Least Cost Analysis of Social Landscapes

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ARCHAEOLOGICAL CASE STUDIES

edited by

Devin A. White and Sarah L. Surface-Evans

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CHAPTER 14

Least Cost Pathway Analysis in Archaeological Research

Approaches and Utility

David G. Anderson

14.1. Introduction

The chapters in this book demonstrate that least cost pathway analysis (hereafter LCPA) can be an important tool for exploring the past, and they illustrate various ways it can be used. While the approach has been known by archaeologists for some time, the method has not seen widespread use, something that this book should help to remedy. My first introduction to the procedure came in the mid-1990s, when my colleague Chris Gillam and I were discussing ways to examine how colonizing populations might have moved into the Americas. We were looking for a more quantitative and replicable method than the traditional intuitive approach of drawing arrows indicating possible movement pathways on maps, however well informed these efforts might have been by consideration of factors such as physiography, glacial geology, or sea-level change (e.g., Sauer 1944). Chris suggested that we try LCPA, which he had seen put to great effect by Fred Limp (1990) a few years earlier, in an attempt to locate where in Arkansas the DeSoto expedition may have traveled, an effort to reconcile historic accounts with local archaeology and physiography. We thought the method could prove useful, although the hemispherical scale of the project was daunting, something we simplified somewhat by conducting separate analyses for North and South America.

The results, in which possible movement pathways were compared with artifact distributions and tied to demographic reconstructions of possible population growth that may have occurred after entry, were presented at the 1997 meeting of the Society for American Archaeology in Nashville and later published in *American Antiquity* (Anderson and Gillam 1997, 2000), albeit not without stirring a little controversy (cf. Moore and Mosely 2001; Anderson and Gillam 2001). The paper has since, fortunately, been widely read and variously applied, sometimes with quite serendipitous results. A primary least cost pathway for human radiation in South America, for example, ran to the east of the Andes instead of down the Pacific coast, and it has subsequently been determined that this is an area of great linguistic diversity, suggesting it may have been a location of early settlement (Dahl et al. 2011). Likewise, the movement pathways generated in North America, calculated from entry points starting in the Pacific Northwest or passing through the ice-free corridor, to accommodate the principal routes now currently believed plausible, trended to the south and east. Some morphometric characteristics of Amerind populations exhibit similar trends, suggesting initial dispersal may well have occurred in these directions (Jantz et al. 2010). While we had assumed that the pathways would lead to the discovery of new archaeological sites, since some ran through regions previously given minimal consideration, these examples

from linguistic and physical anthropological research illustrate how LCPA can sometimes lead to quite unexpected findings.

We have both continued to employ LCPA extensively in our research, Chris in South America and the Russian and Japanese Far East, and together examining Paleoindian site distributions and later Archaic, Woodland, and Mississippian period interaction networks in eastern North America (Anderson 2010:286–287; Anderson et al. 2007; Anderson, Miller et al. 2010; Anderson, Yerka et al. 2010; Banks et al. 2006; Gillam 2008, 2009; Gillam and Tabarev 2004; Gillam et al. 2007, 2008; Uchiyama et al. 2009). The work has led us to address a range of interesting questions and develop more appropriate mapping routines that take into account sea-level rise, pluvial and periglacial lake extent, and ice sheet margins in our Paleoindian research (all of which would have affected movement), and allowed us to better integrate compilations of primary data into other GIS-based applications (Anderson, Miller et al. 2010). As the chapters in this book impressively document, LCPA encompasses a wide range of possibilities, and the results of individual analyses invariably suggest new ones. In the pages that follow, I present my reactions to specific chapters and then offer a brief synopsis of some recent research on interaction networks in eastern North America.

14.2. Observations on the Chapters

A primary lesson of LCPA is that traditional site-catchment analysis (e.g., Vita-Finzi and Higgs 1970), based on the assumption that resource procurement can be monitored using movement directed to areas defined by concentric circles with radii of varying extent, does not accurately reflect the way humans made use of the landscape (e.g., Rissetto, Chapter 2; Surface-Evans and White, Chapter 1; Surface-Evans, Chapter 8). Humans are not able to fly directly between two points. They must walk and deal with terrain features such as slopes, vegetation, watercourses, and so on. Aspects of terrain such as the presence or absence of potable water or the availability of desired resources can profoundly affect the way people move over the landscape. Indeed, the analyses in this volume show that path-distance measures obtained from LCPA rarely correspond to straight-line distances; almost invariably, they are much greater, especially in areas of varied terrain (e.g., Rissetto 2009, Chapter 2). As Rissetto (Chapter 2) argues, furthermore, it is possible for our thinking about resource procurement to be dominated by assumptions about the size of catchments and the "likely" areas human groups are thought to exploit, when in reality, as his work and that of several other authors herein show, they make use of landscapes very differently. Human resource procurement "catchments" are typically anything but circular, but instead are highly irregular in shape and varied in size.

Another lesson from the contributions to this book is that LCPA can be applied to human groups in all times and places. Although Rissetto's (Chapter 2) examination focuses on resource procurement and mobility patterns associated with Magdalenian settlements in Cantabrian Spain, the artifact category employed in his and indeed several of the chapters — stone tools — are as old as humanity itself. LCPA, in conjunction with lithic raw material sourcing studies, can thus be used to examine human settlement and mobility patterns wherever such artifacts are found; similar analyses, of course, can be conducted using other resource or raw material types, meaning the approach is not limited to stone tools (e.g., Copé 2007; Gillam and Tabarev 2004; Krist and Brown 1994; Suárez and Gillam 2008).

Rissetto's analysis, dealing with late Pleistocene environments, also illustrates how changes over time in topography and resource structure and availability must be considered in LCPA. Human movement patterns were profoundly shaped by climate change over time, which at a broad scale affected sea levels, river courses, and the presence of glaciers and pluvial or periglacial lakes (Rademaker et al., Chapter 3), or at closer intervals affected crop yields, erosional patterns, and biotic resource distributions (e.g., Ullah and Bergin, Chapter 9). Another aspect of the environment to consider is how much it has been modified by humans since the period under examination, through drainage channelization, agricultural terracing, deforestation, urbanization, road building, and so on (e.g., Rademaker et al., Chapter 3; Ullah and Bergin, Chapter 9). Even within landscapes not too different from those of the present, seasonal differences should

also be considered, such as in plant, animal, or potable water availability, or flooding patterns or ice cover. River floodplains, for example, although commonly shown in LCPA to be likely movement corridors, may have been avoided during periods when flooding occurred, at least as far as foot traffic was concerned. As Livingood (Chapter 10) argues, watercourses were not just walked alongside but also traversed with boats or canoes in many human cultures; when we conduct LCPA, water travel must be considered a possibility, one that likely assumed great importance in some times and places in the past (e.g., Erlandson 2002; Jodry 2005; see also Surface-Evans, Chapter 8).

