CHAPTER 10

No Crows Made Mounds

Do Cost-Distance Calculations of Travel Time Improve Our Understanding of Southern Appalachian Polity Size?

PATRICK LIVINGOOD

Digital technology and the widespread availability of geographic datasets are enabling researchers to compute cost distances using ever-increasing resolution and model complexity. However, no matter how fast the hardware or elegant the software, cost distance will never be as simple to calculate as straight-line or geodesic distance. Least cost analysis (LCA) will become a regular part of the archaeologist's tool kit only if it provides better insights: better predictions, better understanding of the data, or a better fit to our theoretical models. In this chapter, I calculate cost distances between Mississippian mounds in the southern Appalachians to show that LCA can contribute to an improved understanding of the data by providing a better match to theoretical models.

This case study is based on a famous discovery by David Hally (1993, 1999, 2006). During the Mississippian period in the southern Appalachians (AD 1000–1600), residents built earthen flat-top pyramidal mounds at their civic-ceremonial centers (Figure 10.1). The societies that constructed these mounds are typically referred to as chiefdoms and were kin-based, hierarchical societies with hereditary inequality. The mounds are highly visible features on the landscape, and Georgia archaeologists have engaged in an excellent long-term program of survey, which means we have fairly high confidence that the locations of all the mound sites are known. Hally (1999) compiled chronological data for the 45 known mound sites and computed the pairwise straight-line distance between every set of contemporaneous mounds (Figure 10.2). He identified a major break in the distribution: most mounds are located less than 22 km from each other or more than 32 km. He interpreted this pattern as evidence of the bounds of Mississippian polities, in which secondary centers are located no more than 22 km from their primary center, and primary centers of competing polities are located at least 33 km from each other. The only mound pairs that fell in this intermediate distance ranges were 9Ck1/9Ck2, located 27 km apart, and 9Ge5/46Mg46, located 28 km apart. These are interpreted as being secondary centers of one polity that are located an intermediate distance from the primary center of a different polity.

The goal of this chapter is to convert the units of Hally's analysis from straight-line distance to cost distance in order to see if it improves our understanding of the southern Appalachian Mississippian. One way the cost-distance approach could be judged a success is if it identifies a clearer modal break in the data, implying that cost distance was the true variable underlying the patterning of sites and that straight-line distance was only an approximation.

Another goal is to compare cost distance with the theoretical expectation that chiefdom-type societies worldwide are usually limited in their capacity to control territory greater than a half-day's journey from the center (Bauer and Covey 2002:847–848; Cohen and Schlegel 1968:136;

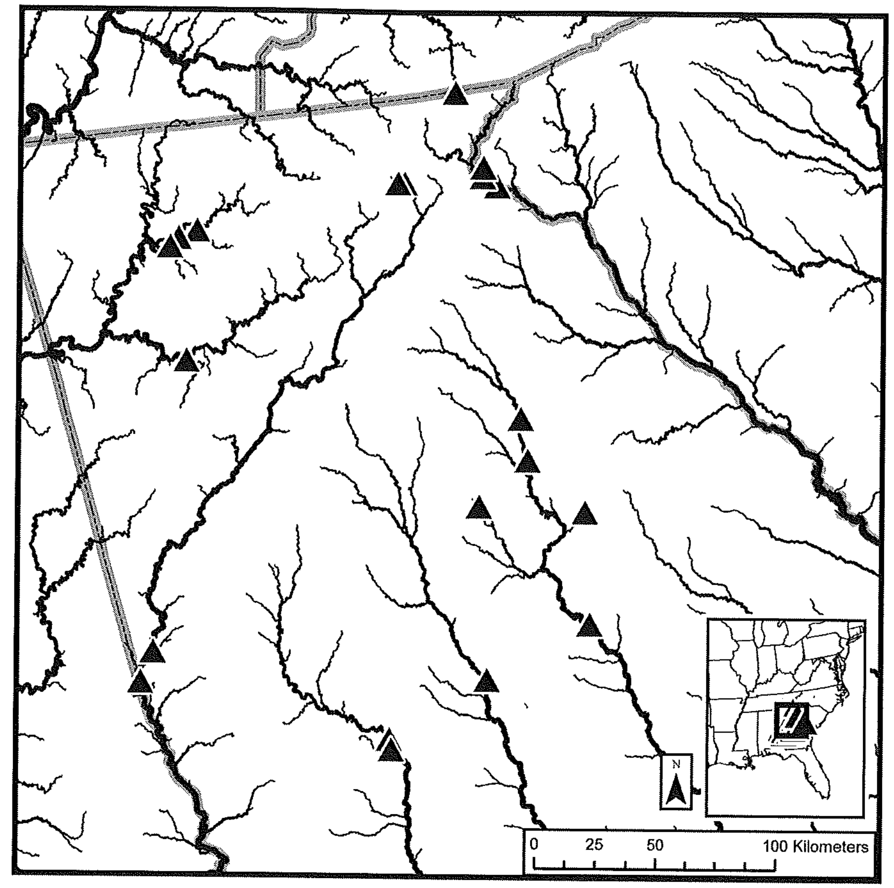

FIGURE 10.1. Map of the 45 southern Appalachian mounds in the case study. Note that they are not contemporaneous.

Helms 1979:51–53; Johnson 1987; Little 1967:240; Spencer 1990:6–8). This limit exists because of the lack of internally specialized administrative units (Wright 1977, 1984), which inhibits chiefs from extensive delegation of authority and imposes on them the requirement to manage their domain from the center (Spencer 1987, 1990, 1993). When polities are within this limit, chiefs can visit members of their communities without having to impose on their hospitality because they can return home at the end of the day (also important for state-level administrators in Mexico, as discussed in Bell et al. 1988:178). It also permitted the chief to respond with coercive force quickly if such action was required. From a bottom-up perspective, communities wanting to be integrated within a polity would choose to live closer to decrease the costs of participation. A community desiring autonomy would opt to live more distantly from a potentially meddlesome or threatening chief or the other apparatus of the polity.

