REPORTS

PALEOINDIAN COLONIZATION OF THE AMERICAS: IMPLICATIONS FROM AN EXAMINATION OF PHYSIOGRAPHY, DEMOGRAPHY, AND ARTIFACT DISTRIBUTION

David G. Anderson and J. Christopher Gillam

GIS-based, least-cost analyses employing continental scale elevation data, coupled with information on the late glacial location of ice sheets and pluvial lakes, suggest possible movement corridors used by initial human populations in colonizing the New World. These routes, demographic evidence, and the location of Paleoindian archaeological assemblages, support the possibility of a rapid spread and diversification of founding populations. Initial dispersal, these analyses suggest, would have been most likely in coastal and riverine settings, and on plains. The analyses suggest areas where evidence for early human settlement may be found in North and South America. In some cases, these areas have received little prior archaeological survey. The method can be used to explore patterns of human migration and interaction at a variety of geographic scales.

En análisis del costo mínimo basado en el Sistem de Información Geografica (GIS) empleando datos en la escala de elevación continental, acoplado con información sobre las posiciónes de las extensiónes de capas de hielo y los lagos pluviales durante el periódo glacial finale, sugiere los possible corredores de movimiento que las poblaciónes humanos iniciales probablemente usaron en la colonizión del Nuevo Mundo. Estas rutas, evidencia demográfico, y la localización del asambleas arqueológicas Paleo-Indios, sostiene la posibilidad de una desparramar rápido y la diversificación de las poblaciónes fundadoras. La dispersión inicial, los análisis sugieren, fueron más probable en las locales costeros y ribereños, y también en llanos. Los análises sugieren áreas donde evidencia de la colonización por los humanos antiguos puedo ser encontrado en America del Norte y del Sur. En unos casos estas áreas han recibido poca evaluación arqueólogicas. Este método se puede usar para explorar los modelos de migración y interacción humano en una variedad de escalas geográficas.

This paper explores movement corridors of colonizing populations in North and South America, using data on terrain conditions, site and artifact distributions, and demographic arguments. Our goal is to suggest routes, rates, and reasons for the initial population dispersal, that is, to explore how the process of New World colonization occurred. The digital continental-scale data sets that make this type of analysis feasible have only recently become available. Given the ease and utility of this approach, however, we expect that these kind of analyses will become common in the years ahead. The data and methods are particularly applicable to the examination of population movement, interaction, and exchange at a range of scales.

How people arrived in the Americas has been the subject of research and speculation for centuries. As early as the 1590s, Acosta postulated the movement of peoples from northeast Asia, and many similarly well-reasoned migration scenarios have been proposed (e.g., as summarized in Bonnichsen and Steele 1994; Fiedel 1999, 2000; Fladmark 1979; Haynes 1964; Huddleston 1967; Meltzer 1983, 1989a, 1994, 1995). The possible dispersion routes taken by these peoples once they arrived—the subject of this paper—also has received considerable attention. Most introductory textbooks on New World archaeology have some variation of a map showing arrows radiating south from Alaska, representing the presumed Late Pleistocene expansion of colonizing

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groups. Probable pathways of initial entry include along the Pacific rim and, assuming a Late Wisconsinan entry, through the ice-free or Alberta corridor. Highly sophisticated, multidisciplinary research efforts have explored the likelihood that one or more of these entry corridors were used, with much of the effort directed to delimiting periods when such routes were open or easily traversed, had the biotic resources necessary to support human populations and, most importantly, have archaeological remains of an appropriate age (e.g., as summarized in Borden 1979; Erlandson and Moss 1996; Fladmark 1979, 1983; Frison and Bonnichsen 1996; Haynes 1969; Jackson and Duk-Rodkin 1996; Mandryk 1992, 1996a, 1996b; Mandryk et al. 2000; Yesner 1996; Zutter 1989). This remains a fruitful area for research, as the dates and movement corridors associated with initial human entry remain unknown.

The Paleoindian literature is replete with analyses at the continental or hemispherical scale directed to reconstructing patterns of population dispersal, and conducted employing demographic, ecological, genetic, geographic, linguistic, and physical anthropological data sets (e.g., Bonnichsen and Steele 1994; Faught 1996; Fladmark 1979, 1983; Greenberg et al. 1986; Lorenz and Smith 1996; Meltzer 1989a:472–475, 1995; Torroni et al. 1994; Wendorf 1989). This research has typically been directed to reconstructing the numbers, dates, and likely directions of major migrations, estimating rates of movement, and delimiting areas favorable or unfavorable for settlement.

A number of excellent locality and regional analyses of possible movement corridors or areas of initial settlement or activity also exist. These have emphasized biotic communities, major physiographic features such as coastal zones, river valleys and mountain ranges, or the locations of animal trails, salt licks, and lithic raw material sources (e.g., Anderson 1990; Dincauze 1993a, 1993b; Erlandson and Moss 1996; Frison 1991; Gillam 1996 a, b; Hoffecker et al. 1993; Judge 1973; Spiess et al. 1998; Tankersley 1985, 1990, 1991, 1997). The co-occurrence of early sites along glacial and pluvial lake margins in the Midwest, Southwest, and Great Basin has been widely noted (Deller and Ellis 1988; Ellis 1994; Ellis and Deller 1998; Ellis et al. 1998:155–158; Judge 1973; Shott 1986; Willig 1996; Willig et al. 1989), for example, as has the occurrence of numerous early assemblages along the major river valleys of eastern North America (Anderson 1990; Dincauze 1993a, 1993b; Mason 1962; Williams and Stoltman 1965). Movement along waterways or lake margins is usually inferred. Analyses of stone tool sources and distributions have likewise long been used to infer Paleoindian movement patterns (e.g., Gillam 1996b; Goodyear et al. 1990; Meltzer 1989b; Tankersley 1990, 1991, 1994; Wilmsen and Roberts 1978). These studies are typically subregional or at best regional in scope, however, and tend to beg the question of how initial populations arrived in or moved on from the areas in question.