Rissetto's research (Chapter 2) also demonstrates the importance of having reliable as well as precise information on raw material occurrence, and hence the critical importance of sourcing studies. Materials occurring at point sources or with a limited distribution are ideal for LCPA, while raw materials that occur widely are likely to be of little use in such studies. Lithic reduction analyses have often been used to inform on mobility, employing assumptions about the characteristics of materials obtained from greater or lesser distances (e.g., Andrefsky 2005, 2009; Goodyear 1979; Surovell 2009); assemblage analyses combined with sourcing and LCPA can provide multiple lines of evidence toward the resolution of mobility patterns. As Rissetto also argues, however, just because humans could have used certain routes doesn't mean they did; people don't always act in optimal or rational ways, and other considerations, such as the location of other people or resources or sacred sites, or even the need for a line of sight to their destination, or as a conscious strategy to reinforce status differences may have shaped movement (e.g., Phillips and Leckman, Chapter 4; Richards-Rissetto, Chapter 7; Gould and Saggers 1985).

Even given these assumptions, LCPA, by offering direct pathways where people *could* have moved, and from the perspectives of efficiency and rationality likely *did* move, allows us to explore specific locations for evidence of their presence. That is, LCPA offers a valuable means of predicting archaeological site locations, places on the landscape where people might have been present (e.g., Rademaker et al., Chapter 3; Surface-Evans, Chapter 8). Rather than regard every point within a specific catchment radii as a likely place of settlement, we can use LCPA to assign greater or lesser probabilities, or likelihoods, of sites being present at a specific location. LCPA can thus be used to refine more traditional predictive modeling efforts, by documenting where within zones having a high probability of site occurrence people likely moved.

At a larger scale, LCPA can help us get a better perspective on seasonal or annual range mobility or extent of trade and exchange networks. Likewise, by knowing what kinds and quality of stone is within what cost distances, we can better understand the uses it is being put to. Many North American Paleoindian groups, for example, are known to have traveled great distances to obtain high-quality stone (Goodyear 1979). LCPA may be able to document whether, for highly mobile foragers, such strategies were energetically as efficient as, or at least not much more costly than, the use of closely available but lower-quality stone sources. Even if high-quality sources were "expensive" to access (i.e., with a high associated travel cost), Rissetto's analysis shows that in such cases they were typically extensively exploited when visited, presumably precisely because they were so hard to reach. That is, given the difficulty of access, it would be important to come away with as much material as possible. Given large-scale procurement, the actual costs may be no more, or not appreciably more, than those involved with the use of more readily accessible materials.

Rissetto (Chapter 2), like many of the authors in the book, offers additional means by which his analyses can be elaborated on in the future. These include using different kinds of or higher-resolution data, employing other cost/currency measures such as nutritional calories, and varying the scaling of slope or caloric costs to terrain conditions. Many of the authors also emphasize that we must take into consideration social or natural features that constrain movement, such as other human settlements, vegetation and terrain conditions, mountain passes, fords, water bodies, or even uphill vs. downhill travel (e.g., Rademaker et al., Chapter 3; White 2007 and Chapter 11). Moreover, the routes revealed through the employment of one measure, such as slope, may be somewhat to very different from those based

on other measures, such as nutritional calories/energy (e.g., Rademaker et al., Chapter 3). Output will also vary when differing factors affecting movement are employed, such as the use of watercraft as opposed to pedestrian travel, warranting care in the selection of weighting factors and the interpretation of analytical output. Indeed, another lesson from some of the chapters herein is that LCPA often yields uncertain or probabilistic results. That is, rather than consider movement as inevitably following narrow lines or pathways, we may find it more appropriate to present output in the form of buffers or corridors that encompass the likely range of variation in routes (Rademaker et al., Chapter 3; Surface-Evans, Chapter 8).

As a number of the chapters herein also demonstrate, the resolution in the landscape data (e.g., 5 m, 30 m, 90 m, 1 km) used in LCPA can be critically important (Ullah and Bergin, Chapter 9). Data at one level of resolution may be ideal for some kinds of analyses and totally inappropriate for others. For continental to hemispherical scale analyses that examine movement pathways over great distances, 1-km resolution would likely be fine, while for analyses of movement within smaller areas, such as those conducted in most of the studies reported in this book, such a scale would be far too coarse-grained. Another factor to consider when we examine movement patterns is that some intermediate locations were likely places to be visited or avoided and must be incorporated as such into LCPA. Raw materials may have been passed between major nodes in settlement hierarchies, for example, if procurement was controlled, or movement may have been designed to avoid such nodes if conflict (or smuggling) between groups was likely. Likewise, in complex societies, as Richards-Rissetto (Chapter 7) documents, movement in urban settings may have been deliberately constrained to ensure or deny access to some groups by others, as part of strategies to reinforce relationships of power, prestige, and social inequality.

Rademaker, Reid, and Bromley's examination of Paleoindian settlement and mobility patterns in southern Peru also aims to resolve trail networks that existed in the remote past. Their chapter documents the routes people may have used to bring obsidian from sources at some distance in the interior highlands to the coastal site of Quebrada Jaguay. Significantly, as in several of the other studies in this book, the authors used the LCPA results to look for archaeological sites presumably contemporaneous with Quebrada Jaguay. They located a number of previously unrecorded Paleoindian sites along the solution pathways, a process they appropriately described as "connecting the dots." Their field survey was also guided by expectations derived from optimal foraging as well as colonization and migration theory with regard to the desirability of specific settings, rather than the assumption that every place along a route would be ideal for settlement. Where the least cost routes intersected the theoretically predicted important places in the kind of hunter-gatherer settlement systems presumed to have been present, their fieldwork showed that these were indeed good places to find sites (see also Surface Evans, Chapter 8).

Rademaker et al.'s research also included ground truthing the movement pathways that their LCPA revealed, demonstrating that some were far less likely to have been used than others, due to difficult terrain features, however optimal they have looked analytically. Another important and indeed critical part of their analysis was determining the location, extent, and geochemical signature(s) of the Alca obsidian used as an archaeological marker of movement; this effort also required extensive field data collection (e.g., Rademaker 2006; Rademaker et al., Chapter 3). Lest anyone think archaeologists conducting GIS least cost analyses are sedentary types sitting in front of computers, it should be noted that the field efforts of several of the authors in this book involved checking routes and looking for sites in difficult and sometimes dangerous terrain. Fieldwork informed by theory and cutting-edge analytical tools such as LCPA, however, is a more accurate picture of the discipline than Hollywood fantasies involving treasure maps, high-speed vehicle chases, or encounters with space aliens.

