Schubauer, Joseph P., J. Whitfield Gibbons and James R. Spotila. 1990. Chapter 18. Home Range and Movement Patterns of Slider Turtles Inhabiting Par Pond. pp. 223-232. In *Life History and Ecology of the Slider Turtle,* J. Whitfield Gibbons (ed.). Smithsonian Institution Press. Washington, D.C.

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Home Range and Movement Patterns of Slider Turtles Inhabiting Par Pond

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Abstract

The home range and individual movement patterns of slider turtles (*Trachemys scripta*) inhabiting a thermally altered reservoir were determined using mark-recapture and radiotelemetry over a 16-month period. Home range areas of turtles inhabiting a thermally altered site and a site with normal water temperatures were not significantly different, nor were the activity patterns of the turtles different between sites except for those of males in the fall. Turtles did not inhabit the warmest areas, nor did they shuttle in and out of the thermal plume, even in the coldest months. Telemetric estimates of home range areas for both sexes were significantly larger, and presumably more accurate, than estimates based on mark-recapture records. Telemetry revealed that the total and aquatic home range areas for males (104 ha and 27 ha, respectively) were significantly larger than those for females (37 ha and 15 ha).

Introduction

Studies in Par Pond have documented how thermal effluents influence the ecology and behavior of fish (Gibbons et al., 1978a) and other aquatic vertebrates, such as alligators (Murphy and Brisbin, 1974), but few studies have addressed how the behavior of aquatic turtles might be affected by thermal effluents (Schubauer, 1981a; Thornhill, 1982). In addition, few behavioral studies of aquatic turtles have been conducted in large reservoirs or lakes, though several have been done in riverine habitats (Wickham, 1922; Mahmoud, 1969; Moll and Legler, 1971; Bury, 1972; Florence, 1975; Plummer and Shirer, 1975; Moll, 1980), bogs and wetlands (Hammer, 1969; Obbard and Brooks, 1981b), and small lakes and ponds (Mahmoud, 1969; Ernst, 1970, 1971c; Moll and Legler, 1971; also see Ernst and Barbour, 1972). Webb (1961) provided information on the movements of aquatic turtles in a large reservoir, but the report was limited to approximate distances moved between points of capture and release for four marked *T. scripta*. Although the slider turtle is one of the most studied aquatic turtles, little quantitative information is available regarding aquatic home range areas, particularly in large bodies of water. Finally, although studies concerned with quantifying the movements and home ranges of aquatic turtles have classically used one or a combination of three main methods (telemetry, mark-recapture, and visual observations), few, if any, have addressed how the results obtained from these different techniques compare with one another.

Our objectives were (1) to examine the home range and movements of a population of slider turtles inhabiting Par Pond, a large thermally altered reservoir, and (2) to determine if estimates provided by two common techniques (mark-recapture and telemetry) were comparable.

Study Site

The study was conducted at Par Pond (Fig. 18.1; Gibbons and Sharitz, 1981; also see Chapter 2). When the reactor is operating, heated water is introduced by a subsurface pipe at a point in the Hot Arm called the Boil (Fig. 18.2). As a consequence, temperatures near the Boil are maintained, on average, about 10° C above ambient (Schubauer, 1981a) during periods of reactor operation. Temperatures near the Boil may reach 40° C in the summer and 30° C in the winter (Schubauer, 1981a), but temperatures in most of the reservoir, because of its large size and its morphology, are not dramatically affected (for a more detailed discussion of these points, see Lewis, 1974a,b; Vigerstad and Kiser, 1977; Hazen, 1978; Schubauer, 1981a), although they are 3° to 5° C higher than those of farm ponds in the region (Schubauer and Parmenter, 1981).

Much of the open littoral zone of the lake is lined with cattails (*Typha latifolia* and *T. domingensis*) and a thick mat of submerged macrophytes, including *Myriophyllum spicatum*. Most of the open-water areas of the shallow bays are covered with spatterdock (*Nuphar luteum*), American lotus (*Nelumbo lutea*), and water lilies (*Nymphaea odorata*). During this study, floating vegetation was sparse or absent in the warmest areas of the Hot Arm.

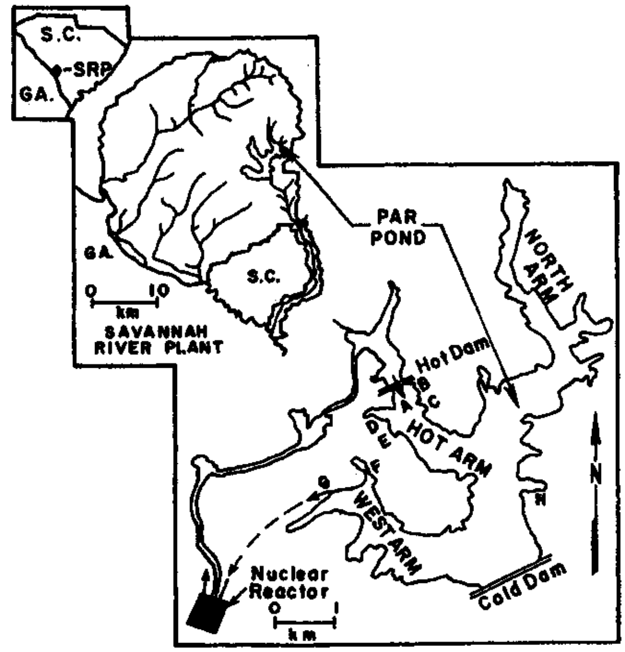

FIGURE 18.1. Study areas in Par Pond. The study focused on the areas marked A through G in the Hot Arm and the West Arm. A = the point at which thermal effluents enter the reservoir.