Other studies of the colonization process have focused on *reasons* for movement, or general patterns of movement. An extensive literature exists on the tethering effect of lithic raw material sources on early populations; that is, that group movement over the landscape may have been greatly shaped by the need to first find and then periodically return to high-quality stone sources (e.g., Daniel 1998; Gardner 1983; Gillam 1996b; Goodyear 1979; Morrow 1996). Likewise, the deliberate movement of colonizing populations into new areas has been described as driven by a "high technology" foraging adaptation focusing on large animals, and hence group movement toward favorable resource patches (Kelly and Todd 1988). That Paleoindian movement was shaped by the need to maintain information and mating networks also has been explored (Anderson 1995; Hayden 1982; Wilmsen and Roberts 1978). As our knowledge of stone sources and Late Pleistocene biotic resource structure improves, these arguments should be increasingly helpful in delimiting possible routes and areas used by colonizing populations.

There have been comparatively few studies at the continental or hemispherical scale, however, directed to resolving *specific* routes taken by colonizing peoples—that is, which particular rivers, passes, lake margins, or other landscape features were likely used by colonizing populations? Where were major barriers to movement located? What landscape features may have predisposed movement? While there have been precursor studies, the availability of GIS technology and global environmental data sets offer, for the first time, the opportunity to explore these questions quantitatively at a high level of resolution and precision.

An early study attempting to reconstruct specific colonization routes employing geographic data at a continental scale was by Carl Sauer (1944)(Figure

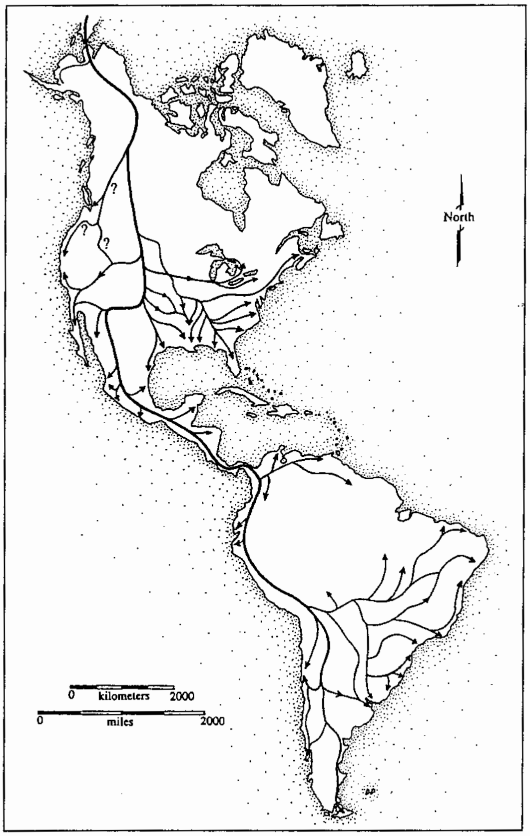


Figure 1. Carl Sauer's inferred Paleoindian colonization routes through the Americas (adapted from Sauer 1944:555).

1). Sauer examined regional physiography, glacial extent, and biotic resource structure, as it was then known, and assessed their impact on population movement. Plains, basins, areas of pluvial lakes, and major river valleys were hypothesized to be major movement corridors in the interior of North and South America. Sauer (1944:554–556) explicitly ruled out the Northwest Coast as an entry corridor to all but the most skilled of navigators because of its rough and glaciated terrain. Movement along the Pacific Rim of South America also was considered extremely unlikely, given the rough topography over much of the area, and the coastal deserts in Peru and Chile (Sauer 1944:557–559). Instead, movement to the east of the Andes was postulated, an inference supported by the current analyses.

Perhaps the best-known hemispherical-scale analysis of New World colonization is Martin's overkill, blitzkrieg, or wave-of-advance model (Martin 1973; Mosimann and Martin 1975; Whittington and Dyke 1984). Strictly interpreted (and as Martin's own illustrations suggest), Martin's model assumes population movement into virtually every environment simultaneously by peoples moving outward along a rapidly expanding front. This movement was fueled by demographic pressure brought on by a postulated extremely high population growth rate of 3.5 percent, and a hunting strategy directed to large, presumably patchily distributed game animals, necessitating frequent group movement.

Hemispherical scale simulation modeling of Paleoindian colonization has been the subject of increasing attention in recent years, with research directed to delimiting the effects of paleovegetation, geographic barriers, and differing habitat categories on population growth and spread (Steele et al. 1996, 1998; Young and Bettinger 1995). Mountain ranges and great lakes, when considered as barriers, profoundly redirect movement patterns, as can differences in regional resource structure and habitat type, with more favorable terrain selected for, traversed, and settled more rapidly than less productive terrain (Steele et al. 1996:226). Importantly, the demographic studies associated with all of this research indicate that rapid landscape filling, on the order of one to at most a few millennia, occurred regardless of the constraints imposed (Young and Bettinger 1995). The geographical analyses associated with this research are, however, somewhat coarse-grained, with data cells typically on the order of 50 by 50 km in extent, and containing primarily categorical data. This results in the masking of topographic or other variation within the landscape. Newly released geographic data sets now make it possible to conduct such analyses at much finer scales, and employing more precise environmental data.