10.1. Selecting the Unit of Cost-Distance Analysis

The work of geographers, urban planners, psychologists, and others makes the case that people use their evaluations of the cost of travel all the time in order to make decisions. There is a substantial body of research on this topic because it is of special interest to urban planners: people's evaluations of the cost of travel influence which route they take, which store they choose to go to, which mode of travel they choose, where they choose to live, where they choose to work, and many other aspects of life. Researchers have examined the way people evaluate the costs of

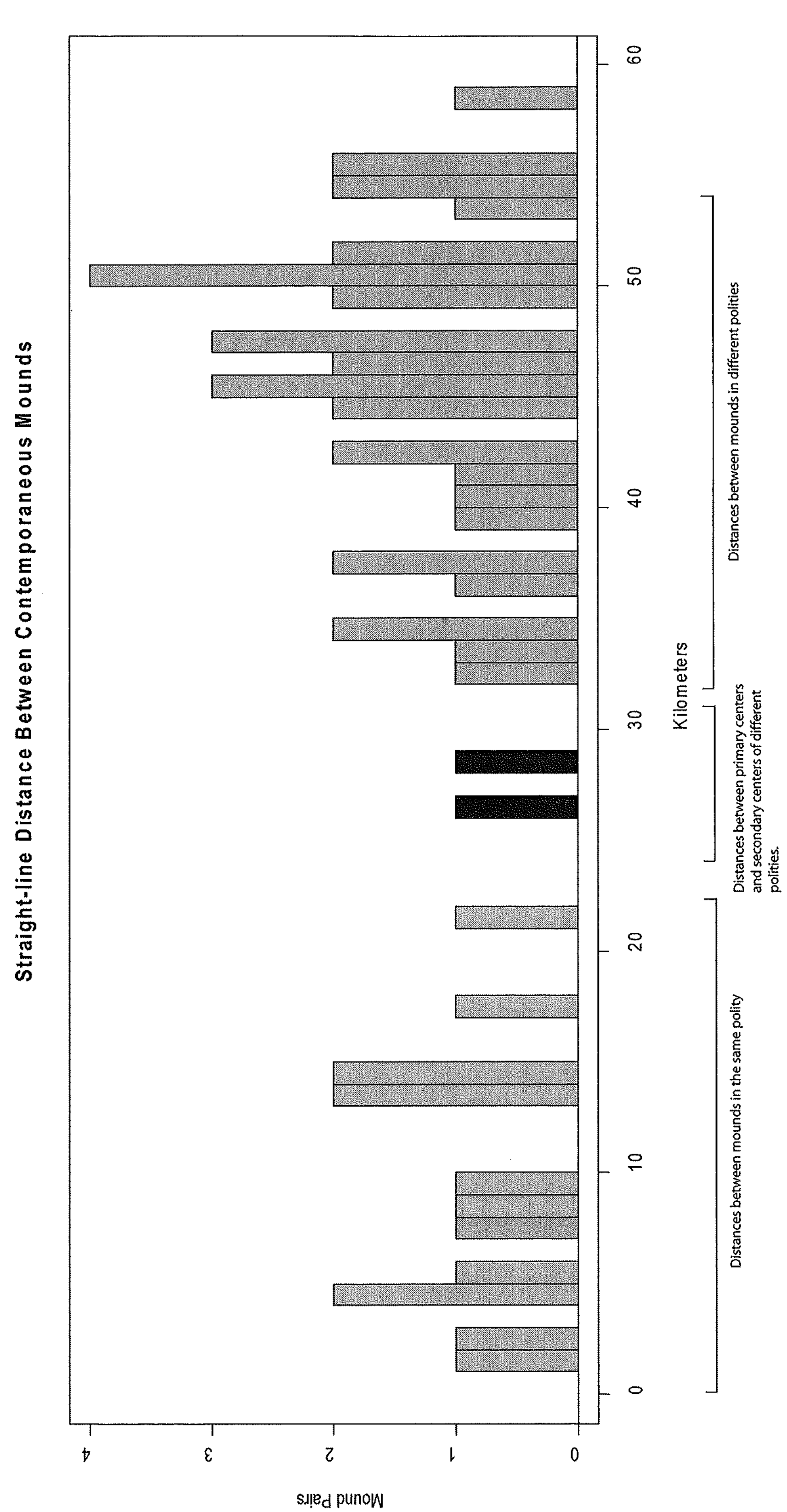

FIGURE 10.2. The straight-line distances between contemporaneous mounds in the study area for which the travel cost is less than 13 hours. A total of 52 mound pairs are represented here.

travel, and it is influenced by many factors, not just the objective distance. This opinion about the costs of a journey is referred to as the subjective distance (Montello 1997).

In Montello's (1997) framework, the subjective distance is influenced by three aspects: environmental features, travel time, and travel effort. Experimental research shows that environmental features are particularly important, but unfortunately these are nearly impossible to model in a prehistoric archaeological context. For example, modern urban travelers will judge a route to be longer despite its objective distance or duration if there are more turns (Sadalla and Staplin 1980), if there are no visible landmarks they are navigating toward (Nasar et al. 1985), or if there are simply more vistas (Montello 1997; Nasar et al. 1985). It is also clear that in many studies, cognitive, experiential, and cultural biases distort subjective distance in sometimes surprising ways. Studies have found that people overestimate distances of nearby destinations and underestimate distances to faraway destinations (McCormack et al. 2008), that people overestimate the distances of routes with which they are more familiar (Crompton 2006), and that people overestimate costs of travel into a city and underestimate costs of travel out of a city (Lee 1970).

Archaeologists are rarely able to incorporate environmental features into our attempts to approximate subjective distance, but we can calculate the other two aspects: travel time and cost effort. While a few archaeological studies use a flow model in which relative costs are computed that are not tied to any real-world units (e.g., Anderson and Gilliam 2000; Limp 1990; Sijia et al. 2007), most recent studies calculate costs in the units of time or calories. Caloric expenditure (e.g., Hare 2004; Hollenbach 2005; Jones and Madsen 1989; Wood and Wood 2006) has the advantage of decades of physiological research that permits one to anticipate the calories burned while factoring in variables such as sex, weight, speed, burden, and slope. Such simulations are especially useful when one is employing an optimal foraging model as the underlying theoretical paradigm, because one can compare the cost of a trip with the anticipated caloric return.