Rademaker, Reid, and Bromley also make the important point that groups exploring and colonizing a landscape for the first time would likely traverse it quite differently than those who had lived within it for generations, specifically that initial exploration would be more likely to be risk-averse and conservative than optimal.

Landscape-learning theoretical arguments, they suggest, need to considered when examining the movements of the first peoples in an area (e.g., Anthony 1990; Barton, Schmich et al. 2004; Beaton 1991; Kelly 2003; Meltzer 2002; Steele and Rockman 2003). An important lesson, they note, is that colonizing routes may be non-optimal with respect to *accumulative* least cost, since colonizing populations, barring the use of scouts (sensu Anthony 1990:902–903), would have had no idea what lay very far ahead. Instead, *sequentially* optimal least cost paths, employing risk-averse behavior and segments involving efficient movement over short distances, are a more appropriate way to proceed with such analyses. In addition, while foragers likely ranged widely in their pursuit of resources and shelter, they also probably quickly learned which areas and routes to take and which to avoid. Rademaker et al.'s (Chapter 3) research, in fact, shows that some pathways into the interior never saw much if any use, since local terrain conditions were difficult and habitats for settlement or resource procurement along them were poor.

As Rademaker et al. (Chapter 3) also document, we must consider characteristics not only of the landscape in our analyses but also of the people traversing it. That is, individual movement is constrained by ability and walking speed as well as body and burden weight; likewise, group movement patterns are constrained by factors such as the presence and numbers of children or the elderly, as well as the rate of the slowest members (e.g., Gillam 2008, 2009; Pandolf et al. 1977). Additionally, just because a solution pathway may traverse one side of a valley, hunter-gathering populations may have used other parts of it, depending on where potable water, exploitable plants or animal populations, south-facing rockshelters, sacred sites, or a host of other variables occurred. Areas ideal for settlement and particularly for multiband aggregation among hunter-gatherers (e.g., Conkey 1980; Anderson 1990), as Rademaker et al. (Chapter 3) and others in this book argue, may thus have been selected for reasons other than their proximity to travel routes, although this was probably an important factor. All the chapters similarly highlight the importance of considering both cultural and environmental factors shaping movement.

Phillips and Leckman's (Chapter 4) analysis of travel routes, what they call footpaths or water transport trails in the Fort Bliss area of west Texas and eastern new Mexico, brought back fond memories of my own work on Jornada Mogollon lithic and ceramic scatters in the low desert near El Paso in the late 1970s (Anderson and Carter 1985). At the time, we were interested in finding and documenting sites, defined as concentrations of artifacts, with only minimal attention given to their relation to watercourses or larger settlements, or whether they were located along or helped to define trails. The use of GPS and GIS technology in recent decades has revolutionized how archaeologists examine past human use of the landscape and the accuracy with which we can record locational data. In particular, Phillips and Leckman argue that a nonsite or landscape archaeological survey approach, in which the locations of all encountered artifacts are precisely recorded, is far more effective at documenting past land use, including where trails were located, than the traditional archaeological focus on large, dense scatters of remains. In particular, they advocate looking for linear arrangements of sites and artifacts, particularly those leading out from larger settlements to important resources such as water, lithic or other useful raw materials, or sacred sites, as a means of reconstructing trail networks. As an aside, in my own survey work in the area, we too piece-plotted the location of all the artifacts we found, although in the absence of GPS technology the locations of the sites we worked on were only approximately determined, to within perhaps 50 m at best, and even that level of accuracy was only possible because we had aerial photographs showing the location of dirt roads and individual mesquite and creosote bushes. The artifactual data Phillips and Leckman worked with, in contrast, were at a maximum 15-m resolution, and were often much more precisely delimited.

Phillips and Leckman (Chapter 4) use archaeological as well as ethnographic evidence to argue that broken pottery often occurs along pathways leading to and from water. That is, if ceramics were used to carry or store water, broken vessels or vessel fragments would be expected along the routes to such sources, and leading away from them as well. Indeed, isolated "pot

busts" are a fairly common feature in many parts of the Southeast, where I am most familiar with the archaeological record; while breakage during transport is commonly assumed, efforts at interpretation rarely go further than this. Such data could be used to infer settlement locations or trail networks, and may also indicate activity loci where other, more perishable remains were employed and are hence not visible archaeologically, such as some kinds of plant collecting or processing. The broken pots found in these areas were likely brought there to provide water for the task groups, for drinking or for use in the processing activity. In cases in which perishable containers other than pottery were in use, as during the preceramic Archaic and Paleoindian periods in the region, examination of lithic artifacts and scatters might prove a useful alternative method of analysis. Phillips and Leckman suggest such an approach might eventually prove productive in their study area, although they argue that lithics were too widespread to be as useful for delimiting trails as pottery, which is much less commonly found away from settlements. Any artifacts found along inferred trails, of course, must also be evaluated for evidence of contemporaneity, through analyses to determine when and how long these routes were in use.

Phillips and Leckman (Chapter 4) also observe that trails do not always follow an idealized least cost pathway, due to geomorphic factors, vegetation patterns such as dense underbrush, landform features, socially constituted group boundaries, or sacred features on the landscape. They make the very good point that having the ability to follow a convenient line of sight, such as a distant mountain peak or some other prominent terrain feature, may shape where trails develop in otherwise undifferentiated terrain. They explore this possibility using viewshed analysis between sources or starting points and destinations, a technique that is seeing increasing use in modern archaeology. One important conclusion they reach is that having visible landmarks is more important in determining trail locations than following optimal routes, especially in terrain where it is possible to lose sight of such landmarks. As they put it, "intervisibility between departure and destination locations plays an important role in path making" (see also Waldron and Abrams 1999). Indeed, where prominent terrain features are being examined that likely served as aggregation loci or sacred sites in prehistory, among the first questions that should be asked is, How were such features accessed? Such analyses in turn can help us better document where the peoples who came to these locations originated.

