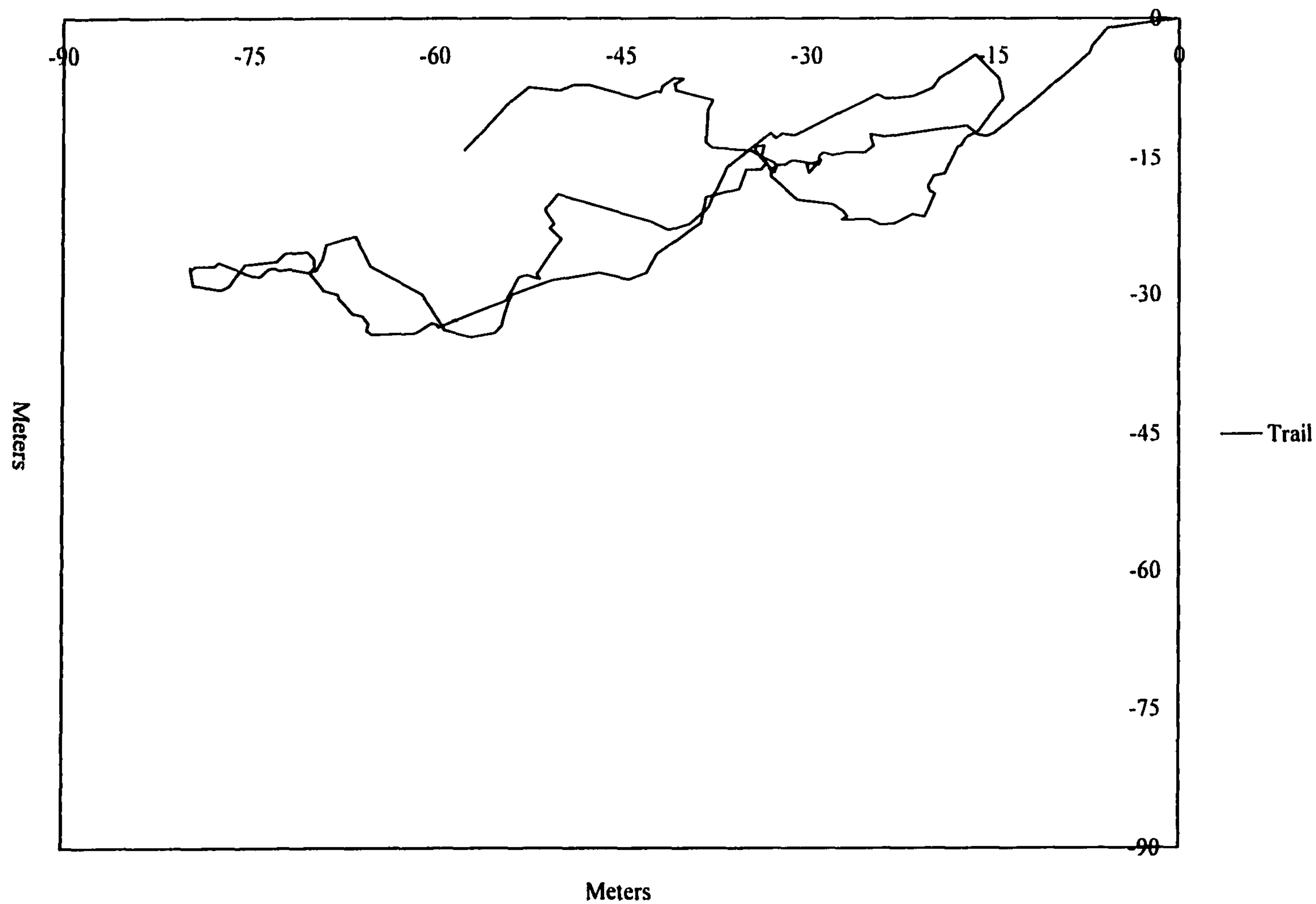
Trail 11: w-g-w-g, 25 June, juvenile female, total distance = 195.9 meters, average turn = 53.24 degrees, total displacement = 42.79 meters, ratio = 0.22, average leg length = 1.98 meters.