Methods

MARK-RECAPTURE

Trachemys scripta activity, abundance, and distribution were monitored in areas of the Hot Arm and the West Arm (Fig. 18.2). We trapped in all seasons from April 1977 to June 1978 (8,848 total trap-days), using traps constructed of chicken wire or hardware cloth as well as funnel net traps. Traps were baited with largemouth bass (*Micropterus salmoides*) obtained from Par Pond or with canned sardines. At the end of each trapping period the traps were removed from the water to minimize habituating turtles to traps and to avoid unintentional containment of animals in traps for long periods. Traps were not set in areas more than 6 m deep. Deeper areas were sampled with trotlines, dip nets, and visual sightings.

Captured turtles were returned to the laboratory, permanently marked with an individual code, sexed, measured for plastron length and mass, and aged. With the exception of the marking procedure, recaptured individuals were similarly treated. All turtles were released at the exact point of capture. Trap locations and captures were marked on scaled aerial maps.

TELEMETRY

Thirty-three adult *T. scripta* (19 males and 14 females) were studied with telemetry, following the techniques de-

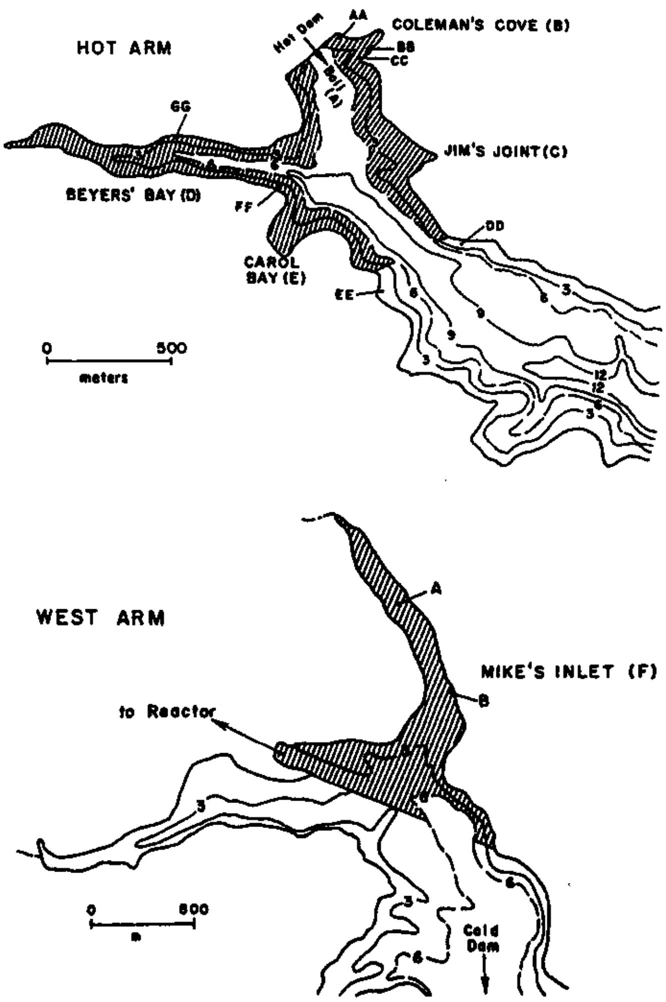

FIGURE 18.2. Enlarged hydrobathymetric maps of the Hot Arm and West Arm study sites in Par Pond. Depth isopleths are marked in meters. The hatch marks depict trapping areas less than or equal to 6 m in depth.

scribed by Schubauer (1981a,b). Twenty-one of these animals (9 males and 12 females) were used to estimate home range areas and movements (Fig. 18.3). Generally, the position of individuals was determined to within 5 m on an average of once a week, from 7 a.m. to 9 p.m., throughout the study. In addition, the movements of 7 individuals (4 males and 3 females) were examined at 4-hour intervals over a 24-hour period in the summer to assess diel activity patterns. Locations of animals were recorded with the date and time of the observation on a scaled map. Mud or thick vegetation did not prevent relocation of transmitters (Schubauer, 1981a,b).

Buoyancy control and movements of turtles were not noticeably affected by the transmitters. Transmitters typically amounted to less than 10% (maximum 12%) of an individual's body mass. Transmitters did not differentially affect a turtle's chances of being trapped, nor was any mortality attributed to transmitter attachment (Schubauer, 1981b).

MOVEMENT PATTERNS AND HOME RANGE ESTIMATES

Many methods have been used to quantify the home ranges of animals, including turtles (for reviews of a number of these methods, see Bury, 1979, and Schubauer, 1981b). The most commonly used methods for aquatic turtles include the convex polygon method of Jennrich and Turner (1969), the minimum polygon index of Mohr (1947) and Mohr and Stumpf (1966), a modified minimum polygon index (Harvey and Barbour, 1965; Ernst, 1970), a linear representation (Moll and Legler, 1971; Bury, 1972), and the recapture radius method (Hayne, 1949; Dice and Clark, 1953). Each technique has inherent advantages and disadvantages. To simplify calculation and comparison and to meet all of the different study objectives simultaneously, we chose to express our results using the convex polygon method (Jennrich and Turner, 1969). Home ranges were determined by recording successive location points ($N \geq 3$) of each turtle on a scaled map, using either mark-recapture or telemetry.