For this case study, time has been selected as the unit for cost distance. As experimental studies have found, travel time is a major, if not the most important, factor in a traveler's evaluation of subjective distance (Burnett 1978; Golledge and Zannaras 1973; MacEachren 1980). One possible reason is that instruments to measure time (clocks, watches, the movement of the sun, meals, etc.) are more readily available than instruments to measure distance (Montello 1997:302). This is somewhat supported by anecdotes from ethnographic and linguistic studies that show that time is used more often than geographic distance as a basis for subjective distance. For example, the basic unit of distance among the twentieth-century Tofa of Siberia is *kösh*, which is the distance one can travel on reindeer-back in one day (Rassadin 1995:23 as cited in Harrison 2007:105). It is approximately 25 km but is affected by terrain, snowfall, and other factors (Harrison 2007). Among the Sherpa and Bantawa Rai people of mountainous Nepal, maps and language emphasize the vertical dimension of place, which is the best predictor of travel time and effort (Harrison 2007:113–114). Finally, a traveler among the Malays in the 1870s noted that the major references to distance included "as far as a gunshot can be heard," "the distance you can travel before your hair dries," "the number of times you chew betel between locations," "the distance covered in a day's walk," and, for boatmen, the number of turns in the river (Bird 1883; Mitra 1910).

I would argue that travel time, more than caloric cost or straight-line distance, was the cost most likely to be perceived by the Mississippian traveler and most likely to be actively incorporated into decisions about routes, actions, and settlement patterns. Time is also useful in this study because the underlying theoretical expectation—that chiefly polities are typically no larger than a half-day's travel from the center—is framed in units of time.

10.2. Selecting the Parameters of the Cost-Distance Model

One of the challenges of using cost distance in any unit is that travel can be extremely variable and costs can be affected by many factors: weather, misfortune, man-made barriers, secondary activities (such as foraging for food, protecting against attack, or transporting goods), whether the traveler knows the route well enough to select the optimal path, and the speed and physical ability of the travelers. As others have done in similar research, but not always explicitly, the cost-distance model must usually simplify matters by specifying a traveler of median speed and ability who is making an optimal trip without any major unforeseen obstacles or delays.

Indigenous peoples of eastern North America had two primary modes of travel: they could walk or they could use a canoe. This case study permits both. For calculating travel times on foot, I use the commonly employed hiker's formula developed by geographer Waldo Tobler (Tobler 1993). The formula has been used in numerous archaeological calculations of cost distance (e.g., Aldenderfer 1998; Gorenflo and Bell 1991; Hare 2004; Jennings and Craig 2001; Kantner 1997; and Phillips and Leckman, Surface-Evans, White, and Kantner in this volume); for further discussion of the application of this formula to archaeological datasets, see Aldenderfer (1998:12), Gorenflo and Gale (1990), and Leusen (2002). The formula calculates walking speed as a function of slope and is expressed

$$Speed\ (km/hr) = 6e^{-3.5|x+0.05|} \qquad (10.1)$$

It predicts a speed of 5 km/hr on level terrain and a maximum speed of 6 km/hr on a 5 percent downslope. This corresponds well to recorded instances of modern and ethnographic rates of travel (Aldenderfer 1998:11–15; Lee 1979), assuming relatively clear terrain and light burdens.

Tobler further suggested that under less than ideal conditions we could reduce the predicted speed by a certain factor. For example, we would apply a 40 percent reduction in speed if travel is off-trail and a 20–40 percent reduction for carrying moderate loads. I have chosen to assume all travel in this simulation is on-trail because the purpose is to predict settlement patterns over a long period of time. Presumably, if a route was important, a trail would have been established. This is supported by accounts of the historic Creeks, who mostly stayed on established, if sometimes obscure, trails (Ethridge 2003:122).

The only additional impediment to walking I have chosen to implement is the barrier presented by crossing waterways. In accounts of historic travelers' overland journeys across the Southeast, often the only landmarks mentioned consistently were rivers and streams (Bartram 1996; Charlevoix [1761] 1966; Clayton et al. 1993; Lawson [1709] 1967; Tanner 1989:16; Waselkov and Braund 1995). They were both notable and all too often notably challenging to cross when there were no bridges (Ethridge 2003:124) or shoals available. In this model, these barriers are modeled by a simple cost (Table 10.1) that is dependent on the size of the waterway as measured in cubic feet of water per second (cfs). In historic accounts, these crossings are extremely variable, from a few minutes for well-prepared travelers with canoes stashed or those crossing at shoals or bridges to multiple days or weeks if unprepared travelers had to wait for flood-swollen rivers to subside. The goals of this simulation are to model a typical optimal trip for a well-prepared traveler who knows the terrain, and thus the costs were arbitrarily and conservatively chosen. Currently, this simulation does not model any other barriers to overland travel, such as wetlands, which were almost certainly a major impediment to overland travel, especially below the fall line (Hudson 1976:314), or shoals, which would have facilitated water crossings. These may be important, but there are no widely available datasets on their Precolumbian locations.

TABLE 10.1. Cost Penalty for Crossing a Waterway.

Water flow (cubic feet per second)	Delay
<10	0
10–100	3 seconds
100–1,000	5 minutes
1,000–10,000	10 minutes
>10,000	30 minutes

Note: This is implemented in the simulation by assessing half the cost in this table in addition to the cost calculated by Tobler's formula for any movement from a land cell to a water cell or vice versa. A complete crossing is assessed the penalty listed here.

Unfortunately, there are no well-established analogues to the Tobler formula for estimating the speed of canoe travel. The most comprehensive study of canoe speeds along eastern North American waterways was done by Little (1987). The single most important factor in determining the speed of canoe travel is the speed and direction of the current: upstream trips take twice as long as downstream ones (Little 1987:59). For this simulation, I have modeled the speed of canoe travel as a base speed, which a canoeist could achieve on calm water, plus or minus the speed of the current, depending on the direction of travel. In order to determine this base speed, I collected several accounts of canoe travel in both historic and modern contexts. Unfortunately, most accounts of canoe travel in the historic Southeast are only moderately helpful because they fail to specify the number of hours spent each day in the water.

TABLE 10.2. Historic Canoe Speeds.