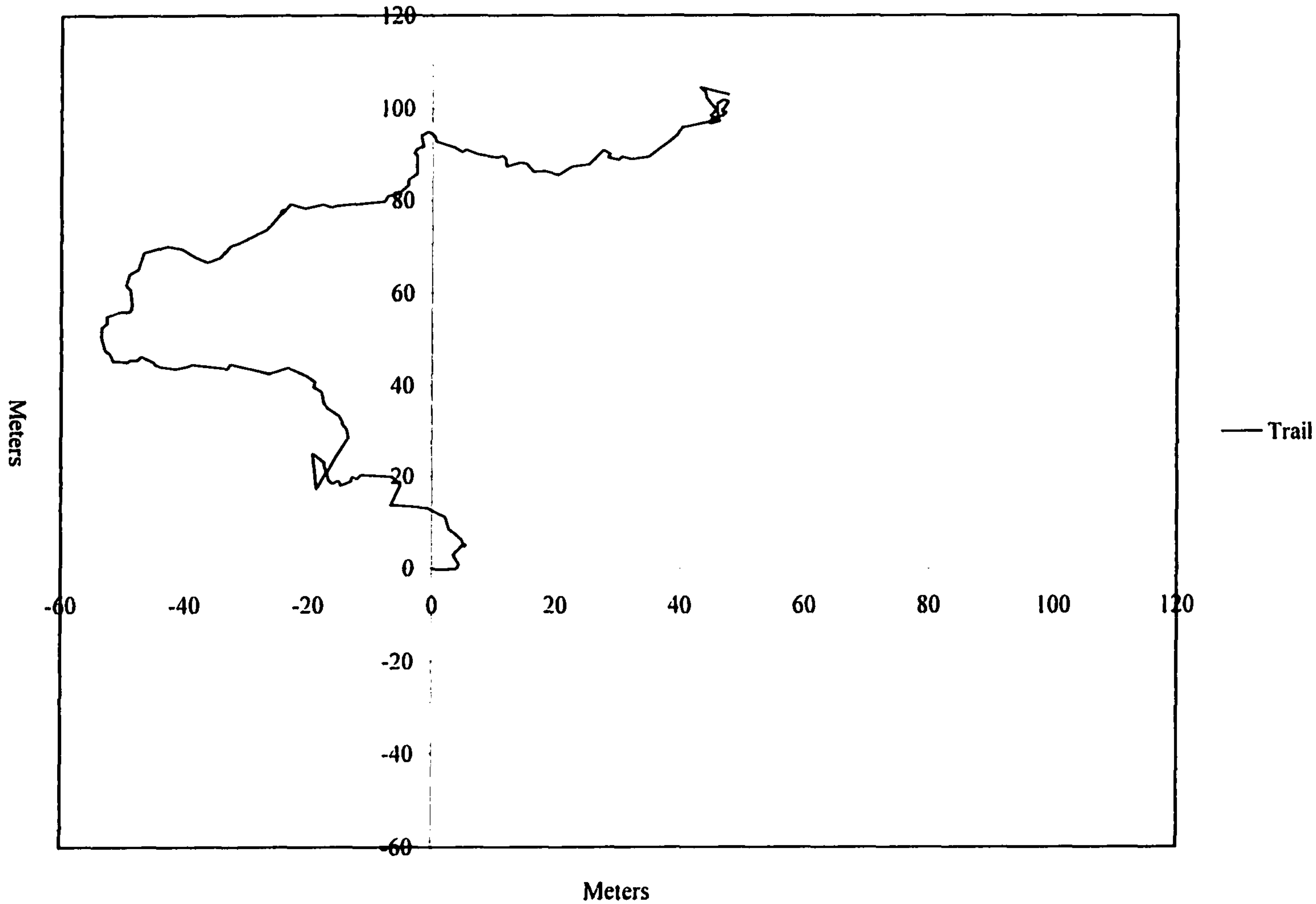
Trail 12: o-o-b-o, 2 July, adult male, total distance = 273.7 meters, average turn = 59.20 degrees, total displacement = 37.75 meters, ratio = 0.14, average leg length = 1.61 meters.



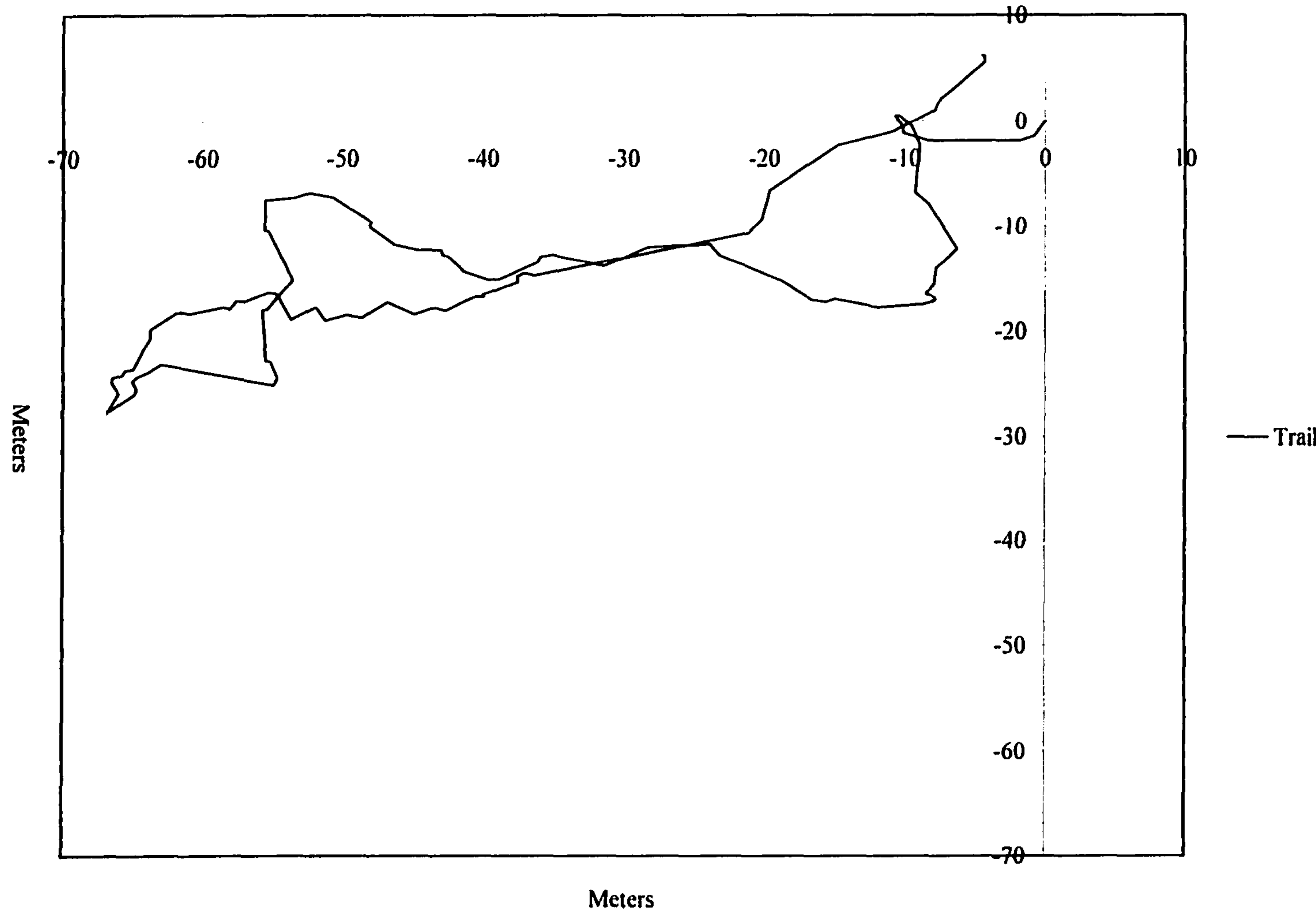
Trail 13: w-g-g-w, 10 July, adult male, total distance = 293.2 meters, average turn = 52.90 degrees, total displacement = 59.29 meters, ratio = 0.20, average leg length = 1.88 meters.