We defined the total home range of *T. scripta* as the total area used in the normal activities of an individual turtle,

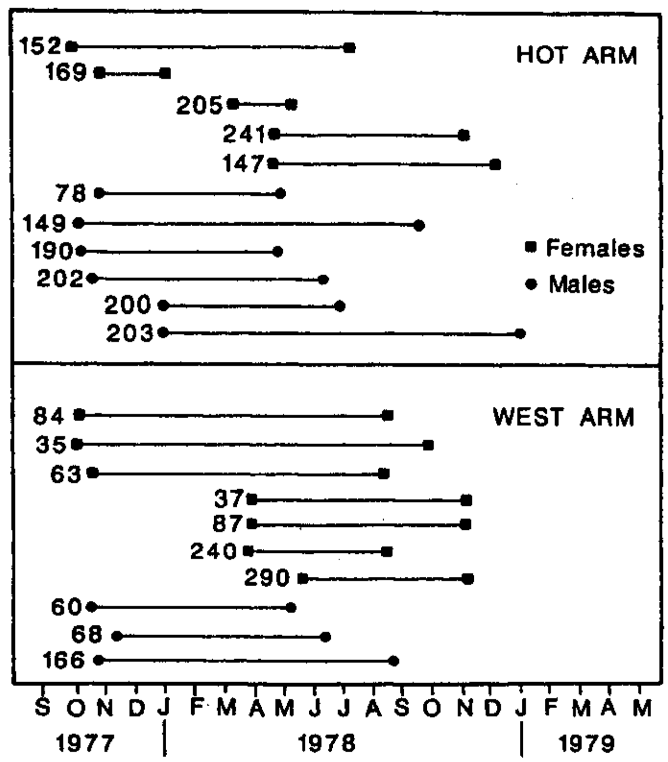

FIGURE 18.3. Tracking length records for 21 of the original 33 turtles used for telemetric home-range analyses in this study. Lengths are based on original battery-transmitter packages without replacement.

including land areas traversed (i.e., for nesting or other activities) but excluding emigration movements to other bodies of water. Animals that emigrated to other nearby aquatic areas or never established a home range were considered transient individuals and were eliminated from this analysis. Although this definition of total home range included land area and eliminated transient individuals from the analysis, we believe that it is valid, for the following reasons: (1) Other authors have noted that adult *T. scripta* migrate out of areas of suitable habitat in great numbers only in cases of extreme drought (Cagle, 1944b; Gibbons et al., 1983), and (2) *T. scripta* are known to move onto land for reasons other than emigration, specifically for feeding and egg laying (Cagle, 1944b). We defined *T. scripta*'s aquatic home range as a subset of its total home range that excluded the terrestrial portions of the total home range. We considered this second measure of home range to be a modified form of the convex polygon, to the extent that any water-land boundaries followed the contour of the shoreline. Home range length was defined as the longest straight-line distance between any two points delineating the home range boundaries.

Home range areas were electronically digitized and analyzed using a Tektronics 4051 microcomputer. Vernier calipers were used to measure distances between locations. Parametric methods were considered appropriate for significance testing after movement data were normalized using a logarithmic transformation (Scheffe, 1959; Kirk, 1968). Differences in movements and home ranges between sexes, areas, and seasons were determined using single-classification analysis of variance, or ANOVA (Sokal and Rohlf, 1969). Null hypotheses were rejected at the .05 level of significance. Differences between means were revealed using the Student-Newman-Keuls (SNK) procedure (Sokal and Rolhf, 1969).

Results and Discussion

HOME RANGE AREAS

The home range areas estimated from telemetry data for *T. scripta* in Par Pond are among the largest reported for a freshwater turtle (Table 18.1). Our maximum estimate for males of nearly 104 ha is almost 30 times greater than the estimate using sonic telemetry for nine *T. scripta* (eight females and one male) in a Panamanian river (Moll and Legler, 1971). Florence (1975), using radiotelemetry with four adult female *T. scripta* in the Tennessee River, reported a home range of 0.66 ha.

Methodology may be partially responsible for these differences. The estimates of Moll and Legler and of Florence were calculated using the linear representation method and were based primarily on females and on relatively small sample sizes. In addition, telemetric observations in the other studies lasted from 30 to 70 days, with most of Florence's observations being made in May and June and Moll and Legler's observations being scattered throughout the year. Our measurements were based on observation periods of 55 to 321 days in all seasons and on both sexes. Thus, longer observation periods, more observations on males, and larger sample sizes may all have contributed to the larger estimates of home range size in our study.

Although methodological differences may have partially contributed to the observed differences among studies, both the size and the type of aquatic habitats in which the studies were conducted may also have played an important role. For example, our mark-recapture estimate of female home ranges is approximately five times larger than the telemetric estimate of Florence (1975) and is similar to the sonic transmitter estimate of Moll and Legler (1971). According to the limited evidence available in the literature (Table 18.1), it appears that turtles living in larger bodies of water have larger home ranges. Obbard and Brooks (1981b) reported a maximum home range of 3.44 ha for snapping turtles (*Chelydra serpentina*) in some Ontario bog lakes, and Mendonca (1983) estimated a home range of 288 ha for green sea turtles in a Florida lagoon. Finally, Moll and Legler (1971) reported a home range of 3.58 ha for *T. scripta* in a river in Panama. However, this does not necessarily imply that a given species in a small aquatic area will have a smaller home range than one in a large aquatic habitat if overland travel is a major component of the species' home range.