Group or Explorer	Citation	Speed (not Current-Adjusted)	Notes
Aztec	Hassig 1985:64	2.6–3.5 km/hr	Travel through canal system of central Mexico with large cargo canoes
French under Iberville	Bénard de La Harpe 1971:23	5.7 km/hr	Travel on March 27, 1700, over a 34-hour period in canoe
French explorer Roullet	Rowland and Sanders 1927	19.25 km/day downstream	Travel along Pearl River from near Leake and Neshoba County line to mouth over 24 days in pirogue
Champlain	Little 1987:59	40–45 km/day upstream, 90–110 km/day downstream	Travel along St. Lawrence and Great Lakes in canoe
Average of Marquette, Joliet, LaSalle, Colden, Celoron	Little 1987:59	16–32 km/day upstream, 45 km/day downstream	Travel on Mississippi, Mohawk, and Ohio Rivers in canoes

Table 10.2 lists several historic canoe journeys. In most cases we have only estimates of trip speed in days, but in some cases we have enough information to confidently calculate speeds in kilometers per hour. These records show that trips varied in speed from 16–45 km/day upstream and 19–110 km/day downstream. If one were to assume 8 hours a day on the water on average, it would provide a calculation of gross speeds of 2–5.6 km/hr upstream and 2.4–13.75 km/hr downstream.

Another, more refined estimate of possible canoe speeds comes from the group of people who have canoed down the entire Mississippi River in relatively recent times for adventure and occasionally profit (Table 10.3). At the extreme end, three pairs of canoeists have set progressively faster world records for travel down the Mississippi River since 1984. These attempts are useful for our purposes because they provide an obvious upper bound for our speed estimates, they are well documented, and the journeys are long enough that small variations in weather and conditions do not overly affect the averages. These record holders traversed the approximately 3700 km of the river in 18–23 days, which represents a gross speed of 6.5–8.5 km/hr. Since they had to spend some time making portages and navigating numerous locks and dams, their actual speed in the water was even higher. However, when we simulate a run taking into account the current speeds of the various segments of the Mississippi River, we can calculate the base speed needed to generate their results. Their current-adjusted speeds were 4.7–6.4 km/hr.

Obviously, many aspects of these attempts do not make good analogues for Mississippian canoe travel: the canoes were modern and ultralightweight; the canoeists were assisted by crews that provided them food they did not have to carry themselves; and they had the advantages of well-marked channels and no natural obstructions. On the other hand, these modern canoeists had to contend with locks and dams and barge traffic, which were not a problem for Precolumbian canoeists. Mike Schnitzka, one of the record holders, characterized these trips as significant demonstrations of endurance, not necessarily speed, because a sprinting speed would be impossible to maintain for three weeks. During world record attempts of this type, the canoeists never leave the canoe except for portages, and they sleep in shifts in the boat for only about three hours a night while their partner keeps paddling (Mike Schnitzka, personal communication 2007). If we assume that the modern barriers of locks and dams are equivalent in magnitude to the ancient ones of beaver dams and log accumulations, the

TABLE 10.3. Modern Canoe Travel with Current-Adjusted Speeds.

Explorer	Reference	Distance (km)	Avg. Speed of Current (km/hr)	Days of Travel	Current-Adjusted Speed at 8hrs/day (km/hr)	Notes
Captain Willard Glazier	Glazier 1891	3766.9	3.1	86	3.6	Traveled down the Mississippi river from Elk Lake to the Gulf of Mexico between July 22 and November 15, 1881. Used multiple birch-bark canoes and a small crew. Assume 8 hours/day of travel
Matthew Mohlke	Mohlke 2001	3583.2	3.3	79	3.9	Traveled solo down Mississippi from Lake Itasca to New Orleans between May 15 and August 1, 1999. Assume 8 hours/day of travel
John Pugh and Jessica Robinson	Pugh and Robinson 2005; Simmons 2005	3484.4	3.1	71	4.4	Traveled as a pair down the Mississippi from Lake Itasca to Sweetwater Bay, La., via the Atchafalaya between May 14 and July 27, 2005. Assume 8 hours/day of travel
Michael Schnitzka and William Perdzock (Wisconsin River)	Schnitzka and Perdzock 2007	725	2	4 days, 2 hours, 22 minutes	12.3	World record holders for canoeing down the Wisconsin River; canoed as a pair in 1989 in a racing canoe
Michael Schnitzka and William Perdzock (Mississippi River)	Schnitzka and Perdzock 2007	3766.9	3.1	23 days, 9 hours, 51 minutes	4.7	1989 world record journey for canoeing the Mississippi River
Verlen Kruger and Valerie Fons (Mississippi River)	Peterson 2006:297	3766.9	3.1	23 days, 10 hours, 20 minutes	4.7	1984 world record journey for canoeing the Mississippi River
Bob Bradford and Clark Eid (Mississippi River)	Peterson 2006:297	3766.9	3.1	18 days, 4 hours, 51 minutes	6.4	2003 world record journey for canoeing the Mississippi River
Average					**5.8**	

Note: Distances were calculated from NHDPlus data (Horizon Systems Corporation 2006). Current-adjusted speeds were calculated from NHDPlus: for the actual speed down the river, take the current-adjusted speed and add or subtract the flow of the channel. In the case of the Mississippi River attempts since 2000, the NHDFlow table data were altered slightly. Attempts were made using the pool and dam location data to identify modern reservoirs and to set the current of those channels to zero for calculating the current-adjusted speed.

most significant difference between these attempts and what the Mississippians would have been capable of is dictated by the technology of the watercraft.

There were also three well-published modern attempts to canoe the Mississippi in which the canoeists were not trying to set any records. From their books it was possible to determine how many days were spent on the water and to calculate their current-adjusted speeds, assuming an average of 8 hours a day on the water. The result is speeds of 3.6–4.4 km/hr. These compare favorably with Aztec cargo canoes that traversed Lake Texcoco and the surrounding canals at 2.5–3.5 km/hr and a French trip down the Mississippi in 1700. These results show a broad range of base speeds, and probably any value between 3.5 and 5 km/hr could be defended, with a range between 4 and 4.5 km/hr as the most likely. For this case study, I decided to use a value of 4 km/hr for the base speed of canoe travel plus or minus the speed of the current and to permit canoe travel only on waterways with flows of 100 cfs or more. It would be ideal to also simulate waterfalls, shoals, and other barriers that would have required portages. Unfortunately, there are no widely available data-

sets on their locations. Also, like land travel, canoe travel would have been variable from season to season and easier in the high waters of spring and early summer than in fall or winter (Little 1987:57).

To summarize, this case study permits its simulated travelers to use two modes of travel. Land travel speed is calculated using the hiker's formula, which takes into account slope plus an additional penalty for crossing waterways, depending on the size of the water body as measured by volume of flow. Water travel speed is calculated by adding or subtracting the velocity of the current from the base speed of 4 km/hr, and no water travel is permitted on waterways with flows less than 100 cfs.