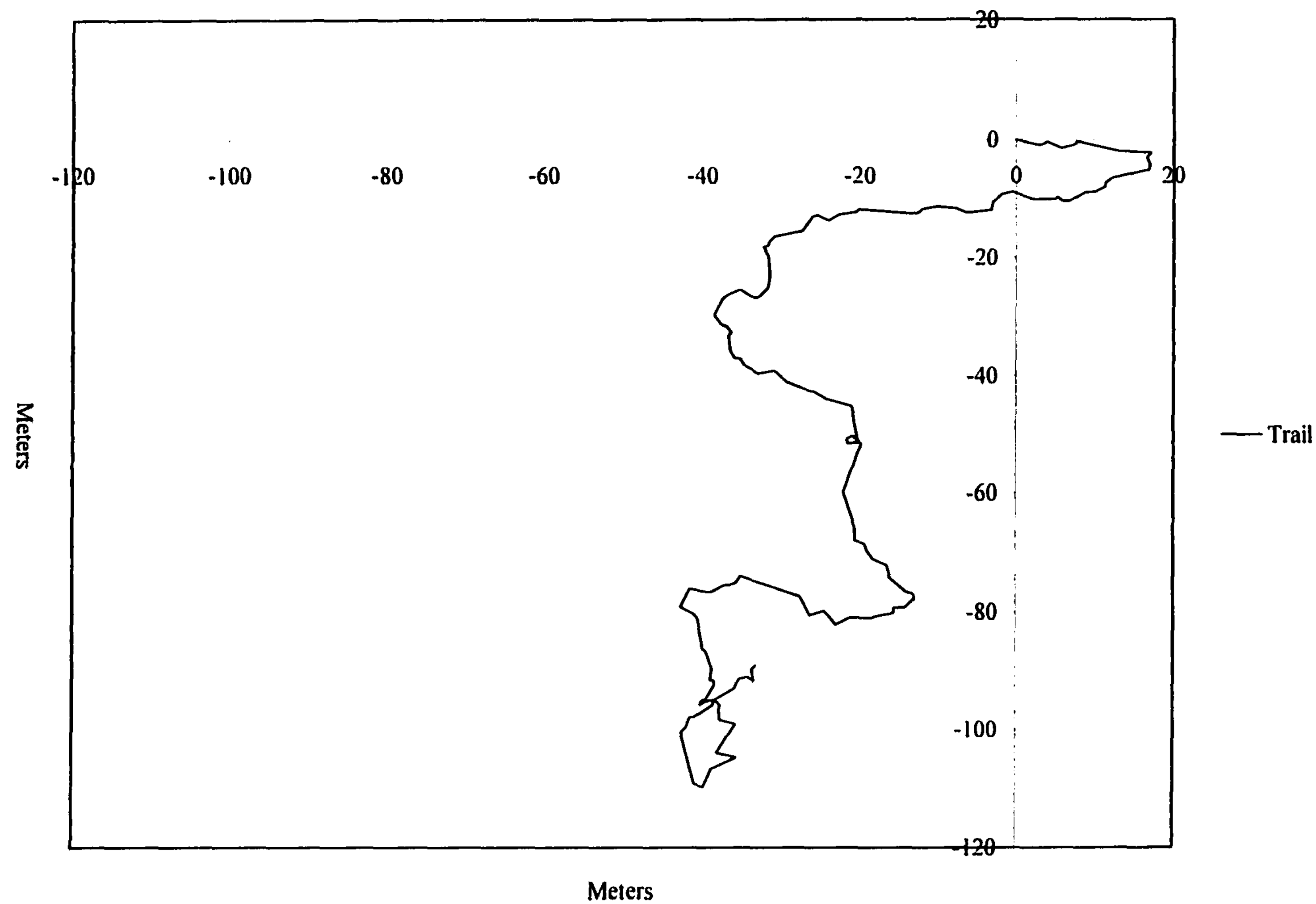
Trail 14: r-r-w-w, 15 July, adult female, total distance = 293.0 meters, average turn = 53.80 degrees, total displacement = 113.30 meters, ratio = 0.39, average leg length = 2.01 meters.