Looking at metabolic considerations, McNab (1963) reasoned that an increase in animal body size (= mass) should also result in larger animal home range sizes. Neither Moll and Legler (1971), studying *T. scripta* in Panama, nor Obbard and Brooks (1981b), studying *C. serpentina* in Canada, found a relationship between home range size and body size. Although Mendonca (1983) found that the overall home range size of juvenile green turtles was positively correlated with increasing body mass, she also noted that centers of activity were not. In the present telemetric study, we found that home range size was significantly and positively related to the body mass of adult female slider turtles, but we did not observe a similar relationship for males. Thus, the relative importance of turtle body size in determining home range size cannot be assessed from available data. Although home range length tended to increase with increasing home range area in our study, home range lengths and areas do not appear to be predictably related in general (Table 18.1), so an increase or a decrease in one measure of home range does not always result in an increase or a decrease in the other measure.

None of the turtles examined with telemetry or mark-recapture ever established a home range within 500 m of the Boil in the Hot Arm. Furthermore, no significant dif-

Table 18.1. Examples of home range areas and lengths for various species of aquatic turtles

Species	Locality	Habitat	*N* and sex	Home range Area (ha)	Home range Length (m)	Methods	Reference
Trachemys scripta	Panama	River	8F,1M	3.58	287	TEL,A	4
		Lagoon	24J	0.42	61	MR,B	4
			10H	0.004	34	MR,A	4
	Tennessee	River	4F	0.66	274	TEL,A	7
	South Carolina	Lake	4F	3.29	133	MR,C	10
			7F	14.96		TEL,D	10
			7F	36.53	401	TEL,C	10
			16M	6.74	200	MR,C	10
			9M	39.75		TEL,D	10
			9M	103.53	731	TEL,C	10
Clemmys marmorata	California	Stream	19M	0.97	976	MR,A	5
			23F	0.25	248	MR,A	5
			18J	0.36	363	MR,A	5
C. guttata	Pennsylvania	Pond	6M	0.53		MR,B	3
			5F	0.53		MR,B	3
Terrapene coahuila	Mexico	Marsh	33F,21M	0.05	13	MR,E	6
Chelydra serpentina	Pennsylvania	Pond	9	1.84	74	MR,E	1
	Canada	Lake	1F,4M	1.54		MR,B	8
			4F,6M	3.44		TEL,B	8
Sternotherus odoratus	Oklahoma	Creek	39M	0.02	67	MR,C	2
			37F	0.05	44	MR,C	2
Kinosternon subrubrum	Oklahoma	Creek	79M	0.05	52	MR,C	2
			115F	0.05	62	MR,C	2
K. flavescens	Oklahoma	Creek	4M	0.10	198	MR,C	2
Chelonia mydas	Eastern Florida	Lagoon	9J	288		TEL,B	9

Note: Studies not expressing home range on an areal basis are excluded. Sample size refers to home range areas and not necessarily home range lengths. Abbreviations: M, male; F, female; J, juvenile; H, hatchling; TEL, telemetry; MR, mark-recapture in some form (includes visual observations and any form of live capture); A, linear representation; B, minimum polygon; C, convex polygon; D, modified convex polygon; E, radius.

References: 1, Ernst, 1968b; 2, Mahmoud, 1969; 3, Ernst, 1970; 4, Moll and Legler, 1971; 5, Bury, 1972; 6, Brown, 1974; 7, Florence, 1975; 8, Obbard and Brooks, 1981; 9, Mendonca, 1983; 10, this study.

ferences in home range area were noted between West Arm and Hot Arm males or between West Arm and Hot Arm females using either method; as a consequence, these data were combined for further analysis. Data from both mark-recapture and telemetry revealed that most of the daily activities of the turtles tended to be centered in shallow (less than 6 m deep) vegetation-covered coves in the lake (see Fig. 18.4 for representative home ranges). Some movement across areas with open, deep water or overland to other bodies of water did occur but was not common. Transplant studies (Schubauer, 1981b) indicated that movement by *T. scripta* from one arm of Par Pond to another also was uncommon. Only 1 of 267 animals marked in this study moved from one arm of the lake to another. No movement was detected at night.

Home range areas determined by telemetry were significantly larger than those determined by mark-recapture (Table 18.2). Telemetry indicated that male turtles had significantly larger total and aquatic home range areas than females. Although mark-recapture determined that the total and aquatic home range areas of males were larger than those of females, these differences were not significant (Table 18.2). The aquatic home ranges of male and female slider turtles monitored by telemetry were significantly smaller than their total home range areas. Land constituted approximately 60% of the area of the total home ranges of the animals studied with telemetry, whereas land constituted little of the total home range areas of mark-recapture females (0%) and males (13.9%; Table 18.2). Home range areas determined by mark-recapture were less than one-fourth the size of those determined by telemetry. The lengths of total home range areas of males and females were significantly larger when determined by telemetry than by mark-recapture (Table 18.3). The longest home ranges were those of males monitored by telemetry (average length of 731 m). Telemetry determined that the average home range length for females was 401 m, whereas mark-recapture determined that length