Analytical Methods

The analyses that follow assume that people would have likely taken easier rather than more strenuous routes when moving across the landscape, particularly if these routes gave them a reasonable expectation of finding food and other useful resources. Accordingly, ice sheets and mountain ranges—areas where slopes are steep—likely would have acted as barriers, while shorelines, plains, and river margins—where slopes were gentle—likely facilitated movement. The utility of such an approach in archaeological research has been demonstrated in a number of case studies, albeit at a much smaller geographic scale. Least-cost analyses have been used, for example, to reconstruct a portion of the route of the DeSoto expedition in Arkansas (Limp 1990), the movement of caribou below Paleoindian lookout sites in the Great Lakes area (e.g., Krist and Brown 1994) and, most commonly, the probable foraging areas around specific sites (i.e., Ericson and Goldstein 1980). Commercial, engineering, and architectural applications of this type of approach are common (e.g., Turner 1978).

The geographic analyses consisted of the calculation of least-cost pathways between presumed points of initial human entry into North and South America and 45 early archaeological sites selected to provide coverage to most parts of each continent, and for their familiarity to Paleoindian researchers. The sites were chosen for heuristic purposes only, to show how different areas could have been reached by colonizing populations, and are not assumed to be contemporaneous.[1] The spatial analyses described here were conducted with Arc/Info Grid, a raster-based GIS toolkit marketed by the Environmental Systems Research Institute Inc.[2] Geospatial data were obtained from a variety of sources. The primary data consisted of the 30-arcsecond digital elevation models (DEM) of North and South America in the GTOPO30 Global 30 Arc Second Elevation Data Set (EROS Data Center 1998). These data were developed by the U.S. Geological Survey in cooperation with the Defense Mapping Agency (1989, 1990, 1992), and can be downloaded from the Internet. The GTOPO30 data set consists of elevation values at a 1-km sampling density covering the entire land surface of the planet. The data set for the Americas consists of over 40 million points, one per square kilometer, with each value corresponding to the mean elevation of the specific cell.

Details on how the GTOPO30 DEM data values were generated are described at length in a number of sources (e.g., EROS Data Center 1998; Gesch 1994; Gesch and Larson 1996; Verdin and Jenson-Greenlee 1996). The 30-arc-second DEM data set is being rapidly refined and expanded, with the HYDRO1k data set now coming on line encompassing data on slope, aspect, and a series of watercourse measurements (Verdin and Jenson-Greenlee 1996; Verdin 1997). The primary elevation data is available for almost all parts of the world, and in some areas, notably over much of the United States and parts of Europe, even finer-grained elevation data is available at approximately 30-m resolution or better. Comparable global data sets at the same resolution encompassing hydrology, vegetation, and other environmental measures also are under development using satellite imagery, and these data sets should eventually all be linked together (e.g., Eidenshink and Faundeen 1994; Verdin and Greenlee 1996).

The DEM data are transmitted in raster-image files using a latitude-longitude coordinate system. Elevation values for each data point are in meters above mean sea-level; vertical accuracy ranges are from approximately ± 30 to 160 meters at the 90-percent confidence level, depending on the source of the primary data, with much of North America falling at the lower end of the range, and South America at the upper end (Gesch 1994; Gesch and Larson 1996). In the analyses that follow, the latitude-longitude data were converted to a Sinusoidal projection, which has the benefit of being both equal-area and equidistant along the central meridian and parallels. Other projections, such as a Simple Conic or Lambert-Azimuthal Equal-Area, could have been used (Steinward et al. 1995). However, distance or area distortions would have been greater at the geographical extremes of the data with an alternative projection.

Supplementing the DEM data, Pleistocene glacier and lake boundaries at ca. 12,000 B.P. were obtained from published maps at a variety of scales (e.g., Dyke and Prest 1987a, 1987b; Hollin and Schilling 1981; Pielou 1991; Smith and Street-Perrott 1983) and were added as barriers to terrestrial movement. Current sea-level positions were used, and shorelines served as barriers—that is, ocean crossings more than 1 km, the resolution of the data set, were not permitted. Hemispheric-scale bathymetric data exists that can provide a measure of the topography and margins of the continental shelf at various times in the past, such as during periods of lower sea-levels and controlling for isostacy (National Geophysical Data Center 1988; Smith and Sandwell 1997). This data is currently available only at a 5-arc minute or ca. 10-km horizontal resolution, however, precluding useful merging with the current terrestrial 1-km scale GTOPO30 DEM data set.[3] Given the current resolution, most offshore topographic features would either not be represented or be coarsely delimited at best, with the result that least cost paths would tend to favor the coastal zone due to characteristics of the data, rather than of the actual landscape itself. Archaeological site locations were obtained from numerous sources, using latitude and longitude data where available, and estimation from fine-scaled maps wherever possible. Drainage information was obtained from the Digital Chart of the World (Danko 1992; Defense Mapping Agency 1989, 1992), to aid in georeferencing (i.e., accurately locating and digitizing) the glacial, lake, and site data sets. Since landscape features such as lake levels, river channels, or ice sheet margins can change appreciably over time, appreciable effort must be made to control for this potential source of error in the data and analyses.

The DEM data set provides a powerful analytical representation of the earth's surface, and can be mathematically manipulated to derive slope and aspect data (Burrough 1986:39–56; McMaster and Shea 1992:99–112). Slope data were used to generate a "roughness" layer which was the basis for least-cost path analyses. Slope values were derived from the DEM using a smoothing operation known as the average maximum technique (Berry 1993:147–49; Burrough 1986:50; Tomlin 1990:119–23). The process involves a moving 3 x 3 neighborhood of cells (each 1 km^2 cell and its 8 adjoining neighbors) that determines the slope of the center cell in turn. This 3x3 window of cells is necessary to transform the elevation data to slope, essentially the same as calculating a local derivative on a plane (Star and Estes 1990:162). The roughness layer simply represents a grid of percent slope values multiplied by itself (slope x slope) with high values representing terrain that is difficult to traverse and low values representing terrain that is easily crossed.