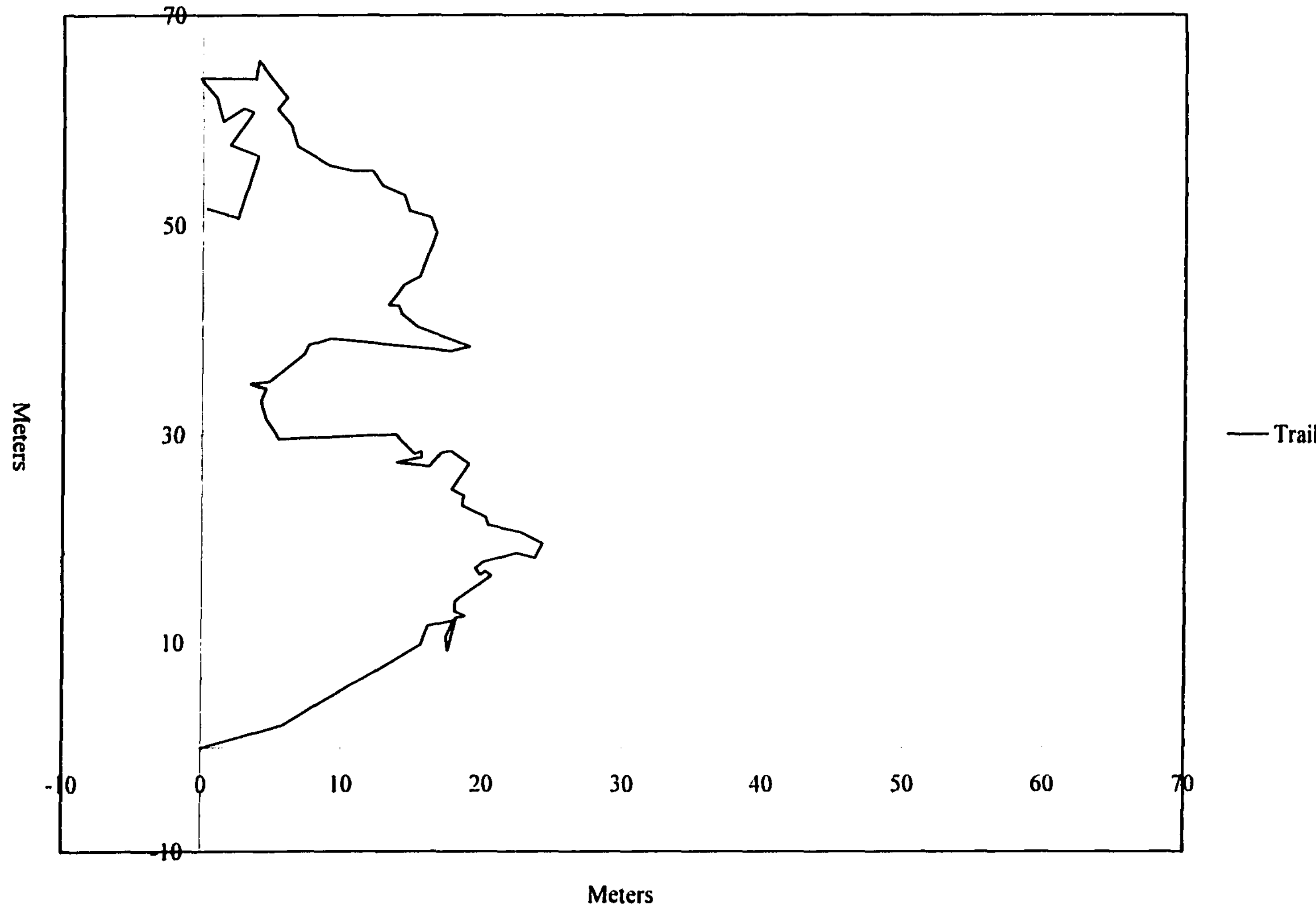
Trail 15: g-w-w-w, 29 July, adult male, total distance = 207.3 meters, average turn = 48.88 degrees, total displacement = 7.62 meters, ratio = 0.04, average leg length = 1.96 meters.