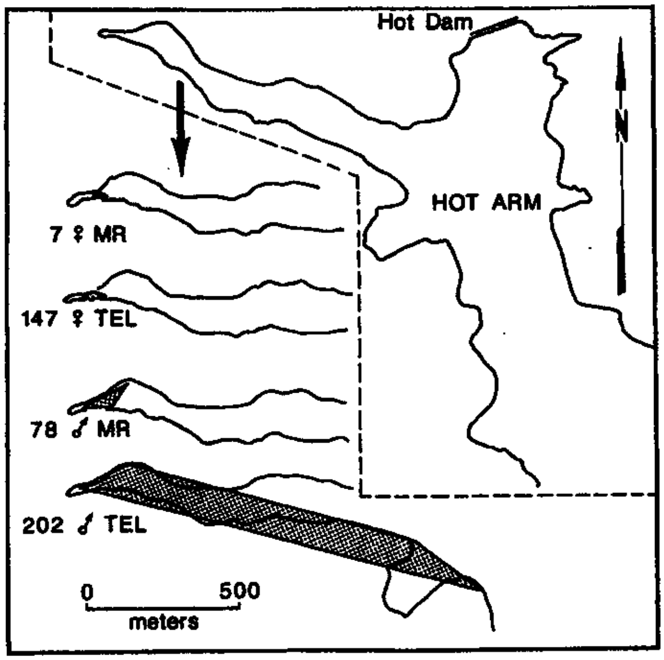

FIGURE 18.4. Representative home ranges of males and females, determined by mark-recapture (MR) and telemetry (TEL). Areas outlined are total home range areas. The shaded subset of each total home range that excludes the land area and is contiguous with the shoreline defines each aquatic home range area.

to be 133 m. Males had significantly longer home ranges than females, according to either method (Table 18.3). However, even the smallest telemetric estimate of home range length for females was significantly larger than the largest mark-recapture estimate for either sex (Table 18.3).

Examination of records of individuals that were simultaneously monitored by both methods (Table 18.4) substantiated that the differences observed using these methods were real and not an artifact of sampling bias. In every instance, home range areas described by telemetry were larger than those described by mark-recapture. When the home ranges determined by the two methods were compared after the same number of relocations, thus truncating the records of animals monitored by telemetry, the home range areas determined by telemetry still exceeded those determined by mark-recapture in all but one case (Table 18.5). This relationship was true even though the observation period was always greater for mark-recapture estimates. Likewise, if the observation periods of the telemetric estimates of these animals were truncated as closely as possible to match the observation periods of the mark-recapture estimates and the home range areas compared, the estimates using telemetry were always greater.

The home range sizes of females monitored by telemetry appeared to be influenced by body mass. A significant positive correlation was found between total home range size and body mass of females (Fig. 18.5). Total home range size was also correlated with body mass for females monitored by mark-recapture ($r = .76$) but was not significant ($F = 3.486$; df $= 1, 3$). No relationship between total

Table 18.2. Total and aquatic home range areas for *Trachemys scripta* inhabiting Par Pond, determined by mark-recapture and telemetry

Study group[a]	*N*	THR (ha)[b,c]		AHR (ha)[b,d]		Land area (% of total)	Area[f] THR	Area[f] AHR
Males								
MR	16	6.74	(1.61)	5.80	(1.13)	13.9	6.5	14.6
TEL	9	103.53	(26.76)[e]	39.75	(6.10)[e]	61.6		
Females								
MR	4	3.29	(0.55)	3.29	(0.55)	0	9.0	22.0
TEL	7	36.53	(5.73)[e]	14.96	(3.51)[e]	59.0		

Note: See text for computation methods. One standard error is given in parentheses to the right of each mean. Data were logarithmically transformed before testing for statistical significance. Abbreviations: AHR, aquatic home range area; MR, mark-recapture; TEL, telemetry; THR, total home range area.

[a]Female estimates are based only on animals monitored in the West Arm of the lake. Only one MR record was available for Hot Arm females because of low capture rates. No significant differences were found between estimates for males studied in different arms of the lake (Schubauer, 1981a), so those groups were combined.

[b]Significant differences between estimates for MR males and females could not be detected; however, significant differences among all other values within this column were detected.

[c]One-way ANOVA: $F = 28.181$; df $= 3, 32$; $p < .05$, followed by Student-Newman-Keuls procedure (SNK).

[d]One-way ANOVA: $F = 39.315$; df $= 3, 32$; $p < .05$, followed by SNK.

[e]THR is significantly different from AHR (one-way ANOVA: $F = 6.61$; df $= 1, 16$; $p < .05$; and $F = 11.2$; df $= 1, 12$; $p < .05$, followed by SNK).

[f]Area is (MR area/TEL area) × 100, or the percentage of the TEL home range area that consists of the MR home range area.

Table 18.3. Comparison of total home range length of *Trachemys scripta* inhabiting Par Pond, determined by telemetry and mark-recapture

Study group	*N*	Mean length of total home range (m)
Males		
MR	36	200 (26)
TEL	11	731 (130)
Females		
MR	12	133 (35)
TEL	12	401 (80)

Note: One standard error is given in parentheses to the right of each mean. Data were logarithmically transformed. All groups were significantly different from one another (one-way ANOVA: $F = 13.585$; df = 3, 67; $p < .05$, followed by Student-Newman-Keuls procedure). Abbreviations: MR, mark-recapture; TEL, telemetry.

home range size and body mass for males was detected with mark-recapture or telemetry.

Total home range measurements for male turtles were influenced by the length of time the animals were observed. A significant positive relationship was detected between total home range size and the length of time observed for male turtles monitored by both methods (Fig. 18.6). No such relationship was detected for females by telemetry ($r = .187$; $F = 0.361$; df = 1, 10) or mark-recapture ($r = -.249$; $F = 0.198$; df = 1, 3).