The determination of least-cost movement paths is essentially a "spreading" operation acting upon the roughness layer (Tomlin 1990:134–149). The wavefront expanding from the starting cell (A) is impeded by the values of the roughness layer. For all cells containing values, a relative cost of movement is thus established from the source. A least-cost path is established by defining a destination cell (B) from which the minimum cumulative cost path is derived by tracing back through the cost surface to the source cell (A). The current analyses generated binary or cell-by-cell (linear) least-cost routes between various selected starting and ending points. Other types of output are also possible, such as "fuzzy" maps, where zones of equal movement probability or cost can be delimited.

It is important to remember that when considering the ease of movement across a landscape we are more interested in the travel-cost of movement between two points than the actual distance between them. Colonizing populations would have had no idea what lay ahead of them, beyond the comparatively short distances likely covered by scouting or hunting parties. That is, intentionality or awareness of what lay ahead cannot be assumed. The first people to arrive in the area of what is now the western United States and Canada, however they entered, certainly had no idea land extended for another 13,000 km (8,000 mi) to the south, or that vast mountain ranges, plains, lakes, and rivers lay before them. Therefore, it is plausible to assume that movement occurred, at least in part, in relation to minimum cost rather than minimum distance.

Results of the Least-Cost Analyses

Four least-cost analyses were conducted, encompassing pathways beginning (1) in western Alaska and passing though the ice-free corridor, (2) at the mouth of the Columbia River along the Pacific Northwest Coast, (3) at the Isthmus of Panama running south, and (4) at the Isthmus of Panama running north. In each analysis, an initial solution was run from the starting point to the farthest point on each continent that was of archaeological interest, specifically the Isthmus of Panama for the first two analyses, the Los Toldos site in southern Argentina for analysis (3), and the west-central coast of Alaska for model (4). This initial solution is represented by the bold line in each figure. Secondary routes, or pathways to specific archaeological sites, always started from some point along the initial solution pathway, and are shown as lighter lines. The isolated black dots at the ends of each pathway are the locations of these sites.

The four analyses are based on the location of glacial ice sheet and lake margins as they were across the hemisphere at approximately 12,000 B.P., or around 12,050–11,850 cal. B.C. (calibrated using Kitigawa and van der Plicht 1998; Stuiver et el. 1998:1066). We wish to stress, however, that this method is not dependent on any specific date for human entry. It is a relatively straightforward matter to adjust the locations of ice sheet and glacial lake margins and other physiographic features as they were earlier or later in time (assuming reasonably accurate data exists, of course), and rerun the analyses.

All of the movement pathways were profoundly shaped by the occurrence of level terrain, something that is not at all surprising given the analyses are based on terrain roughness characteristics. The resulting solutions, or movement pathways, however, are sometimes appreciably different than expected from traditional approaches emphasizing the importance of coastlines, river valleys, or lake margins; least-cost solutions can involve at least some overland (i.e., upslope) travel. Whether they are ultimately verified, these solutions provide a valuable perspective on the colonization process, and areas to look for early sites.

Ice-Free Corridor Entry (Analysis 1)

The ice-free corridor is the best known and, at least for much of the past 40 years until quite recently, was the most widely accepted route for Late Pleistocene human entry into the areas south of the ice sheets (e.g., Haynes 1964, 1969). This corridor is assumed to have opened some time after 14,000 B.P., although the date at which it may have been habitable by human populations may have been appreciably later, perhaps 12,000 B.P. or even later (Mandryk 1996a; Mandryk et al. 2000). The actual starting point for the analysis (Figure 2) is on the coast of western Alaska near Norton Sound, to explore movement through Alaska and down the ice-free corridor itself. Interestingly, the least-cost pathway solutions to all destination points south of the ice sheets, including destinations on or near the Pacific coast, moved to the north along the coast and then south down the MacKenzie River. The Northwest Coastal route to the south, along the Pacific rim, which is highly dissected, was never a least-cost solution, even when Canada was left deglaciated. This does not mean, of course, that it may not have been the route of human entry, particularly by people using watercraft. It only means that there were easier ways to travel by land and reach the unglaciated south.

The solution pathway proceeds up the Yukon River, overland to Kotzebue Bay, and then along the northern coast of Alaska to the mouth of the MacKenzie River. From there the route runs south down the MacKenzie and overland through the unglaciated ice-free corridor. The route skirts the western margin of glacial Peace Lake, and then bears to the east, skirting the southern margin of the Laurentide ice sheet and its associated glacial lakes, entering the eastern High Plains near the North Dakota-Montana border. The primary pathway proceeds to the south until it intersects the Missouri River, from whence it moves south along the river valley to the confluence with the Mississippi, and from there south to the Gulf of Mexico. The route to Panama follows the nearly level coastal plain and shoreline of eastern Mexico to the Isthmus of Tehuantepec, at which point it crosses over to the Pacific coast and proceeds south along that coast to Lake Nicaragua, at which point it recrosses overland along the San Juan River, and from there runs down the Atlantic coast to the Panama/Columbia border.