Trail networks are well documented in the historic period, and widely inferred in prehistory, although actual landscape features created by human movement (i.e., wear patterns on resistant material, sunken roadbeds, associated debris scatters) may not always or even commonly be evident. Archaeologists often find historic sites using old maps and carefully examining the terrain along the roads or trails delimited on them. Only rarely, however, do well-delimited trails survive from prehistory, such as the Chacoan and Incan road systems. Even the exact routes of many historic period Indian trails or Anglo/European expeditions, much less the routes of earlier trail networks or of initial colonizing populations, remain partially or largely unknown (Anderson and Gillam 2000; Hudson 1990; Kantner 1997; Limp 1990; Myer 1928; Snead 2002, 2008; Tanner 1989; Ware and Gumerman 1977; Whitley and Hicks 2003). When portions of obvious trails or routes are found, however, LCPA can be used to infer where remaining segments may have been located. Likewise, when we are attempting to locate trails mapped historically, LCPA can quickly indicate whether the mapping bears any relation to reality, at least if these routes are assumed to have approximated ideal least cost pathways; such analyses can also be used to suggest places on the landscape we can look for traces of these trails. Structures or shelters, cairns, worn or sunken pathways, rock art, and the occurrence of artifacts or other landscape features such as water sources or dramatic physiographic features can all be used to infer possible routes people may have regularly used, as well as their periods of use (e.g., Phillips and Leckman, Chapter 4).

Phillips and Leckman also note that the existence of known roads or trails may constrain where archaeologists look, under the assumption that sites are likely to be located along such presumably optimally placed corridors. Less charitably, I would suggest, this is also because some archaeologists (not anyone herein!) don't wander

very far from their vehicles or venture into difficult terrain during field survey work. Indeed, given the kind of data already in many GIS systems today, we can explore such "observer" or "recorder" effects by comparing site locations and numbers with their distance from modern roadways by individual or organization. It very quickly becomes clear when conducting such analyses, as I have done on occasion out of curiosity or when overseeing cultural resource management (CRM) contracts for the National Park Service, whose survey coverage is more thorough and hence likely more reliable. LCPA can thus be used to examine the movement patterns of modern archaeologists as well as those of past populations.

What all the chapters in this book provide are clear examples of how to link LCPA with archaeological data. Indeed, some of the archaeological and locational datasets employed are extensive, such as the 14,000 15-×-15-m survey units in the Chihuahuan Desert of New Mexico used by Phillips and Leckman (Chapter 4), the nearly 600 Mayan households and larger building complexes at Copán examined by Richards-Rissetto (Chapter 7), and the 45 Mississippian mound centers in northern Georgia examined by Livingood (Chapter 10). LCPA can also be linked to other innovative approaches, such as the use of viewshed analyses by Phillips and Leckman and Richards-Rissetto (Chapters 4, 7), precipitation surfaces and other environmental data layers (Nolan and Cook, Chapter 5; Ullah and Bergin, Chapter 9), and lithic sourcing studies (Rissetto, Chapter 2; Rademaker et al., Chapter 3). One of the important things about LCPA, from a scientific perspective, is its replicability; analysts using similar methods and datasets should arrive at similar or identical mapped outcomes, something that lends confidence to interpretations based on them, as well as their application in other research. Finally, the ground truthing of output from LCPA is a standard aspect of much of this work, at least at smaller scales of analysis, further removing such research from categorization as an armchair method somehow apart from the real world of archaeology.

Kevin Nolan and Robert Cook (Chapter 5) used LCPA to determine likely trading relationships among late prehistoric Fort Ancient culture sites in the Ohio area, based on expectations from environmental modeling and theoretical assumptions about factors shaping interaction between groups. A baseline analysis employed dendroclimatologically based reconstructions of rainfall patterns at 50-year intervals from AD 800 to 1400 (after Cook et al. 2004) to determine potential crop yields and, from that, the likely political stability of agricultural populations in their study area. Such an approach was initially developed in the Southwest and has been conducted with some success in other parts of eastern North America in recent years (Anderson 1994; Anderson et al. 1995; Benson et al. 2009; Blitz and Lorenz 2006; Meeks and Anderson 2006, 2007). Employing arguments by Winterhalder (1996) and Kelly (1995) about conditions under which territorial behavior will occur, Nolan and Kelly maintain that interaction was likely to be greater between groups whose harvest returns were different, and that warfare and active boundary maintenance and defense, if not outright conflict, were more likely when harvest returns were highly variable and intercorrelated. They conducted LCPA from two major centers, SunWatch and Reinhardt, to outlying late prehistoric sites yielding certain types of remains (i.e., fauna, ceramics) and superimposed the output over the precipitation reconstructions for specific periods.

Significantly, Nolan and Cook also conducted systematic LCPA from the two principal sites to locations on the landscape at varying distances and at cardinal and intermediate intercardinal or subcardinal directions (i.e., N, NE, E, SE, S, SW, W, NW) purely as analytical controls, to show how movement may have occurred regardless of whether identified sites were present in a given direction. Use of such controlled comparisons should be standard in LCPA, and indeed in any analysis employing partial samples of either sites or landscapes, to determine whether outputs are being skewed by sample size or locations, extent of survey coverage, prevailing landscape characteristics, or some other parameter (Anderson and Smith 2003:187–188). The LCPA showed that SunWatch may have been more of a cultural nexus, or center for interaction, than Reinhardt, that is, a site whose location shaped the occurrence of other settlements and the interaction pathways between them. The results of Nolan and Cook's

analyses, while preliminary and to a large extent exploratory, as well as constrained by questions of contemporaneity between the centers and outlying sites (which the authors acknowledge), illustrate how both climate and terrain features can help shape interaction extent and direction and hence regional political conditions. The authors' analyses were also tied to prosaic but long-studied aspects of the archaeological record, ceramic stylistic variability. Not surprisingly, during periods when greater interaction was inferred from climatic conditions, greater similarity in ceramic assemblages was also noted. Although they were originally classified as different foci by Griffin (1943), the LCPA indicated that Fort Ancient sites in the Miami and Scioto valleys interacted, reinforcing more recent interpretations that these areas were closely linked and similar culturally (Brady-Rawlins 2007; Cook 2008; Nolan and Cook 2010).