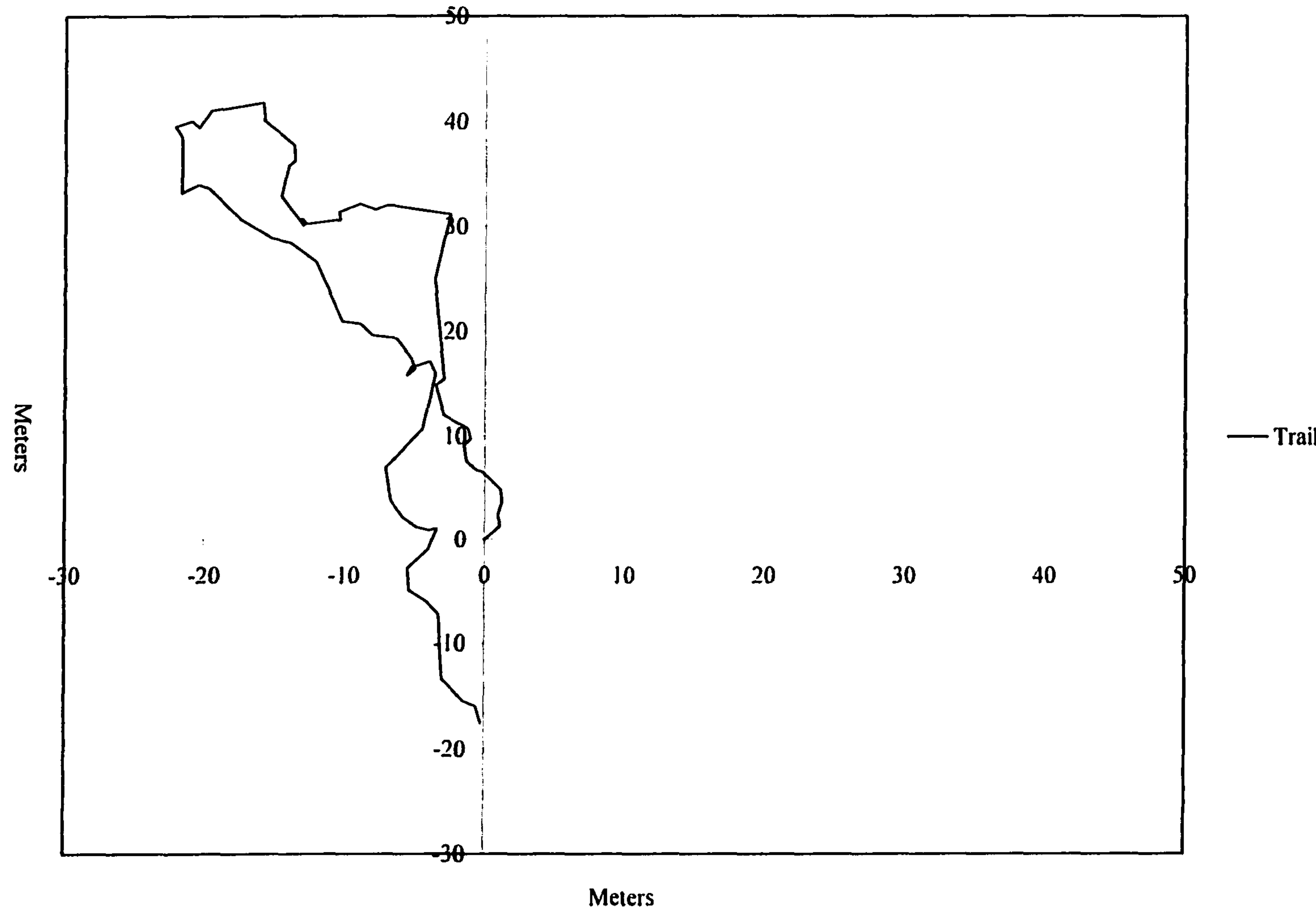
Trail 16: b-o-o-b, 19 August, adult male, total distance = 273.3 meters, average turn = 48.04 degrees, total displacement = 94.85 meters, ratio = 0.35, average leg length = 1.99 meters.



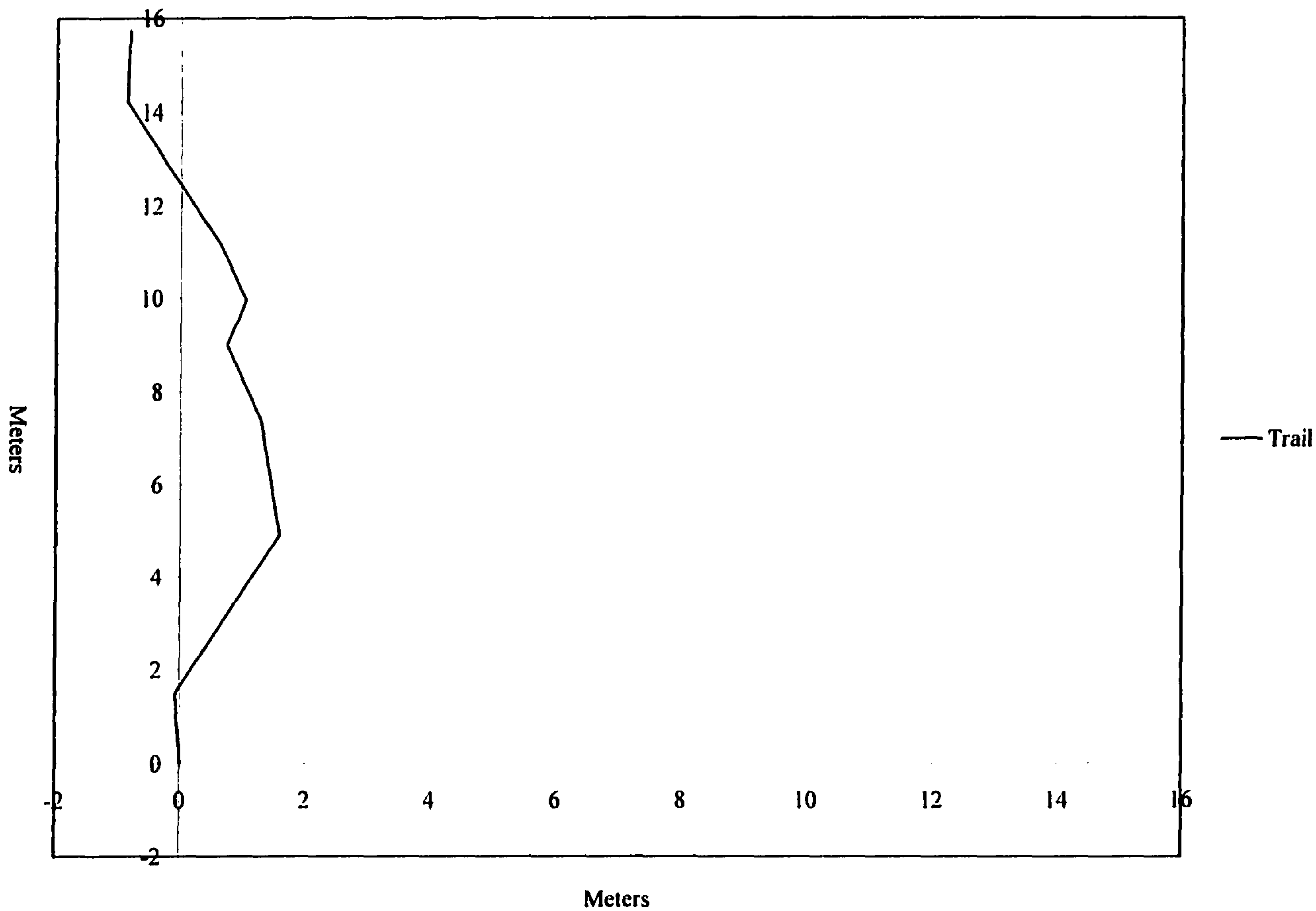
Trail 17: o-g-o-g, 28 August, adult male, total distance = 164.1 meters, average turn = 65.53 degrees, total displacement = 51.58 meters, ratio = 0.31, average leg length = 2.25 meters.