The side branches show how movement away from the main solution pathway into other parts of North America could have occurred. Entry into the central Plains and on into the Pacific Northwest proceeds in an east-to-west manner, from the Missouri to the Platte and across the northern Great Basin, through what would have been a dense region of pluvial lakes in the Late Pleistocene. Movement south from the mouth of the ice-free corridor, or directly west along the ice margin, the traditional pathways to the Central Plains and Pacific Northwest illustrated on many maps of inferred colonization routes, is not indicated. The routes into the southern Plains and the Southwest into southern California are also from the east, from the Missouri River system and the Gulf coast of southern Texas. Only when the starting point is in the Pacific Northwest, as noted in analysis (2) below, are at least some north-to-south movement corridors generated, and even then the main pathway runs east-west.

The least-cost solution pathway for entry into the eastern Great Lakes region proceeds overland across central and northern Illinois and Indiana, instead of up the Ohio River as might be expected. Early Paleoindian sites are found along glacial lake margins in this region (e.g. Deller and Ellis 1988; Ellis and Deller 1998; Shott 1986), and movement into this zone would have been facilitated by local topography. The pathway for the settlement of the remainder of Eastern North America proceeds, in general, along the Gulf and Atlantic coasts, although entry into the midsouth is from the central and lower Mississippi Valley. Greater emphasis on coastal margins than along interior river valleys, the traditionally inferred entry corridors (e.g., Anderson 1990; Mason 1962; Williams and Stoltman 1965), is indicated, suggesting the continental shelf may have been a major movement path-

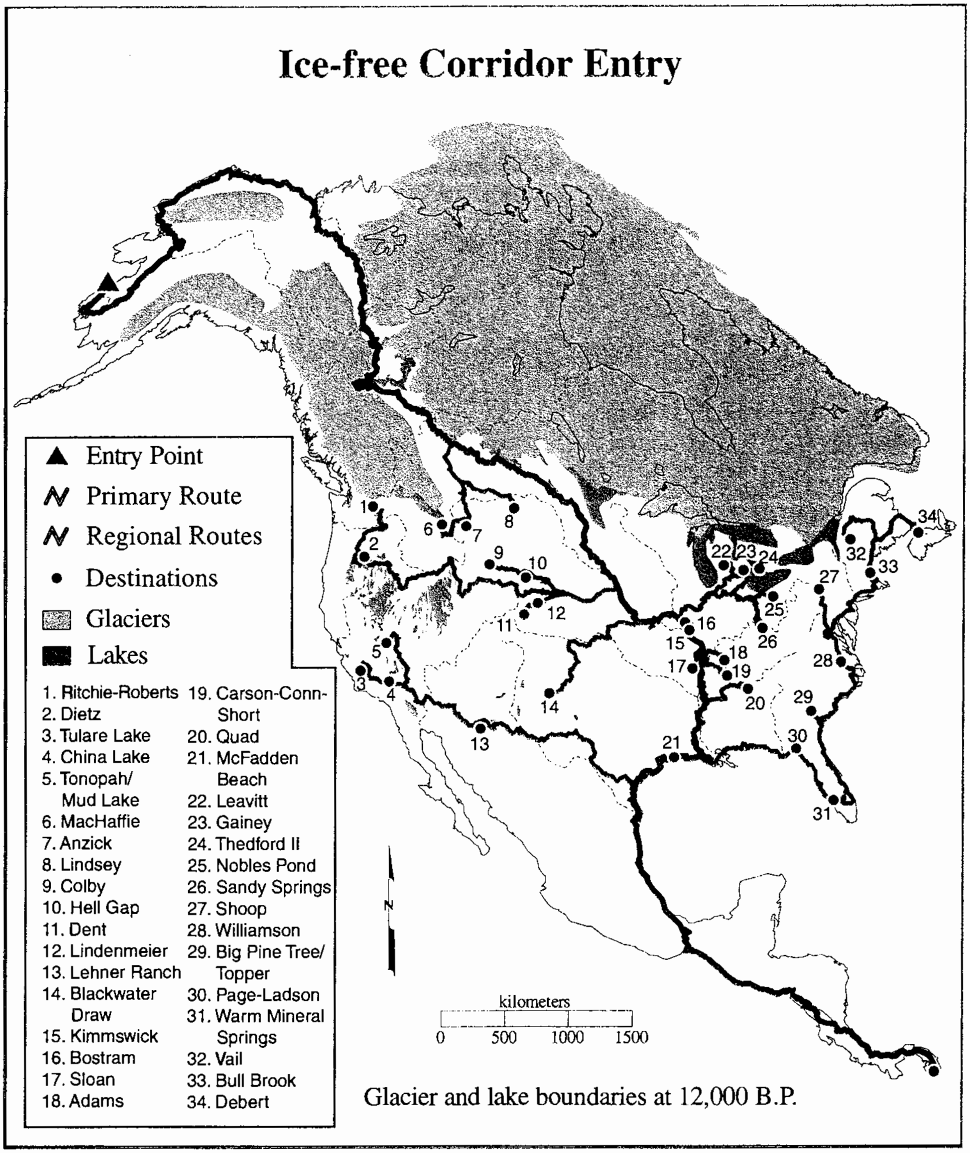


Figure 2. Ice-free corridor entry least-cost solution pathways for North America (Analysis 1).

way for these early populations (Faught 1996).[4]

Northwest Coast Entry (Analysis 2)

Human entry along the Pacific rim is the alternative, and increasingly popular route of choice for the introduction of people south of the Canadian ice sheets. If the area of the ice-free corridor was closed or inhospitable for long periods of time during the Late Pleistocene, a Northwest Coastal route is in fact the only plausible way people could have entered during those periods, short of long-distance ocean voyages. The starting point for this analysis is the mouth of the Columbia River (Figure 3). How people actually entered the Pacific Northwest is not explored, since (as the first analysis indicated) overland movement south from Alaska along the coast is not an optimal solution. Some use of watercraft, these analyses suggest, may have been needed to make a Northwest Coastal entry route attractive. Paleoindian populations certainly appear to have used watercraft, although direct evidence is currently lacking (e.g., Engelbrecht and Seyfort 1994; Josenhans et al. 1997).