10.3. Implementation of the Cost-Distance Model

The data used to calculate the cost distances come from two sources. Elevations are based on digital elevation model (DEM) data produced by the U.S. Geological Survey. The data's original resolution is such that each raster square corresponds to a spot of land 30 m by 30 m. I coarsened the data to 180-m^2 blocks in order to compute the results in adequate time. The hydrography data come from the NHDPlus dataset (Horizon Systems Corporation 2006) and include average annual current volume and velocity for each segment of waterway, which were themselves calculated from catchment sizes and modern rainfall data (Research Triangle Institute 2001). These data are accurate for our purposes insofar as we are willing to assume that rainfall amounts in the Mississippian period were similar to the average rainfalls recorded between 1960 and 1999 and we are willing to consider only mean annual flows for waterways.

To calculate least cost distances, I wrote a custom software application because available software was inadequate to handle the complex factors considered by my model (a problem also recorded by White this volume). The algorithm required for this simulation needs to be anisotropic, meaning the costs vary by direction, and generalizable, meaning the costs in each direction are independent of each other. With ArcGIS or IDRISI it is possible to implement a simulation of Tobler's anisotropic walking function alone, but it is currently impossible to also factor in costs associated with waterways.

In order to analyze the case study, I wrote custom code in the Visual Basic module within ArcGIS and in Visual Basic.NET. The code I wrote is an implementation of Dijkstra's algorithm (Dijkstra 1959) and the A* algorithm (Hart et al. 1972). These algorithms are simple, and I have chosen not to optimize the algorithm, which is referred to as the "brute-force" solution. As implemented, these algorithms are slow, but they are guaranteed to find the optimal solution rather than settle on a local optimum, which is a concern with the implementation in the widely available GIS packages (see Kantner this volume). Both algorithms are described in Chapter 1 of this volume.

10.4. Results

Figure 10.3 shows the least cost times between mounds in the sample. As in the distance measurement, there are two primary modes and a pair of outliers. The least cost distance calculations inform us that most secondary centers were less than 4 hours' travel from the administrative center of their polity and all are located less than 5 hours away. A single secondary center, Wilbanks (9Ck5), was located 22 km from its administrative center, Etowah (9Br1). That is a trip that would have taken 4.7 hours downstream from 9Ck1 to Br1 and 4.9 hours upstream. On average, contemporaneous mounds belonging to the same polity were located 2.2 hours or 9.9 km from each other. If we exclude the outlier, 9Ck5, these averages are 2.0 hours and 9.0 km.

Mounds from different polities are located at least 26 km or 5.6 hours from each other, and no competing administrative centers are closer than 33 km or 7.5 hours distant. Most mounds from competing centers are located a minimum of 8–10 hours from each other. A comparison of the straight-line distances and average speeds show that there is a high degree of correlation, which is to be expected: the greatest predictor of travel time is travel distance. On average, these journeys were made with a net speed of 4.6 km/hr. However, there is a significant range of variation with a low of 3.3 km/hr for the 4-km trip from 9St3 to the nearby 38Oc47. The fastest journey is the 46 km between 9Hk1 and 9Bl1, which averaged 4.9 km/hr.

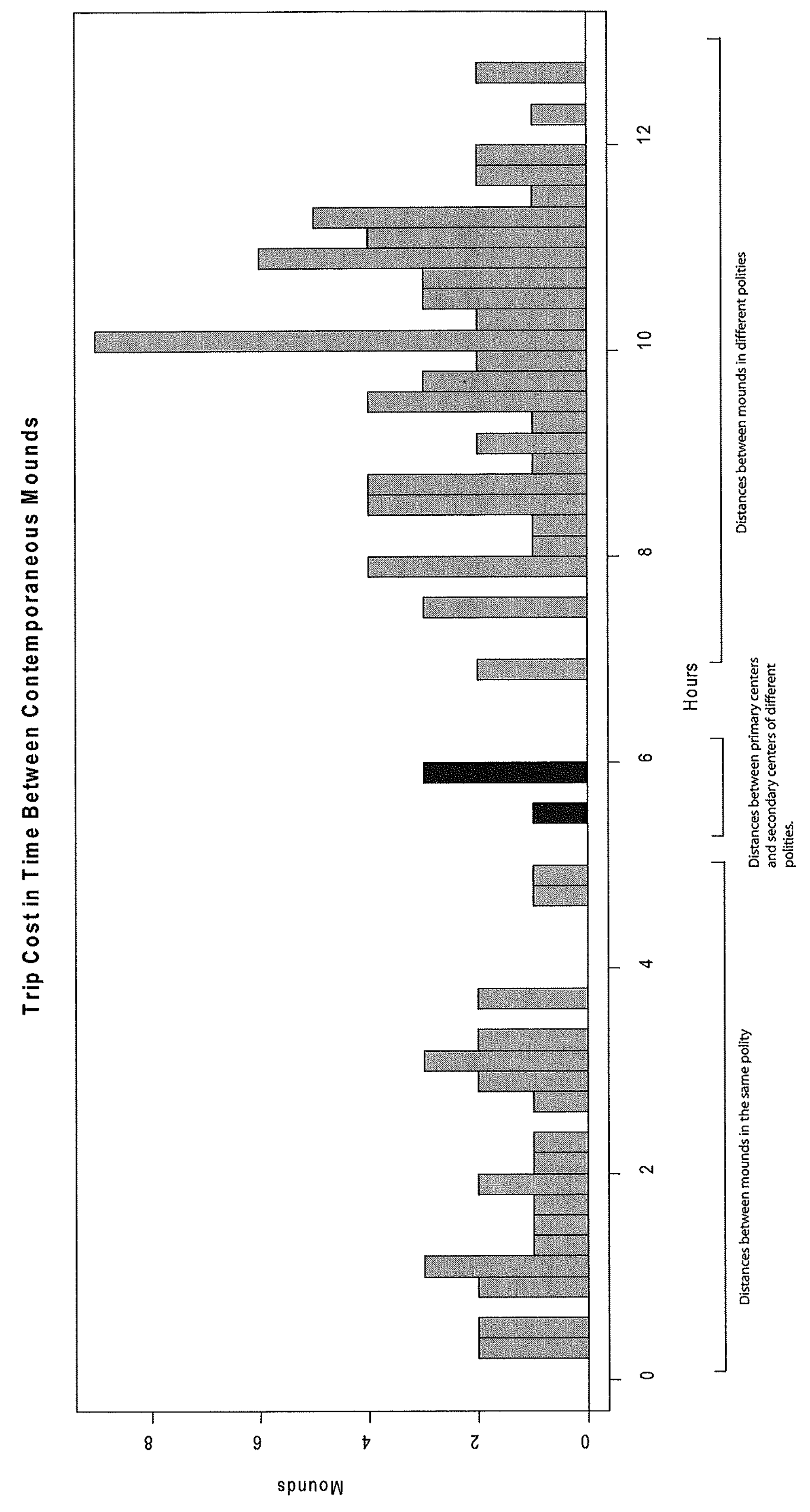

FIGURE 10.3. The travel time between contemporaneous mounds in the study area for which the travel cost is less than 13 hours. A total of 104 journeys between 52 mound pairs are represented here.