Erin Hudson (Chapter 6), like Richards-Rissetto (Chapter 7), uses space syntax analysis, or what is sometimes called social space theory—the relationships between the built environment, spacing of structures and settlements, and social organization—to examine whether segregation in architecture reflected segregation in other aspects of social life (e.g., Bustard 2003; Grøn 1991, Hillier and Hanson 1984; Van Dyke 1999). Community accessibility and integration, in this approach, is measured by degree of access, which ranged from open to restricted, in part through a determination of the number of ways a room or building could be reached or entered. Hudson expanded the analysis beyond building accessibility to employ LCPA as well as line-of-sight and viewshed analyses as proxies for measuring the openness and accessibility of entire communities, in this case the Pueblo II Lion Mountain site cluster and the late Pueblo III Gallinas Springs community in west-central New Mexico. In this her work is similar to what Richards-Rissetto (Chapter 7) calls configurational analysis, albeit the latter study was conducted within an urban environment, the late Classic period Mayan city of Copán. Correlates of communities characterized by open access, Hudson argues, include high visibility, line of sight between communities, large viewsheds, and numerous routes of access, suggesting fairly egalitarian relationships. Opposite patterning would be expected in sites with restricted access, something in turn suggesting greater social inequality. Important differences between the Pueblo II and Pueblo III occupations were observed in terms of ease of access and line-of-sight networks, factors that imply that great differences also existed in the way and extent to which these communities interacted with the rest of the world. The Lion Mountain peoples, the author observes, apparently wanted to see and be seen; their sites were highly visible on the landscape, and access between sites within the cluster was open. Yet at the same time, the overall cluster was located in a setting (primarily along ridgetops) that restricted access. They wanted the world to know where they were, and possibly visit, but had some restrictions on access. In this case, high visibility did not necessarily equate with ready access and presumably a warm welcome. The Gallinas Springs site, a large, ca. 500-room pueblo, in contrast to the Lion Mountain sites, was more hidden and inaccessible, and there was evidence for internal inequalities and increased sociopolitical complexity. To understand these findings (i.e., of space syntax and LCPA within a specific area), as Hudson's work demonstrates, we must sometimes evaluate the results over much larger regions, and over time as well. During Pueblo II and Pueblo III times, for example, dramatic changes were occurring in the eastern Southwest, and the differences between the Lion Mountain and Gallinas Springs settlements appear to be part of regional trends involving population migration, relocation, and nucleation, as well as increased warfare.

Differences in access and organization linked to site setting and community layout need to be explored beyond the Southwest or Mesoamerica, where some of the major space syntax studies conducted to date by archaeologists have occurred. In the Southeast, for example, some Mississippian sites are located prominently along major waterways, while others are located in the interior along minor drainages well away from main channels (e.g., Anderson 1994:250–253; Hally 1993, 1999; Smith 1978). Why this is the case appears linked to larger regional patterns of warfare and political organization, factors that may help to explain local situations. Likewise, some sites have multiple exterior palisade or internal fence lines, as well as clusters of buildings

around discrete plazas, restricting visibility and access to some precincts, whereas other sites are more open, with single plazas and minimal internal partitioning (e.g., Anderson 1994, n.d.; Holley 1999; Pauketat 2007). Access to community buildings, such as structures atop mounds, may also be restricted, as documented ethnohistorically (e.g., Hudson 1990, 1997), although this is harder to demonstrate prehistorically. Intra- and intersite analyses of centers in the eastern Woodlands would thus appear to be another profitable area for space syntax, viewshed, line-of-sight, and (following Richards-Rissetto) configurational approaches, particularly as ever more complete community plans are appearing through excavation and remote sensing analyses (e.g., King et al. 2011).

Heather Richard-Rissetto (2010, Chapter 7) examined the distribution and arrangement of elite and commoner households at the late Classic period Mayan center of Copán in the development of an Urban Digital Elevation Model, to explore how and why the city was laid out as it was and possible patterns of movement and interaction by its inhabitants — what she calls the relationships between "site configuration and social connectivity" among people in different social classes and in different parts of the city. As the author notes, we have moved beyond simplistic analyses of such things as cardinality, the geographic orientations of the built environment, to exploring how site configuration not only enshrines cosmic beliefs but leads to the enactment of such beliefs through patterns of daily movement. We have also moved beyond simpler forms of space syntax analysis, which previously focused on architectural characteristics of individual or small numbers of buildings, often of a specific type (i.e., temples, palaces), to multiscalar analyses of architecture and terrain features to encompass entire communities and landscapes.

Configurational analyses subsume space syntax studies and include such things as examining pedestrian access to and visibility of different parts of a community (Hillier 1999; Hillier and Hanson 1984; Hillier et al. 1993; Preziosi 1979; Richards-Rissetto 2010). They have the advantage of considering space in three rather than two dimensions, the traditional axial space syntax approach, and, as used by Richards-Rissetto, the natural as well as the built environment. The layout of the Mayan city of Copán was examined, and "integration values," or movement costs, were calculated based on whether spaces were readily accessible and visible or not and whether people were more or less likely to walk to or through them. The analysis, significantly, also evaluated the impact even minor differences in topography had on movement as facilitators, barriers, or effectively neutral. Richards-Rissetto's research was directed to determining how differing social groups within Copán and over the surrounding landscape — including both presumed elites and commoners (whose social status was inferred in part based on the types of structures in which they lived) — were integrated within the society as a whole.

GIS technology is enabling since it allows travel costs between one location and all others to be quickly calculated, with terrain and cultural factors weighted as appropriate, providing a numerical measure or value of integration. Such analyses offer replicable measures of integration and accessibility, given as the average (or alternatively the total) travel costs between a specific building or location and whatever subset of other buildings or landscape features the researcher wishes to examine. Richards-Rissetto provides exceptional detail on her methods at Copán, offering a useful guide for researchers interested in conducting similar analyses in other locations, which could be any urban setting anywhere, or indeed any human community. Her study also employs multiple structure types and spatial scales of analysis from the urban core to the surrounding countryside, and generates insights and patterning not always seen at specific levels of resolution.

As Richards-Rissetto's work shows, the results of LCPA are not always as expected. Elites, for example, while living in places where access was spatially restricted, were nonetheless in settings that were among the most visible and had the greatest accessibility to all other members of society, in part because of their often central or strategic locations in the community. They were thus the most connected of the people within Copán, at least in terms of their ability to see or access all other residents, although it is doubtful whether they actually visited many commoner

residents. Commoners, in contrast, rarely had ready access to many other members or classes of society, and while they might be able to access the center, their entry into elite precincts was restricted. The difference between commoners and elites was thus reflected, in part, by who could see and hence be seen by the most other members of society. The analyses also demonstrate that some structure/household types were likely misclassified by earlier researchers, at least in terms of who may have lived in them, given their locational characteristics as reflected in calculated integration values. Configurational analyses thus offer an independent means of evaluating site or building classifications, and can be used by themselves or in tandem with other measures to generate such classifications. They can also be used to determine whether social hierarchies were present, as well as document the relative amount of access or control subgroups may have had, based on whether specific ranges of integration values fell within discrete groupings. Such analyses can also be conducted with subsets of site types within different settings, as was done at Copán between the urban core and hinterland, to determine whether the degree of integration differed between the two areas.