The sampling effort that was needed to define the home ranges was examined by plotting the percentage of the estimated home range size against the number of observations for each animal (Fig. 18.7). Most male turtles monitored by telemetry reached 100% of their total estimated

Table 18.5. Influence of sampling period and frequency on home range estimates determined by telemetry and mark-recapture

Turtle ID and sex	Method	Total home range: Area (ha)	Total home range: % determined by MR[a]	Days observed	Times located
78M	MR	3.27	--	94	3
	TEL1	1.14	286.8	32	3
	TEL2	10.70	30.5	101	10
149M	MR	2.38	--	188	4
	TEL1	2.42	98.3	13	4
	TEL2	15.95	14.9	183	10
166M	MR	3.93	--	34	3
	TEL1	11.08	35.5	24	3
	TEL2	44.74	8.8	33	4
35F	MR	4.36	--	188	4
	TEL1	4.80	90.8	23	4
	TEL2	30.44	14.3	179	14
37F	MR	2.70	--	319	5
	TEL1	10.14	26.6	2	35
	TEL2	18.76	14.4	205	8
63F	MR	4.05	--	188	4
	TEL1	32.74	12.4	16	4
	TEL2	45.20	9.0	172	16

Abbreviations: MR, mark-recapture; TEL1, telemetry, with number of relocations equal to maximum number of recaptures using MR for that individual; TEL2, telemetry, with observation period matched as closely as possible to total MR observation period.

[a][(MR area/TEL1 area) × 100] or [(MR area/TEL2 area) × 100].

Table 18.4. Comparison of home range areas of individuals simultaneously monitored by mark-recapture and telemetry

N and sex	Method	Home range (ha): Total	Home range (ha): Aquatic	Area[a]: Total	Area[a]: Aquatic	Days observed	Times located
78M	MR	3.27	3.27	7.8	10.8	94	3
	TEL	41.84	30.04			182	21
49M	MR	2.38	2.38	1.9	4.6	188	4
	TEL	124.31	51.55			253	22
166M	MR	3.93	3.52	2.2	7.7	34	3
	TEL	74.20	45.79			321	24
35F	MR	4.36	4.36	11.1	18.6	188	4
	TEL	39.04	23.51			297	20
37F	MR	2.70	2.70	14.4	25.7	319	5
	TEL	18.76	10.49			205	9
63F	MR	4.05	4.05	9.0	13.2	188	4
	TEL	45.20	30.59			238	20

Abbreviations: MR, mark-recapture; TEL, telemetry.

[a]Area is (MR area/TEL area) × 100.

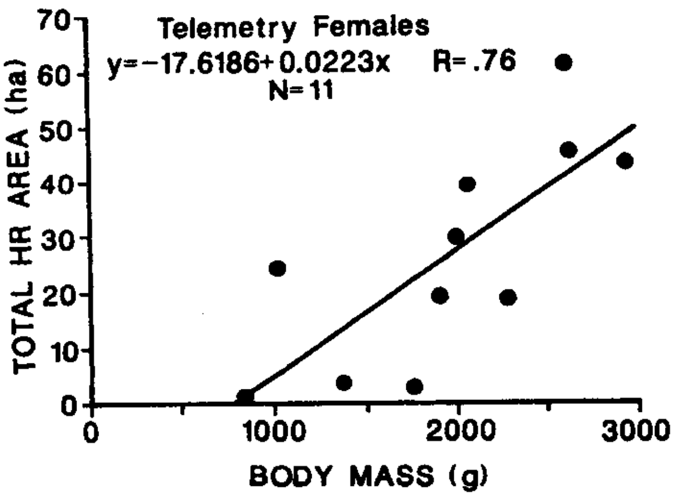

FIGURE 18.5. Relationship between body size and total home range area for females monitored by telemetry. HR = home range.

home range sizes after 15 to 20 observations; however, this relationship was highly variable. In contrast, the total home ranges of females monitored by telemetry could be described more easily. Most reached 100% of their final home range size within 15 observations and with much less variability than males. No such analysis was possible for animals monitored by mark-recapture, because most were captured fewer than 3 times (Schubauer, 1981b).

HOME RANGE DIFFERENCES BETWEEN MALES AND FEMALES

Male home range areas and lengths measured with telemetry in this study were significantly larger than those of females (Table 18.2). Most of the home ranges of male *T. scripta* overlapped with home ranges of other males and females inhabiting the same arm of the lake. The limited results available in the literature for other species of freshwater turtles are conflicting. Bury (1972) reported that home range areas and lengths of male *Clemmys marmorata* were larger than those of females, but there was no difference between the home ranges of male and female *Clemmys guttata* (Ernst, 1970) and *Chelydra serpentina* (Obbard and Brooks, 1981b). Mahmoud (1969) reported that the home ranges of *Kinosternon subrubrum* and *Sternotherus odoratus* males were smaller than those of females, but that those of *K. flavescens* males and females were equal. The relationship of home ranges of males and females may be species-specific, and additional studies will be necessary to resolve it.