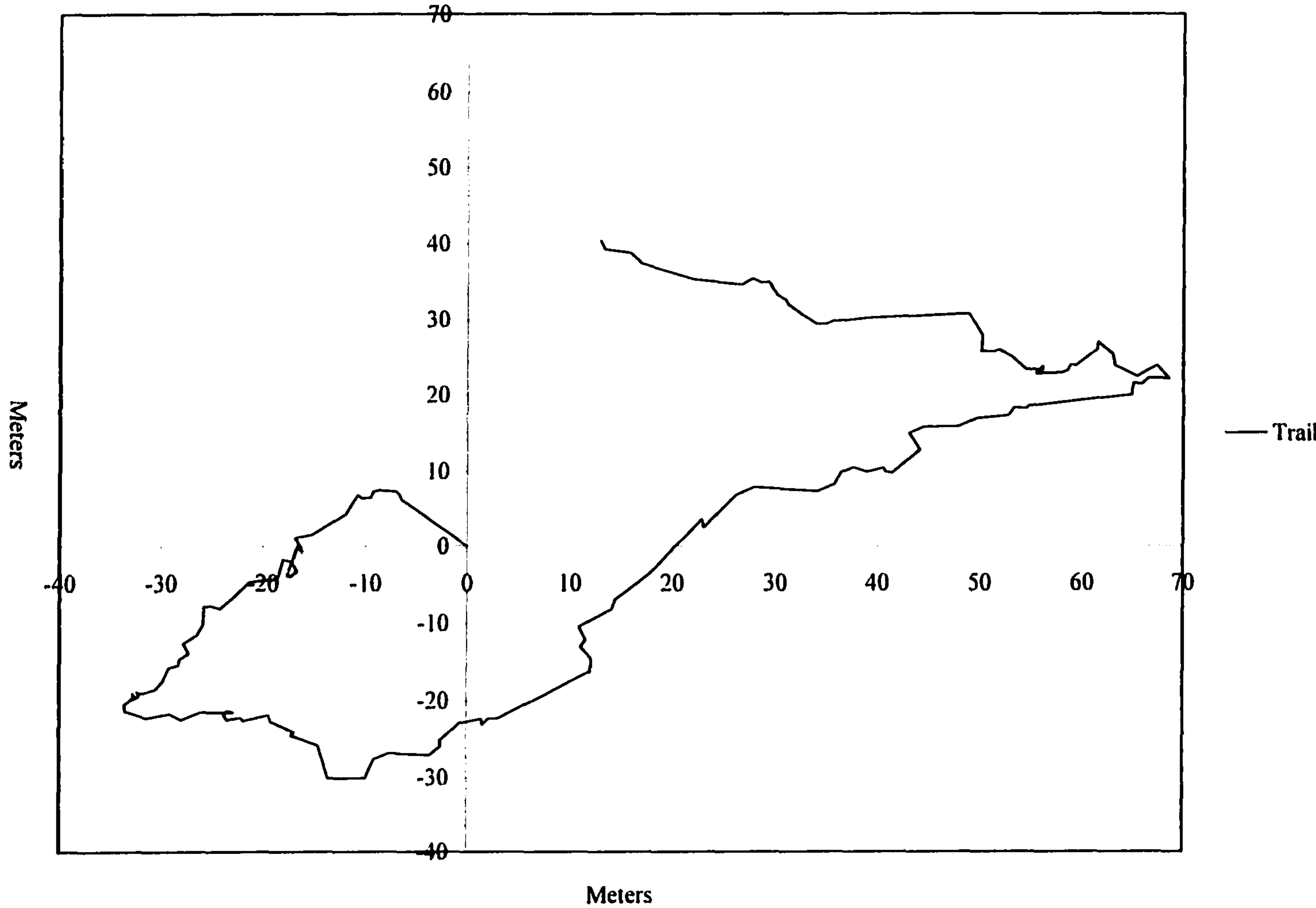
Trail 18: g-w-w-w, 6 September, adult male, total distance = 144.0 meters, average turn = 50.58 degrees, total displacement = 17.50 meters, ratio = 0.12, average leg length = 2.12 meters.