Conducting such configurational analyses diachronically, Richards-Rissetto also suggests, would be one way to evaluate whether Copán society became more stratified over time, something indicated by the fact that more and more elites established residences in and near the urban core (Fash 2001). Too often research employing LCPA is synchronic in approach, which may not reflect how movement patterns or settlements themselves changed over time. Configurational analyses, Richards-Rissetto's research demonstrates, are thus useful for the exploration of a wide range of archaeological questions, from establishing site and structure classificatory systems, to evaluating whether social hierarchies were present (both overall and how they operated in different parts of the landscape), to investigating how measures of social hierarchy and integration changed through time. If ancient cities were generative arenas of change, or crucibles of interacting factions in which early state formation occurred, as scholars such as Yoffee (2005:62) have argued, configurational analyses offer a means by which such groups might be recognized and their actions documented.

Sarah Surface-Evans's contribution (Chapter 8) was directed to testing whether Shell Mound Archaic (SMA) sites in the Falls region of the Ohio River were "positioned" within the landscape to access and control key resources. The analysis, through a direct comparison of the two procedures, shows the value of LCPA/corridor cost-surface modeling as opposed to more traditional site-catchment analyses (see also Rademaker et al., Chapter 3). Using cost-weighted corridor analyses as opposed to direct or linear distance pathway analyses, Surface-Evans evaluated how movement was constrained by terrain and other environmental factors. Indeed, Surface-Evans, like others in this volume, as noted previously, provides an effective demonstration that the use of fixed catchment radii as a means of documenting how people accessed the landscape must be replaced by analyses considering the "cost" of access or movement over the landscape. Site-catchment analyses may still prove useful for providing first approximations of the kinds of resources and activities that may have occurred within a specific distance of a given point, but they can no longer be considered an effective way of examining how humans made use of landscapes. Indeed, all such fixed measures linking distance with resource procurement zones, what are sometimes called foraging radii, should be replaced with cost surfaces, or what Surface-Evans calls "cost catchments."

Reconstructing hypothetical travel pathways between shell mound sites and examining river travel and overland corridors, Surface-Evans demonstrates that the SMA sites in her sample were highly accessible to each other. This in turn suggests a high degree of interaction or affinity between the peoples creating these sites. An important part of her research, presented at the conference that led to this volume (Surface-Evans 2009a, 2010) but not reported here, was something also noted by other researchers in this book, that LCPA can be used to suggest areas where previously unknown and undocumented sites might be located on the landscape (see also Rademaker et al., Chapter 3). In particular, she suggests that sites were likely to occur in locations where travel paths converged, or intersected,

what she calls "high traffic areas" (Surface-Evans 2009a, 2009b, 2010). The lesson for researchers using LCPA is not just to look along trails for new sites, or where trails pass by or near areas likely to facilitate interaction — such as settings rich in exploitable food resources or prominent physiographic features on the landscape — but also to examine areas where different trails may have intersected.

Isaac Ullah and Sean Bergin (Chapter 9) combine agent-based and landscape process modeling with LCPA to simulate human interactions with the environment, specifically at four hypothetical village locations in the Penaguila Valley of eastern Spain. Their analyses employ high-resolution 5-m DEM data, a fine-grained scale unimaginable even a few years ago, yet one now feasible given advances in computational capabilities. As the authors note, while much LCPA employs an accumulative, or what they call a "cellular automata movement model," in reality almost all human movement is based on some prior knowledge of what lies ahead, save for the very first representatives of colonizing populations entering an area. *Sequentially* optimal LCPA (Rademaker et al., Chapter 3) is thus preferred. Ullah and Bergin's analyses appear decidedly complicated, but as they argue, such a comprehensive approach is critical to realistic simulation; Occam's razor (*lex parsimoniae*) is not a principle that offers much comfort or utility when one is investigating complex phenomena. Significantly, the authors consider dynamic aspects of the landscape in their modeling, such as vegetation cover and soil fertility, erosion, and deposition, as well as changes over time in affected human populations. Explicit details about how the analyses were conducted are provided, with reference to computational algorithms as well as programs. Their analyses, as they explicitly state, are designed to assist archaeologists in understanding "the effects of village location on agropastoral economy, village population, and landscape change," serving as a "hypothesis generator against which to test data from the archaeological record." The procedures should prove useful for examining the establishment and impact of initial Neolithic farming populations in the region, about which much is already known (e.g., Barton, Schmich, and James 2004; Barton, Bernabeu, Aura, and Molina 2004). I look forward to analyses linking the modeling with the local archaeological record, and the new understanding such an approach will undoubtedly provide.

Patrick Livingood's (Chapter 10) reevaluation of David Hally's (1993, 1999, 2006) classic work on Mississippian mound center spacing in northern Georgia is an elegant demonstration of the value of applying new analytical procedures to old datasets and observations developed from them. Livingood uses LCPA to evaluate whether cost-distance measures should replace the straight-line geographic distance measures Hally arrived at twenty years ago linking the spacing and political organization of complex societies in the region. Hally (1993) documented two major groupings of sites, mound centers located within 18 km of one another that he argued were likely within the same polity, and centers much farther away (>32 km) that were assumed to be within different polities. Happily, Livingood's work, using travel time as opposed to distance, both supports and improves on the original model, revealing a clear bimodal grouping of centers comparable to that found by Hally. In Livingood's analysis, the break came between those centers within six hours' travel time of each other (one way) and those beyond this range. Livingood looked at both overland and waterborne travel, and examined factors influencing the rate of travel, such as the delays involved in crossing rivers and whether travel was on trail or off trail. Livingood's analyses, significantly, include measures derived from real people traversing the landscape, in this case from historic records of canoe trips down the Mississippi. He also argues the need to consider the occurrence of swamps, logjams, falls, and shoals; river ways were not the unimpeded routes we sometimes think they were, but were often more difficult to move along than overland routes. As he notes, we also need to consider movement by water as anisotropic in nature, more difficult in one direction than another, as anyone who has paddled a canoe with and against a current can testify. Water travel appears to have been important in North America as far back as the Paleoindian era (Jodry 2005) and is thus a form of movement that LCPA should incorporate wherever possible.

I can sympathize with the extensive computational time Livingood noted (in his original presentation) that it took to complete his analyses. The pathway analyses Chris Gillam and I conducted in the mid-1990s evaluating Paleoindian colonization routes over the Americas took massive amounts of time to complete with the technology then available — half a day or more, given the millions of 1-km grid cells we were employing for each continent — and problems such as power fluctuations often literally short-circuited analyses in midstream, requiring us to start over again many times. Happily, LCPA is now much more routine and, with improved computers and software, nowhere near as time-consuming as it once was. If we are to develop and evaluate ever more sophisticated models of past human behavior, however, we are going to need to continue to refine our theoretical approaches, our field data collection efforts, and our computational algorithms.