THERMAL EFFECTS

That the turtles in this study did not incorporate any of the warmer areas within their home ranges is puzzling,

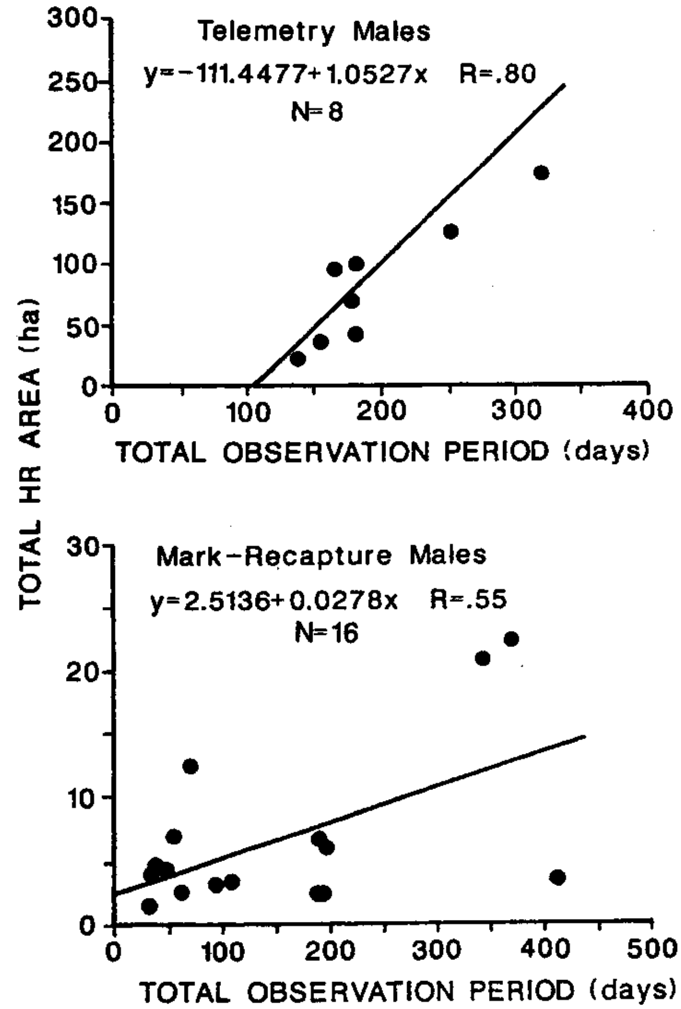

FIGURE 18.6. Relationship between length of observation period and total home range area for males monitored by both methods. HR = home range.

because water temperatures in these areas usually did not approach their critical thermal maximum (40° C; Hutchison et al., 1966) and moderated temperatures in these areas in the winter months. However, there is at least one plausible explanation for this response.

At the time the study was performed, water lilies, spatterdock, and American lotus were conspicuously less abundant within approximately 500 m of the Boil than in the surrounding area and in the West Arm site. It appears that *T. scripta* may avoid colonizing these areas because of the lack of this vegetative structure. Sexton (1959a) reported that *Chrysemys picta* avoided open water. In addition he noted that they were attracted to areas with plants that produced a surface mat attached to the bottom by long stems. He also demonstrated a relationship between habitat preferences of hatchling snapping turtles and the physical structure of vegetation (Sexton, 1958). Similarly, based on the results of our study and transplant studies

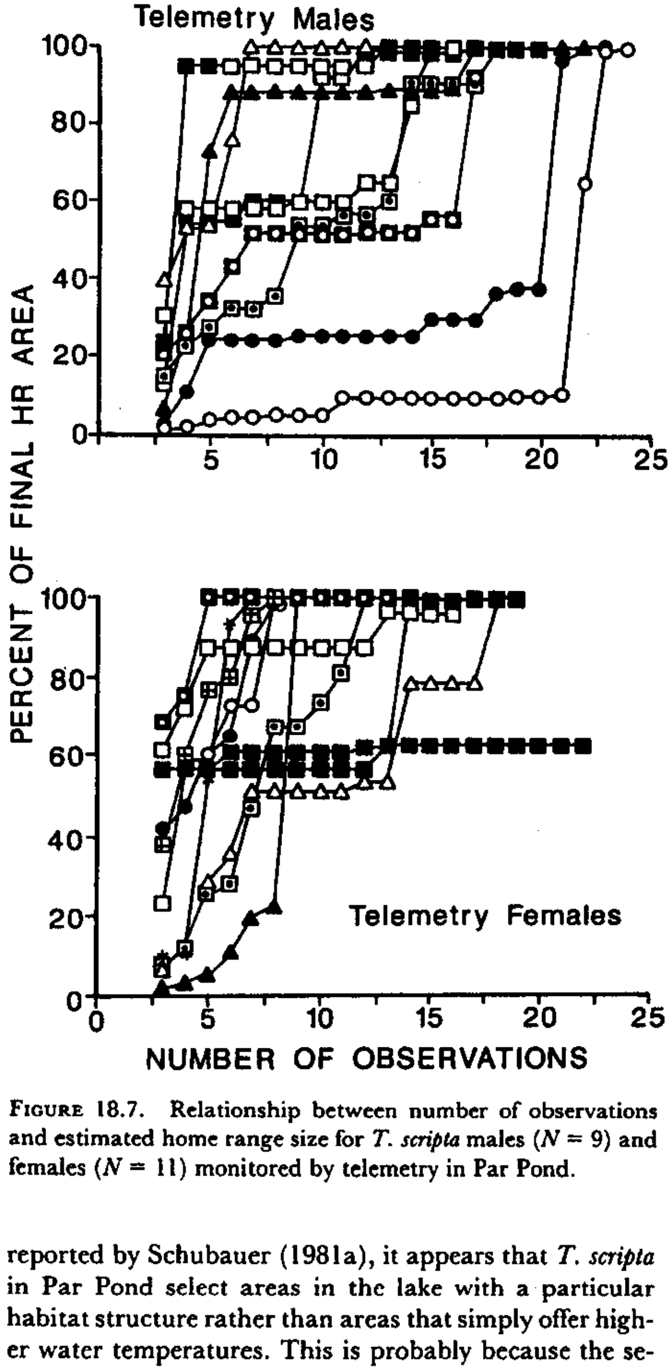

FIGURE 18.7. Relationship between number of observations and estimated home range size for *T. scripta* males ($N = 9$) and females ($N = 11$) monitored by telemetry in Par Pond.

reported by Schubauer (1981a), it appears that *T. scripta* in Par Pond select areas in the lake with a particular habitat structure rather than areas that simply offer higher water temperatures. This is probably because the selected areas offer either better refugia or a higher-quality diet (Parmenter, 1980; Schubauer, 1981a). Whether the higher water temperatures prevented the growth of particular aquatic plants close to the Boil is unclear.