One of the reasons for this result is that under the parameters in this simulation, water travel is utilized very rarely. If one calculates the optimal path between pairwise combinations of all 45 mound pairs (ignoring, for now, contemporaneity), water is on average used to cover only 2 percent of the distance or 1.8 percent of the travel time. In most trips, water travel would not have been used at all for an optimal journey. In only 94 of the trips between mounds (out of 1,980 possible mound pairs, or 4.7 percent) is water used to travel more than 10 percent of the needed distance, and it is used to cover more than half the distance for only 6 of the possible trips (.3 percent). If we focus on the mounds that have been the subject of most of the discussion here, that is, pairs of mounds that were contemporaneous and located less than 13 hours' travel from each other, water travel was important between only one pair of sites: 9St1 and 9St3. Water travel was negligible (<6 percent of the travel distance) in all other cases.

Clearly, pedestrian travel is most significant, and given the relatively low relief of much of the study area, the most significant influence on travel times is the number and size of the river crossings. This corresponds fairly well with Hally's original estimation that canoe travel was a minor form of transportation in this region (David Hally, personal communication 2008). Of course, if one were to try simulating travel for the movement of heavy loads, it is likely that canoe travel would be more efficient in more cases.

Despite the high correspondence between travel time and distance, there are some subtle, but important, differences in the results. Namely, a visual inspection of the two histograms shows a stronger pattern of bimodality when travel time is used because of small shifts in some of the boundary cases. This can be statistically evaluated with Silverman's test (Baxter and Cool 2010; Silverman 1981, 1986), which helps quantify the probability of a certain number of modes being present.

For travel time, the test of the null hypothesis that there is just a single mode provides an associated probability of $p = .047$ (at bin width 2.253, or $p = .014$ with the calibrated version suggested by Hall and York 2001), which meets the traditional standard of statistical significant ($\alpha = .05$). Stated another way, the null hypothesis of a single mode is rejected, suggesting two modes. A subsequent test of more than two modes fails to hold ($p = .546$, calibrated $p = .423$, critical bin width = .746), which provides statistical evidence that there are two, but not more than two, modes. In contrast, the Silverman's test on pairwise distance has a $p = .059$ (calibrated $p = .051$, critical bin width = 10.244), which if we use a α of .05 says that we cannot reject the null hypothesis of a single mode. Phrased another way, we are fairly confident that there is more than one mode in the travel time data, with only a 1–5 percent chance that this is just statistical noise, but we have a little less certainty with the distance data, with a 5–6 percent chance that there is really just a single mode. The differences between these results are small ($p = .047/.014$ for time and $p = .059/.051$ for distance), but they provide empirical evidence that the histogram of travel time is more strongly bimodal that that of distance.

10.5. Evaluation

Straight-line distance certainly has many advantages as the unit of comparison in this study or in others like it. It is simple, it can be calculated rapidly, and it does not rely on any intervening models. The cost-distance simulation, in contrast, is built on multiple assumptions, such as the speed of canoes and the penalty to cross a water channel. The values used in this simulation are reasonable, but they are not the only reasonable values.

I argue that LCA, despite these disadvantages, can still be a useful tool for archaeologists if it helps demonstrate that our data meet theoretical expectations. In this case it does this in two ways. First, the underlying theoretical expectation is that secondary centers should be no more than a half-day's travel from the chiefly center. If we convert geodesic distance to travel time, we have a rather clear demonstration of this principle. Second, we expect that Mississippians had no direct way to measure straight-line distance and that instead their settlement patterns are shaped by a subjective distance evaluation of whether their mounds are either closer than a certain threshold to a polity center or more distant than another threshold from a neighboring polity; the best proxy we have for subjective distance in a prehistoric case study is travel time. It is subtle, but the Silverman's test confirms that travel time is more strongly bimodal than distance, which suggests it does a better job of explaining the patterning. This confirms our theoretical expectation that travel time was what was being perceived and manipulated by Mississippians when they located mound sites.

10.6. Future Research

There are several ways that the cost-distance simulation could be improved. As mentioned previously, we expect that swamps were a major barrier to overland travel below the fall line, that waterfalls were a major barrier to canoe travel, and that shoals were a barrier to canoe travel and an aid to river crossings. Unfortunately, we currently lack digitized datasets with the locations of these features, but they could be reconstructed and digitized from historic maps. Furthermore, the base canoe speed and penalties to water crossings used in this simulation are reasonable, but they are not the only reasonable values. In the future, one could sweep a range of possible parameter values to see what their effects are on the results. One approach would be to look for parameters that create stronger modes in the data as potentially useful.

In addition, it would be possible to extend this model to create a more nuanced understanding of the regional settlement system. For example, one could simulate waterways in different seasons instead of using waterway data based on average annual rainfall.

10.7. Conclusion

In summary, most Mississippian archaeologists are now familiar with the traditional Hally circles, showing 18-km as-the-crow-flies radii around presumed polity centers. I suggest that the measure of distance Mississippians were most aware of and the most likely to act on in determining settlement location was travel time. Therefore, the better representations of polity boundaries are isolines representing an estimate of 5 hours' travel. These lines are more complex to calculate and are based on more complex assumptions, but technology is catching up to the task and these arguably represent a better depiction of the dynamic underlying Mississippian regional systems. After all, one thing we know for sure is that crows didn't build the mounds.

References

Aldenderfer, Mark S.
1998 *Montane Foragers: Asana and the South-Central Andean Archaic.* University of Iowa Press, Iowa City.

Anderson, David G., and J. Christopher Gilliam
2000 Paleoindian Colonization of the Americas: Implications from an Examination of Physiography, Demography, and Artifact Distribution. *American Antiquity* 65:43–66.