The final case study in the book, by Devin White (Chapter 11), examines prehistoric and historic trails in the Western Papaguería region of the U.S. Southwest, showing how they were both transportation networks and a means of local and regional integration. As in the analyses from the eastern part of the Southwest by Phillips and Leckman (Chapter 4), water, useful raw materials, and settlement locations strongly dictated trail network occurrence. White's study explores an array of research questions using multiple forms of analysis, including remote sensing, field survey, and GIS-based predictive modeling. Predictive modeling was used to generate efficient movement pathways between settlements and water sources, which were then compared with trail segments located using imagery followed by on-the-ground examination, or truthing. This proved a highly effective means of locating past trails and reconstructing larger networks from surviving segments. The analysis was facilitated by the presence of landscapes favoring trail preservation (i.e., desert pavement) coupled with fairly minimal recent human disturbance of the terrain in the study area. Finding archaeological signatures of trails in more densely vegetated environments, as some of the chapters in this book demonstrate (Nolan and Cook, Chapter 5; Surface-Evans, Chapter 8), is a major and still largely unresolved challenge facing archaeologists (Phillips and Leckman, Chapter 4). White's methods for examining imagery to resolve terrain types, and from there possible trail segments, should have widespread utility around the world, and ideally not just in sparsely vegetated environments.

White's use of movement coefficients weighted by terrain characteristics, such as whether one was walking on hard ground or loose soil (e.g., Pandolf et al. 1977; Santee et al. 2001), or upslope or downslope, or the weight of the load being carried — together with his consideration that different types of trails would be likely to occur given the type and scale of interaction and the kinds and dating of the sites and activities being connected — exemplifies the type of diachronic, multivariate, and multiscalar LCPA done today. Indeed, his research demonstrates that single variables, however important they may seem (i.e., the location of water sources in a desert environment), probably only rarely account for all the variation observed. As White, and indeed many of the contributors to this volume show, modeling interaction requires consideration of not just energetic efficiency but other factors such as "sacred/ritual" considerations that bind local communities; wherever possible, we should consider entire networks rather than focus on local segments or areas.

14.3. Conclusion

The chapters in this book offer innovative and thoughtful applications of LCPA, and the future looks bright for this form of analysis in archaeology. Indeed, I expect that the research examples presented here will help generate many new studies. In recent years, with Chris Gillam and other colleagues, I have continued to conduct LCPA, looking at changes in the location of trail networks over time in eastern North America, during both the prehistoric and early historic eras (Anderson et al. 2007) (Plates 13 and 14). These analyses, which look at the flow of materials into and out of major prehistoric centers such as Poverty Point in Louisiana, the Scioto River valley of southern Ohio, and Cahokia in Illinois, during the Late Archaic, Middle Woodland, and Mississippian periods, respectively, demonstrate rather conclusively that road or trail net-

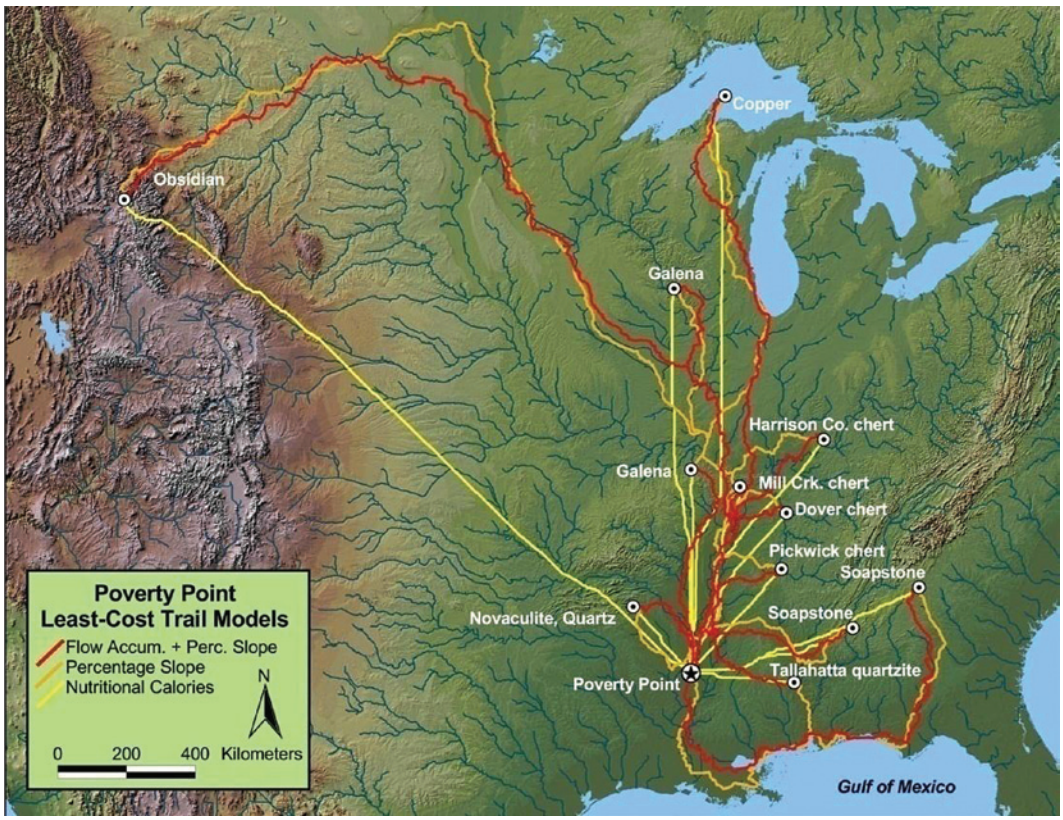

PLATE 13. Raw material acquisition routes into Poverty Point, Louisiana, ca. 3200 cal yr BP (image courtesy J. Christopher Gillam, from Anderson et al. 2007).