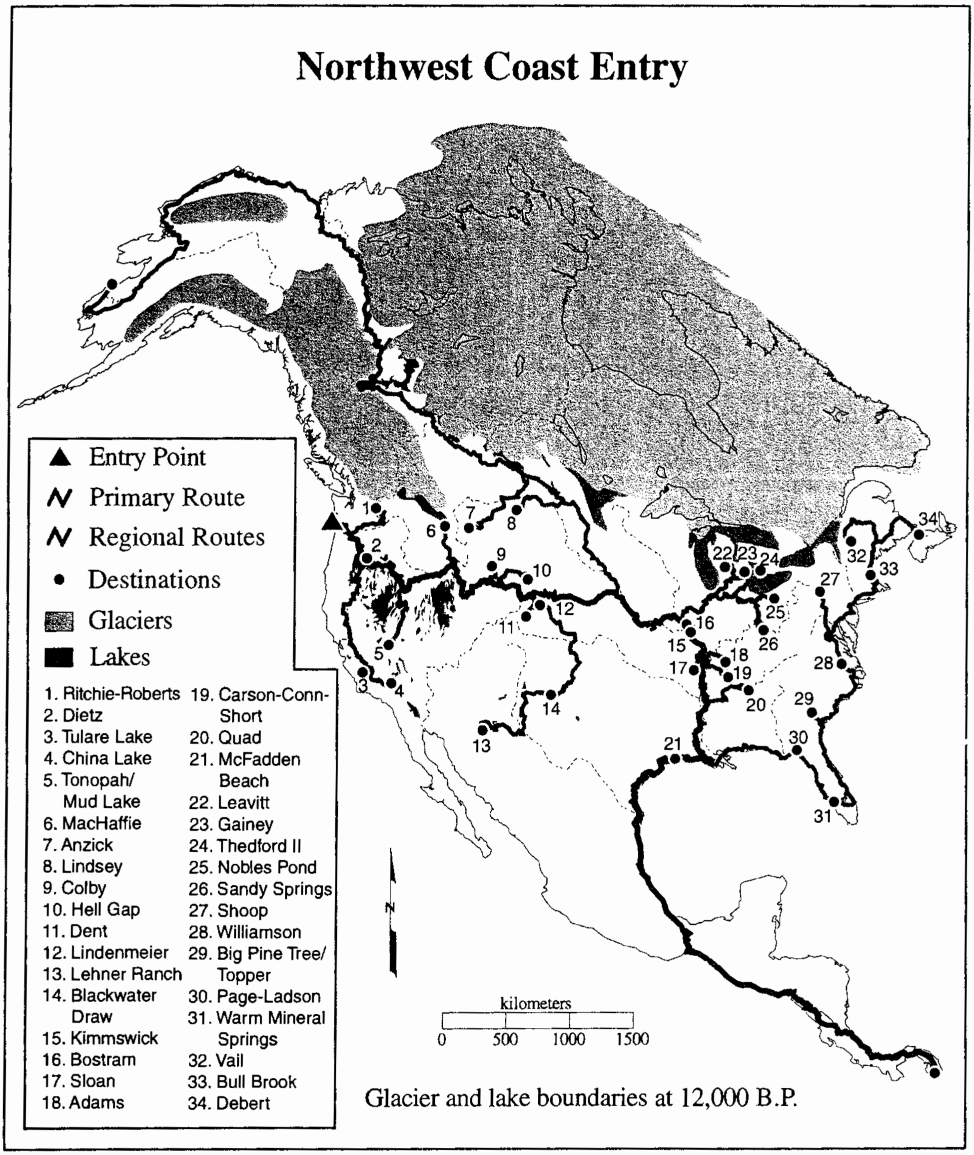


Figure 3. Northwest coastal entry least-cost solution pathways for North America (Analysis 2).

The primary least-cost pathway runs west to east across the Plains, and from the central Missouri River valley southward duplicates the results of Analysis 1 for movement both to the south and into eastern North America. Where the two models differ is in movement through the western half of the continent. Greater north–south movement is indicated, both in the far west and in the southern and central Plains. The route leading to the Tulare Lake and China Lake sites proceeds south down the Sacramento and San Joaquin valleys, for example, while the least-cost pathway to the Tonopah/Mud Lake locality skirts the eastern side of the Sierra Nevada mountains. Both routes pass through areas characterized by numerous pluvial lakes in the Late Pleistocene, and hence may have been particularly attractive countryside for early populations (Willig et al. 1989).

The secondary least-cost pathway to the Blackwater Draw and Lehner Ranch sites in this analysis runs north to south from the central Platte, with an appreciable jog to the east and then back to the west. The differences in the routes to these (and other) sites in Analyses 1 and 2 are due to the different starting points; when the two primary routes intersect, in this case at the Missouri-Platte confluence, the pathways to destinations not already reached and in the same direction of movement proceed in an identical fashion. The analyses highlight the importance of the point of initial entry in shaping the subsequent dispersal of population, including the relative timing and direction of movement into new areas. In particular, for populations entering the western half of the continent from the Pacific Northwest, the analyses indicate greater north– south movement may have occurred, while populations entering the region from the north-central part of the continent (i.e., in the vicinity of the ice-free corridor) may have traveled a considerable distance to the east and south before moving west. Analysis 2 also illustrates how movement from south to north along the ice-free corridor could have occurred, given initial human entry in the Pacific Northwest. Such analyses might prove useful to the examination of "back migration" hypotheses for the occurrence of fluted points in Alaska—that is, that these artifacts reflect a movement of fluted point using peoples from south to north (Clark 1991; Yesner 1996).