Bartram, William
1996 *Travels, and Other Writings.* Library of America 84. Library of America, New York.

Baxter, M. J., and H. E. M. Cool
2010 Detecting Modes in Low-Dimensional Archaeological Data. *Journal of Archaeological Science* 37:2379–2385.

Bauer, Brian S., and R. Alan Covey
2002 Processes of State Formation in the Inca Heartland (Cuzco, Peru). *American Anthropologist* 104(3):846–864.

Bell, T. L., R. L. Church, and L. Gorenflo
1988 Late Horizon Regional Efficiency in the Northeastern Basin of Mexico—A Location-Allocation Perspective. *Journal of Anthropological Archaeology* 7(2):163–202.

Bénard de La Harpe, Jean Baptiste
1971 *Historical Journal of the Settlement of the French in Louisiana.* University of Southwestern Louisiana, Lafayette.

Bird, Isabella
1883 *The Golden Chersonese and the Way Thither.* J. Murray, London.

Burnett, P.
1978 Time Cognition and Urban Travel Behavior. *Geografiska Annaler Series B—Human Geography* 60(2):107–115.

Charlevoix, Pierre de
[1761] 1966 *Journal of a Voyage to North-America.* 2 vols. Readex Microprint, New York.

Clayton, Lawrence A., Vernon James Knight, and Edward C. Moore
1993 *The De Soto Chronicles: The Expedition of Hernando de Soto to North America in 1539–1543.* 2 vols. University of Alabama Press, Tuscaloosa.

Cohen, Ronald, and Alice Schlegel
1968 The Tribe as a Socio-Political Unit: A Cross-Cultural Examination. In *Proceedings: Essays on the Problem of Tribe*, pp. 120–149. American Ethnological Society, Seattle.

Crompton, A.
2006 Perceived Distance in the City as a Function of Time. *Environment and Behavior* 38(2):173–182.

Dijkstra, Edsger Wybe
1959 A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik* 1:269–271.

Ethridge, Robbie Franklyn
2003 *Creek Country: The Creek Indians and Their World.* University of North Carolina Press, Chapel Hill.

Glazier, Willard W.
1891 *Down the Great River: Embracing an account of the discovery of the true source of the Mississippi, together with views, descriptive and pictorial, of the cities, towns, villages and scenery on the banks of the river, as seen during a canoe voyage of over three thousand miles from its head waters to the gulf of Mexico.* Hubbard Bros., Philadelphia.

Golledge, R. G., and G. Zannaras
1973 Cognitive Approaches to the Analysis of Human Spatial Behavior. In *Environment and Cognition*, edited by W. H. Ittelson, pp. 59–94. Seminar, New York.

Gorenflo, L. J., and Thomas L. Bell
1991 Network Analysis and the Study of Past Regional Organization. In *Ancient Road Networks and Settlement Hierarchies in the New World*, edited by C. D. Trombold, pp. 80–98. Cambridge University Press, Cambridge.

Gorenflo, L. J., and Nathan Gale
1990 Mapping Regional Settlement in Information Space. *Journal of Anthropological Archaeology* 9(3):240–274.

Hall, Peter, and Matthew York
2001 On the Calibration of Silverman's Test for Multimodality. *Statistica Sinica* 11:515–536.

Hally, David J.
1993 The Territorial Size of Mississippian Chiefdoms. In *Archaeology of Eastern North America: Papers in Honor of Stephen Williams*, edited by J. B. Stoltman, pp. 143–168. Mississippi Department of Archives and History, Jackson.
1999 The Settlement Pattern of Mississippian Chiefdoms in Northern Georgia. In *Settlement Pattern Studies in the Americas: Fifty Years since Virú*, edited by B. R. Billman and G. M. Feinman, pp. 96–115. Smithsonian Institution Press, Washington, D.C.
2006 Nature of Mississippian Regional Systems. In *Light on the Path: The Anthropology and History of the Southeastern Indians*, edited by T. J. Pluckhahn and R. Ethridge, pp. 26–42. University of Alabama Press, Tuscaloosa.

Hare, Timothy S.
2004 Using Measures of Cost Distance in the Estimation of Polity Boundaries in the Postclassic Yautepec Valley, Mexico. *Journal of Archaeological Science* 31:799–814.

Harrison, K. David
2007 *When Languages Die: The Extinction of the World's Languages and the Erosion of Human Knowledge.* Oxford University Press, Oxford.

Hart, P. E., N. J. Nilsson, and B. Raphael
1972 Correction to "A Formal Basis for the Heuristic Determination of Minimum Cost Paths." *SIGART Newsletter* 37:28–29.

Hassig, Ross
1985 *Trade, Tribute, and Transportation: The Sixteenth-Century Political Economy of the Valley of Mexico.* Civilization of the American Indian Vol. 171. University of Oklahoma Press, Norman.

Helms, Mary W.
1979 *Ancient Panama.* University of Texas Press, Austin.

Hollenbach, Kandace Detwiler
2005 Gathering in the Late Paleoindian and Early Archaic Periods in the Middle Tennessee River Valley, Northwest Alabama. Unpublished Ph.D. dissertation, University of North Carolina, Chapel Hill.

Horizon Systems Corporation
2006 *NHDPlus User Guide, July 1, 2006.* Horizon Systems Corporation, Herndon, Virginia.

Hudson, Charles M.
1976 *The Southeastern Indians.* University of Tennessee Press, Knoxville.

Jennings, Justin, and Nathan Craig
2001 Politywide Analysis and Imperial Political Economy: The Relationship between Valley Political Complexity and Administrative Centers in the Wari Empire of the Central Andes. *Journal of Anthropological Archaeology* 20: 479–502.

Johnson, Gregory A.
1987 The Changing Organization of Uruk Administration on the Susiana Plain. In *The Archaeology of Western Iran: Settlement and Society from Prehistory to the Islamic Conquest*, edited by F. Hole. Smithsonian Institution Press, Washington, D.C.

Jones, Kevin T., and David B. Madsen
1989 Calculating the Cost of Resource Transportation: A Great Basin Example. *Current Anthropology* 30(4):529–534.