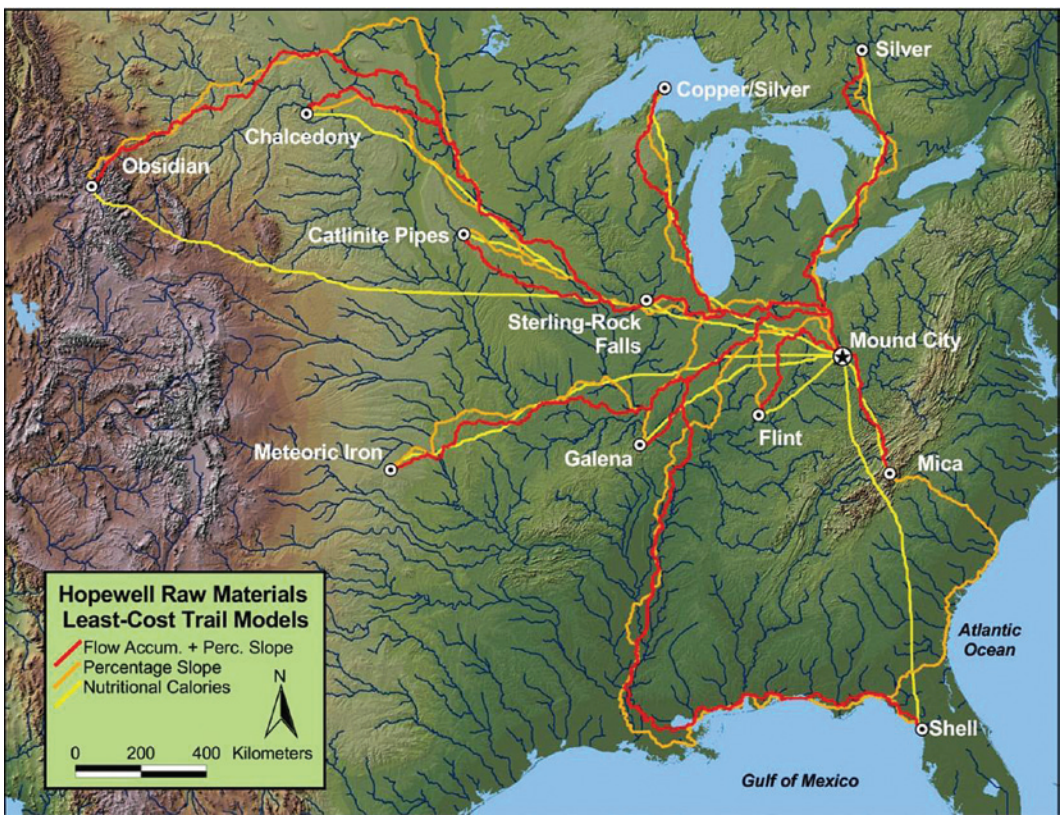

PLATE 14. Raw material acquisition routes into the Scioto River valley of central Ohio, ca. 1800 cal yr BP (image courtesy J. Christopher Gillam, from Anderson et al. 2007).

works are shaped as much by regional political geography—the location, size, spacing, and influence of centers on the landscape, and their relationship to one another—as by physiography or natural resource occurrence. Aspects of the so-called natural environment are certainly important: transportation routes clearly make use of mountain passes and fords, follow river valleys, and often lead to locations where large numbers of people can make a living from the bounty of the surrounding landscape. But trail networks in eastern North America also changed over time. When the Poverty Point site was at its height ca. 3200 years ago, people apparently came and went from northeastern Louisiana in large numbers, probably in much greater numbers as a proportion of the regional population than do so today, although New Orleans, to the south, is a good example of a likely modern-day equivalent. In later times, movement corridors changed, as first Hopewellian and then Mississippian centers rose and fell on the landscape. Only rarely were centers or large numbers of people located in many of these areas previously. In the early historic era, in turn, many trading paths as well as Indian trails led to previously all-but-ignored places on the eastern seaboard such as Charlestown, St. Augustine, and Jamestown (Myer 1928; Tanner 1989). Modern railroad and interstate corridors in turn were built to tie new manufacturing and population centers together, sometimes following older routes, but sometimes not.

Formal roads might be replaced by less formal trails, or vice versa, when environmental or political conditions changed. These analyses of regional interaction provide important lessons: first, not all roads or trails were straight, even though that is perhaps the view permeating popular interpretation, and second, neither ideologically significant directionality nor transport efficiency were the sole explanations for the location of pathways. Third, as White (Chapter 11) demonstrates, while long-distance trail networks may have spanned an area, where sites were located often shaped local patterns of movement or routes that trumped efficiencies at larger scales. Fourth, even when a site was reduced in influence or abandoned, its presence (at least in some instances) may have continued to shape movement. In the Southeast, for example, major Mississippian period mound centers such as Etowah and Moundville underwent periods of reduced or changed use, from large towns to more vacant centers with smaller resident populations; both, however, were apparently still considered important by surrounding populations (Knight and Steponaitis 1998; King 2003). Some sites that were once major centers were, in fact, consciously avoided because there were prohibitions against visiting them. In the Southwest, the perception of Chaco Canyon among some contemporary Puebloan peoples, as a place where bad things happened, as Steven Lekson (1999, 2008:198–200) has suggested, may help explain why the site was avoided by later peoples. In the twelfth century, however, as Kantner (1997, 2004, Chapter 13) and others have classically documented, many very real roads led to Chaco.

A final major lesson these LCPA examples from prehistoric eastern North America provide, subsuming the others, is that interaction networks must be considered diachronically. That is, they are profoundly shaped by changes in regional political geography, which must be carefully monitored. All roads may have led to Chaco, or to Rome, or to Poverty Point or Cahokia when these centers were at their height, but when they declined, the roads leading to them often did so as well, as did the relationships between the peoples they connected. Interaction networks, like the centers themselves, apparently took appreciable time to create, maintain, or—once lost and if conditions permitted—reconstitute. Often this occurred in new locations, necessitating new trails. Portions of these new routes may have reappeared in the same places where older trails ran, but this was typically when movement was in the same direction or when it was constrained by physiographic features such as river courses, fords, or mountain passes. Population distributions and political conditions were more important in shaping movement, and these changed over time (Anderson 2010:286–287), something archaeologists need to consider when conducting LCPA.

LCPA can also evaluate the efficiency or lack thereof of the routes early explorers took across the landscape. One of the first least cost pathway analyses conducted in archaeology, by Fred Limp (1990), examined the route of a portion of

Hernando DeSoto's expedition in Arkansas in 1541. As noted, it inspired the work Chris Gillam and I did later in that decade examining possible colonization pathways in the remote past (Anderson and Gillam 2000) and offers a means by which more recent expeditions, military campaigns, or trade routes can be potentially reconstructed in the absence of precise historic documentation. Least cost pathway analysis, as the chapters in this book illustrate, has much to tell us about how, why, and where peoples move around on the landscape, both in the past and in the shaping of our current world.

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