Isthmus of Panama Moving South (Analysis 3)

Figure 4 presents the results of the least-cost solution for movement into South America from the Isthmus of Panama. Most strikingly, the primary pathway does not follow the coastline for more than a short distance, but instead swings south near Caracas, just east of Lake Maracaibo and the Cordillera de Merida, and proceeds through the central part of the continent well to the east of the Andean chain. While movement in the interior of South America may seem implausible, it must be remembered that in the Late Pleistocene some of this region may have been in grassland, scrub forest, or savannahs (Clapperton 1993; Whitmore and Prance 1987). Portions of the interior of South America may have been characterized by conditions similar to those encountered by early peoples on the Great Plains, and a similar way of life and movement may have been practiced. Tropical rain forest was present in the western Amazon basin, however, so movement may have been difficult (Colinvaux et al. 1996). If the route taken by initial populations was east of the Andes, much of it lies in areas that have received minimal archaeological examination for early sites (e.g., Ardila Calderon 1991; Borrero 1996; Politis 1991).

Secondary routes to major sites do tend to follow major rivers and coastlines, although coastal movement south of Guitarrero Cave in Peru to sites like Tagua-tagua or Monte Verde in Chile is not, as Carl Sauer suggested many years before, an optimal pathway. Instead, the least-cost solution runs through the interior of the continent to the vicinity of northern Bolivia, where it cuts to the west and south and eventually reaches the coast.[5] Movement along the southern Pacific coast is ultimately forced by the presence of north–south trending ice sheets along major portions of the Andes, blocking east–west movement across much of the southern cone. Interestingly, and likewise perhaps counter to expectations, the analysis suggests that initial colonization of the Amazon basin may have proceeded from the headwaters to the mouth, rather than the other way around. In passing, the irregular zig-zag pattern of a portion of the secondary route across the central Amazon to Monte Alegre and Puedra Furada is due to problems with the elevation data in this area (Bliss and Olsen 1996); these problems do not appear to have compromised the analysis, however, as the irregularities are evident only over a short distance.

Isthmus of Panama Moving North (Analysis 4)

A final analysis examined movement north from the Isthmus of Panama (Figure 5), since it is possible (albeit not indicated by our analysis) that the initial settlement of South America was by peoples who skirted the Pacific coast and never realized, until appreciably later, that Panama was a good place to cross over and get to another coastline to follow. Alternatively, populations moving down the Pacific rim may have crossed the isthmus and moved north into eastern North America. Based on similarities between fishtail point forms in South America and in the southeastern United States, in fact, it has been suggested that people may well have moved north out of South America at an early date (Faught and Dunbar 1997; Stanford 1991:9). A Pacific rim colonization scenario followed by movement north from South America has increased relevance in light of the recent general acceptance of a ca. 12,500 B.P. date for Monte Verde (Dillehay 1997; Meltzer et al. 1997; Taylor et al. 1999; however, Fiedel 1999:107 argues that a date of 11,800–12,000 B.P. for this site may be more likely). As we shall see, demographic modeling indicates that it is almost impossible to have peoples in southern South America at this time period

Figure 4. Isthmus of Panama entry least-cost solution pathways for South America (Analysis 3).

without appreciable evidence for their presence in areas to the north (in both continents), unless movement followed the coastline, or took place in portions of the interior that have received minimal examination to date, or employed a truly remarkable leapfrogging pattern.

This least-cost solution is almost identical to that from the mouth of the ice-free corridor (Analysis 1), save for slight differences in the routes to a few sites in the central Mississippi Valley, and to Blackwater Draw. It should be noted that site distributions from a south-to-north colonization of eastern North America could be almost identical to those resulting from a north-to-south route. Site *assemblages* might differ, however, particularly in the incidence of lithic raw material types, if movement consistently trended in one direction. That is, sites created by groups moving south might be expected to yield more northern materials, while sites created by groups moving northward might be expected to yield more materials from areas to the south (see also Tankersley 1994). Given sufficient, well-dated early sites, and careful stylistic and sourcing analyses, it eventually be possible to reconstruct rates and directions of popula-