Kantner, John
1997 Ancient Roads, Modern Mapping: Evaluating Chaco Anasazi Roadways Using GIS Technology. *Expedition* 39(3):49–62.
Lawson, John
[1709] 1967 *A New Voyage to Carolina*. University of North Carolina Press, Chapel Hill.
Lee, Richard B.
1979 *The !Kung San: Men, Women, and Work in a Foraging Society*. Cambridge University Press, Cambridge.
Lee, Terence
1970 Perceived Distance as a Function of Direction in the City. *Environment and Behavior* 2(1): 40–51.
Leusen, Pieter Martijn van
2002 Pattern to Process Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes. Unpublished Ph.D. dissertation, Rijksuniversiteit, Groningen, the Netherlands.
Limp, Fred
1990 Continuous Cost Movement Models. In *Applications of Space-Age Technology in Anthropology*, edited by C. A. Behrens and T. L. Sever, pp. 231–250. NASA, Bay St. Louis, Mississippi.
Little, Elizabeth A.
1987 Inland Waterways in the Northeast. *Midcontinental Journal of Archaeology* 12(1):55–76.
Little, Kenneth
1967 The Mende Chiefdoms of Sierra Leone. In *West African Kingdoms in the Nineteenth Century*, edited by D. Forde and P. Kaberry, pp. 239–259. Oxford University Press, London.
MacEachren, Alan M.
1980 Travel Time as the Basis for Cognitive Distance. *Professional Geographer* 32(1):30–36.
McCormack, Gavin R., Ester Cerin, Eva Leslie, Lorinne Du Toit, and Neville Owen
2008 Objective versus Perceived Walking Distances to Destinations: Correspondence and Predictive Validity. *Environment and Behavior* 40(3): 401–425.
Mitra, Sarat Chandra
1910 Further Notes on the Primitive Method of Computing Time and Distance. *Journal of the Anthropological Society of Bombay* 9(2):83–92.
Mohlke, Matthew
2001 *Floating Down the Country*. Lone Oak Press, Red Wing, Minnesota.
Montello, Daniel
1997 The Perception and Cognition of Environmental Distance: Direct Sources of Information. In *Spatial Information Theory: A Theoretical Basis for GIS*, pp. 297–311. Springer, Berlin.
Nasar, J. L., H. Valencia, and Z. A. Omar
1985 Out of Sight, Further from Mind: Destination Visibility and Distance Perception. *Environment and Behavior* 17(5):627–639.
Peterson, Phil
2006 *All Things Are Possible: The Verlen Kruger Story; 100,000 Miles by Paddle*. Adventure Publications, Cambridge, Minnesota.
Pugh, John, and Jessica Robinson
2005 *Source to Sea: The Mississippi River Project*. Electronic document, http://www.sourcetosea.net, accessed July 24, 2007.
Rassadin, Valentin Ivanovich
1995 *Tofalarsko-russkii slovar' russko-tofalarskii*. Vostochno-Sibirskoe knizhnoe izd-vo, Irkutsk, Russia.
Research Triangle Institute
2001 *The National Water Pollution Control Assessment Model, (NWPCAM) Version 2 Draft Report, Prepared for the U.S. Environmental Protection Agency*. Research Triangle Institute, Research Triangle Park, North Carolina.
Rowland, Dunbar, and A. G. Sanders
1927 *Mississippi Provincial Archives: 1729–1740, French Dominion*. Press of the Mississippi Department of Archives and History, Jackson.
Sadalla, E. K., and L. J. Staplin
1980 The Perception of Traversed Distance: Intersections. *Environment and Behavior* 12(2): 167–182.
Schnitzka, Michael, and William Perdzock
2007 *Conquer the Rhine*. Electronic document, http://www.conquertherhine.com/team.html, accessed July 26, 2007.
Sijia, Wang, Cecil M. Lewis Jr., Mattias Jakobsson, Sohini Ramachandran, Nicolas Ray, Gabriel Bedoya, Winston Rojas, Maria V. Parra, Julio A. Molina, Carla Gallo, Giovanni Poletti, Kim Hill, Ana M. Hurtado, Damian Labuda, William Klitz, Ramiro Barrantes, Maria Cátira Bortolini, Francisco M. Salzano, Maria Luiza Petzl-Erler, and Luiza T. Tsuneto
2007 Genetic Variation and Population Structure in Native Americans. *PLoS Genetics* 3(11):e185. doi:10.1371/journal.pgen.0030185.
Silverman, B. W.
1981 Using Kernel Density Estimates to Investigate Multimodality. *Journal of the Royal Statistical Society, Series B (Methodological)* 43(1):97–99.
1986 *Density Estimation*. Chapman and Hall, London.
Simmons, Tim
2005 Via Detour, Paddling Students Reach the Gulf; Weather Took Pair off Mississippi. *News & Observer* (Raleigh, North Carolina), August 8.
Spencer, Charles S.
1987 Rethinking the Chiefdom. In *Chiefdoms in the Americas*, edited by R. D. Drennan and C. Uribe, pp. 369–390. University Press of America, Lanham, Maryland.
1990 On the Tempo and Mode of State Formation: Neoevolutionism Reconsidered. *Journal of Anthropological Archaeology* (9):1–30.
1993 Human Agency, Biased Transmission, and the Cultural Evolution of Chiefly Authority. *Journal of Anthropological Archaeology* 12:41–74.
Tanner, Helen Hornbeck
1989 The Land and Water Communication Systems of the Southeastern Indians. In *Powhatan's Mantle: Indians in the Colonial Southeast*, edited by P. H. Wood, G. Waselkov, and M. T. Hatley, pp. 6–20. University of Nebraska Press, Lincoln.
Tobler, W.
1993 Non-isotrophic Geographic Modeling. In *Three Presentations on Geographic Analysis and Modeling*. Technical Report 93-1. National Center for Geographic Information and Analysis, University of California, Santa Barbara.
Waselkov, Gregory A., and Kathryn E. Holland Braund
1995 *William Bartram on the Southeastern Indians*. Indians of the Southeast. University of Nebraska Press, Lincoln.
Wood, Brian M., and Zoe J. Wood
2006 Energetically Optimal Travel across Terrain: Visualizations and a New Metric of Geographic Distance with Anthropological Applications. *SPIE Electronic Imaging*, January.
Wright, Henry T.
1977 Recent Research on the Origins of the State. *Annual Review of Anthropology* 6:379–397.
1984 Prestate Political Formations. In *On the Evolution of Complex Societies: Essays in Honor of Harry Hoijer*, edited by T. Earle, pp. 41–78. Undena Publications, Malibu, California.