MARK-RECAPTURE VERSUS TELEMETRY

Telemetry provided significantly larger estimates of home range area than did mark-recapture, even though the effort exerted with the latter method was greater. Obbard and Brooks (1981b) compared telemetric and mark-recapture estimates of home range area for *Chelydra serpentina* (Table 18.1) and found that the telemetric estimate of home range was more than twice as large as the mark-recapture estimate, but the difference was not statistically significant, according to a t test. However, if the original data reported in Obbard (1977) are normalized using a logarithmic transformation, the resulting two estimates are significantly different ($t = 2.293$, df $= 13$, $p < .05$).

The results mentioned above are not surprising, considering the biases and sampling problems associated with common capture methods. Because bait is generally used to lure the animals into traps, capture success and thus data acquisition can be influenced or interrupted by seasonal cessation of feeding due to low body temperatures (Ernst, 1972, 1976; Bury, 1979) or shifts in diet (Mahmoud, 1968a; Schubauer and Parmenter, 1981). Furthermore, baited traps may distort movements and home ranges by revealing only the movements of hungry turtles or by luring animals to areas occupied by the traps. In this way, trap density (too many or too few) or placement could distort or misrepresent home ranges and most likely miss long, unexpected movements out of the study areas.

Although visual sightings avoid many of the biases mentioned for trapping, and examples of their successful use exist in the literature (Moll and Legler, 1971; Plummer and Shirer, 1975), they are generally limited to use in small areas and for monitoring relatively short movements. Also, visual sightings are inherently severely limited by objects that can obscure them, such as aquatic vegetation or terrain.

Ideally, telemetry should provide a much less biased estimate of the movements and home ranges of aquatic turtles. However, even this technique can produce biases. For instance, both sexes and a range of body sizes should be well represented in the group monitored telemetrically, and the telemetric package should not alter or interfere in any way with the normal movements or behavior of the animals. In fact, in some situations (as with hatchling turtles) telemetry may be of limited usefulness, and trapping, some other form of mark-recapture, or visual observations may provide the only means of assessing movements.

The two major types of transmitters used to study animal movements are radio transmitters and sonic transmitters. Many factors must be considered in choosing the correct type of transmitter for a particular application. The signal produced by radio transmitters is highly attenuated by water of high conductivity (including salt water), and thick aquatic vegetation will produce similar results with sonic transmitters. Furthermore, noise produced by turbulent waters such as river rapids may also prevent relocation and signal reception from sonic transmitters. Our experience with both types of transmitters (Schubauer, 1981a,b; Spotila et al., 1984) has convinced us that radio transmitters are better suited for use with freshwater turtles.

The power requirements of the transmitter (i.e., the size and mass of the battery) and the packaging materials themselves generally set the lower limit on the size of animal that can be monitored telemetrically. Situations that require increasing the transmitter signal strength (related to transmitter range), lengthening the transmitter life, or increasing the durability or waterproofing of the package usually necessitate increasing the size and mass of the transmitter package.

Summary and Conclusion

It appears that introduction of heated effluents into the Hot Arm of Par Pond indirectly excludes turtles from using areas close to the Boil by affecting the availability of suitable habitat. No other major effects of the effluents on the behavior of *T. scripta* were noted.

The mark-recapture method can severely underestimate home range areas of aquatic turtles, especially estimates for aquatic turtles inhabiting large habitats such as Par Pond. We suspect that up to a point, as available aquatic habitat size decreases (with other factors being equal), home range areas estimated by mark-recapture and telemetry should converge. Thus, for most species of aquatic turtles inhabiting relatively small (less than 50 ha) aquatic habitats, the mark-recapture method may be sufficient for assessing home ranges, assuming that capture biases are not severe and that terrestrial movements are not a major component of the species' home range.

Telemetry provides a number of experimental advantages over mark-recapture, exclusive of the expected distortions due to capture-method biases. Most important, telemetry provides more experimental control over design features such as sample size and sampling time and rate. Once the animals are tagged, these features are under the control of the observer, not the experimental subject. Additionally, long movements and unusual behavior are less likely to be missed. Other important advantages of telemetry are that it allows observation of both terrestrial and aquatic movements and is by far more cost-effective in terms of time and effort. Although telemetry is an excellent tool to study the short-term ecological studies of turtles (particularly movements), it is not sufficient by itself to gather long-term information that is collected on an intermittent basis. In most instances, using a combination of mark-recapture and telemetry methods will prove to be the best course of action.

Acknowledgments

We thank numerous colleagues at SREL who provided assistance during the course of this study. We particularly thank J. Coleman for her help in drafting a number of the illustrations used in this chapter and S. Smith and E. Standora for help in developing the transmitter used in the study. This research was supported by research grants from the U.S. Department of Energy to SREL (E-381-1-819) and SUNY College at Buffalo (E-11-1-2502), student research grants from the Society for the Sigma Xi and the Faculty of Natural and Social Sciences (SUNYCAB), and travel grants from Oak Ridge Associated Universities.