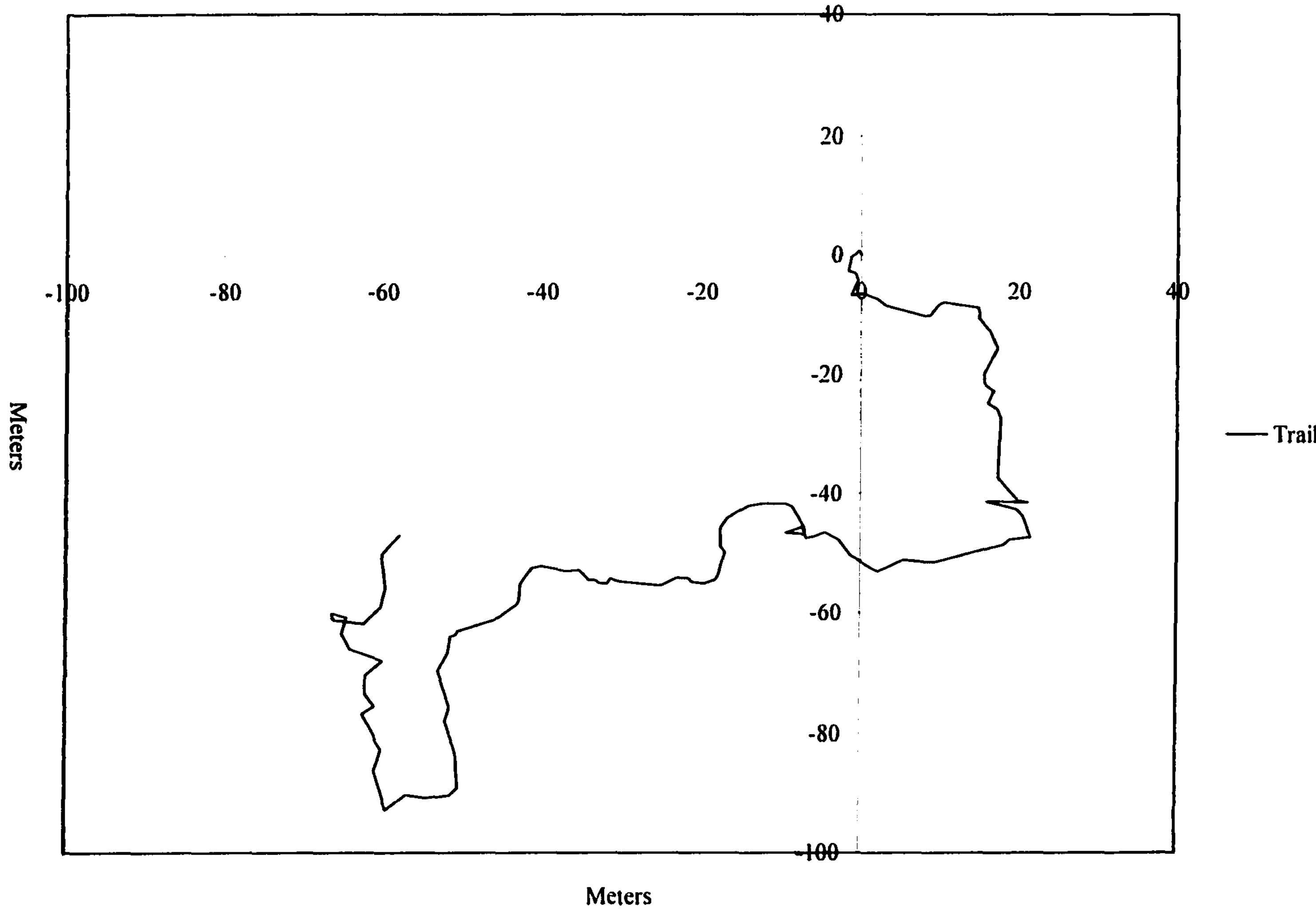
Trail 19: o-g-o-g, 25 September, adult male, total distance = 16.7 meters, average turn = 26.14 degrees, total displacement = 15.76 meters, ratio = 0.94, average leg length = 2.09 meters.



Trail 20: y-y-o-o, 15 October, adult female, total distance = 286.3 meters, average turn = 60.36 degrees, total displacement = 42.44 meters, ratio = 0.15, average leg length = 2.03 meters.



Trail 21: b-b-b-b, 25 October, adult male, total distance = 282.5 meters, average turn = 46.55 degrees, total displacement = 74.58 meters, ratio = 0.26, average leg length = 2.62 meters.



APPENDIX B

Available Temperature Profile from Surface Models: hourly averages from each month with each month's turtle active period in boldface. Monthly average temperature is given in the last row. Monthly minimums and maximums are noted with asterisks (*).

Active	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
0:00	17.44	21.05	25.65	24.87	25.98	20.86	15.36	7.97
1:00	16.78	20.06	24.67	23.85	25.20	19.94	15.05	7.42
2:00	16.25	19.27	23.70	23.00	24.48	19.11	14.76	6.92
3:00	15.64	18.54	22.87	22.35	23.86	18.28	14.43	6.31
4:00	14.94	17.91	22.34	21.85	23.34	17.62	14.08	5.82
5:00	14.37	17.11	21.74	21.38	22.86	17.06	13.87	5.39
6:00	14.00*	16.45*	**21.13***	**20.93***	22.32	16.74	13.81	5.07
7:00	15.55	**18.24**	**21.84**	**21.28**	**22.11***	**16.53***	**13.73***	4.97*
8:00	21.41	**24.31**	**25.17**	**23.81**	**23.69**	**17.99**	**13.88**	5.18
9:00	**28.11**	**30.44**	**30.02**	**28.28**	**27.91**	**24.14**	**15.68**	7.36
10:00	**34.73**	**35.57**	**35.31**	**33.30**	**32.25**	**29.89**	**18.68**	10.59
11:00	**39.56**	**40.54**	39.84	38.24	36.82	34.93	**22.13**	12.73
12:00	43.09	44.58	43.98	42.92	41.45	40.12	25.19	15.86
13:00	45.60*	47.12*	47.80	46.48	45.09	43.56	**28.19**	17.98
14:00	45.54	46.83	49.98	48.43	47.79	45.93	**30.54**	**22.71**
15:00	44.07	46.22	50.13*	49.04*	48.77*	46.49*	**31.96***	24.12*
16:00	42.21	45.19	47.71	47.63	47.78	46.16	**31.12**	24.03
17:00	38.12	41.26	44.53	44.74	44.94	43.94	**28.95**	21.42
18:00	32.82	36.48	40.37	41.28	**40.64**	39.74	**24.79**	15.85
19:00	26.95	31.30	36.06	**36.79**	**35.44**	**31.56**	**20.46**	11.43
20:00	22.74	27.15	31.49	**31.02**	**30.68**	**26.34**	17.77	10.36
21:00	20.89	24.70	29.02	28.24	28.50	24.13	16.72	9.61
22:00	19.82	23.53	27.59	26.81	27.35	22.82	15.98	9.04
23:00	18.69	22.48	26.57	25.82	26.50	21.59	15.44	8.44
AVG.	27.06	29.85	32.90	32.18	32.32	28.56	19.69	11.52

Available Temperature Profile from Burrow Models: hourly averages for each month with monthly averages given on the last row. Monthly minimums and maximums are noted with asterisks (*).

Burrow	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
0:00	25.52	29.75	31.49	30.42	27.88	20.72	14.16
1:00	25.02	29.32	31.13	30.04	27.61	20.53	14.05
2:00	24.54	28.93	30.75	29.73	27.34	20.35	13.88
3:00	24.08	28.40	30.39	29.41	27.08	20.20	13.75
4:00	23.64	28.00	30.12	29.14	26.79	20.09	13.88
5:00	23.22	27.60	29.86	28.87	26.58	19.95	13.47
6:00	22.91	27.26	29.53	28.58	26.29	19.79	13.37
7:00	22.68*	26.96*	29.24	28.35	26.01	19.72	13.66
8:00	23.37	27.00	28.98*	28.28*	25.80*	19.58*	13.33*
9:00	24.88	27.34	29.02	29.10	26.21	19.58*	13.43
10:00	26.36	27.84	29.17	30.55	27.08	19.71	13.54
11:00	27.40	28.63	29.44	31.77	27.86	19.95	13.68
12:00	28.44	29.59	29.78	32.50	28.54	20.23	14.37
13:00	29.36	30.64	30.14	32.93	29.12	20.53	14.45
14:00	30.11	31.50	30.67	33.19	29.53	20.82	14.39
15:00	30.60	32.27	31.29	33.35	29.84	21.02	14.55
16:00	30.68*	32.66*	31.91	33.44*	29.97*	21.20	14.67*
17:00	30.44	32.71	32.46	33.24	29.94	21.23*	14.66
18:00	29.91	32.41	32.73	33.00	29.79	21.14	14.66
19:00	29.30	32.12	32.84*	32.53	29.55	21.05	14.63
20:00	28.53	31.70	32.75	32.10	29.24	20.92	14.59
21:00	27.71	31.18	32.55	31.64	28.89	20.77	14.51
22:00	26.99	30.73	32.21	31.15	28.53	20.61	14.39
23:00	26.36	30.25	31.84	30.72	28.21	20.43	14.30
AVG.	26.75	29.78	30.85	31.00	28.07	20.42	14.10

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Professional Positions:

Biological Scientist, AB Engineering/ A. E. Holm and Associates, 8-97 to 5-03. Duties included background literature searches, Phase 1 assessment reports, wetlands delineations, site inspector, and endangered species consul.

Graduate Assistant, ASU, 8-00 to 8-01, 1-03 to 5-03. Duties included setting up weekly labs for Limnology, Ecology, Zoology, Invertebrate Zoology, Introductory Biology I and II for non-majors.

Teaching Assistant, ASU, 8-01 to 5-02. Duties included teaching, grading, and assignment of final lab grades for five lab sections weekly for Introductory Biology I and II for non-majors.

Field Technician, Crouch Environmental Services, 3-00 to 8-00. Duties included habitat restoration, crew supervisor, and wetlands delineations.

Professional Affiliations:

American Society of Ichthyology and Herpetology
Society for the Study of Amphibians and Reptiles
Texas Academy of Science