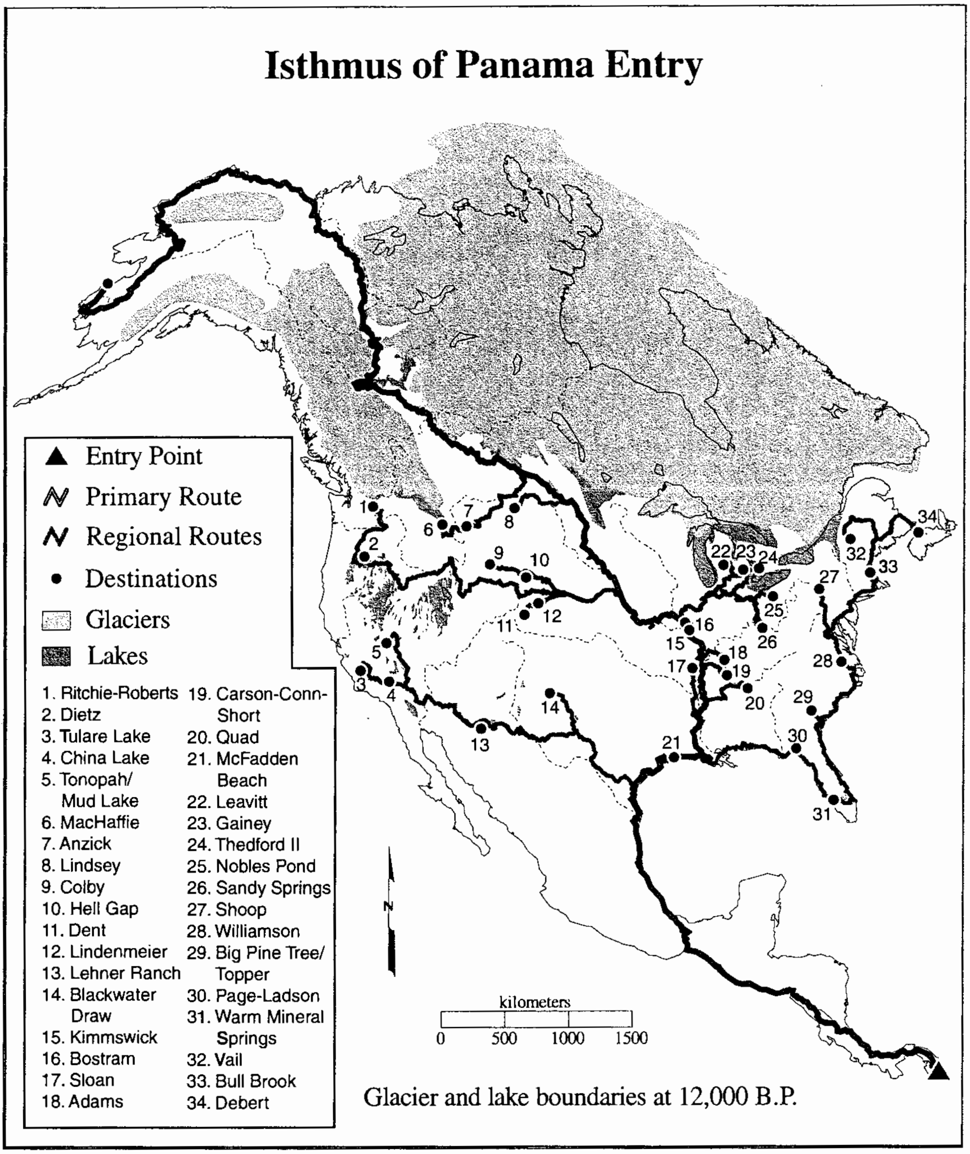


Figure 5. Isthmus of Panama entry least-cost solution pathways for North America (Analysis 4).

tion dispersal over time (i.e., Morrow and Morrow 1999; Whitley and Dorn 1993:628–633).

Implications from Demographic and Archaeological Analyses

Demographic and archaeological evidence can be used to evaluate these least-cost pathways, as well as suggest rates and movement patterns along them. In particular, characteristics of forager mobility, technological organization, and reproductive rates can be used to suggest possible parameters for population movement and growth (e.g., Birdsell 1957; Hassan 1981:201–203; Martin 1973; Mosimann and Martin 1975; Whittington and Dyke 1984). Critical variables to consider in such analyses include founding population size, average group size, population growth rate, group size when fissioning occurs, and group range. Once modeling parameters are programmed, it is easy to adjust the values for each variable and run great numbers of analyses. Besides delimiting the time needed to traverse the least-cost pathways, information about total population size, number of separate groups, and total area occupied by all groups can be generated simultaneously for each year the model is running. Such data can provide important clues or perspectives on the colonization process. Analyses were conducted assuming founding populations of 25, 50, or 175 people; group sizes of 25 or 50 people, population doubling every 100, 134, or 268 years; group fissioning when group size reached 50 or 100; and group ranges of 25, 50, 100, 200, or 400 km in diameter.[6] One such analysis is shown in Table 1.

The group and founding population size values (25, 50, 175) employed in the various analyses that were run represent typical minimum and maximum forager band sizes, and the minimum number of people that has been suggested are needed to form a reproductively viable population (Kelly 1995:209–213; Wobst 1974:163). Population doubling intervals (100, 134, and 268 years) were selected to encompass average modern forager growth rates (.5 percent per year, or doubling every 134 years; Hassan 1981:137–142); a value half that (.25 percent per year, or doubling every 264 years); and a somewhat higher than optimal rate, with doubling every 100 years, selected because the unexploited New World may have favored rapid human population growth, and because 100 years was a convenient round number. Group fissioning was assumed to occur when local population reached twice the average group size; in actuality, fissioning may have taken place well before these values were reached, given the subsistence, information management, and conflict resolution stresses such numbers of people likely placed on these groups (Johnson 1982; Moore 1981). Group range values (25, 50, 100, 200, and 400 km in diameter)—the area occupied by a group until it fissioned, which in these analyses means from roughly one to three centuries—were somewhat arbitrarily chosen, although these values encompass fairly well the upper and lower annual ranges of modern foraging groups (Kelly 1995:111–132). Long-term land-use patterns, of course, likely encompassed much larger areas (e.g., Binford 1983).

The results of these analyses indicate that New World could have been traversed and filled up fairly quickly, something Mosimann and Martin (1975) demonstrated over two decades ago, albeit using much higher population growth rates (3.5 percent per year), exceeding even those of most modern agricultural populations. By the most conservative scenario, employing a founding group size of 25, population doubling every 268 years, fissioning when group size reached 50, and a group range 25 km in diameter, the entire land surface of the New World could have been filled up by groups in 4,556 years, with population expanding from 25 to over 3 million; the actual time would have been appreciably less, given areas covered by ice sheets or under water, or in desert or jungle conditions that may have been avoided. With the other variables held the same and population doubling reduced to every 134 years, the time drops to 2,278 years, while reducing the doubling time further, to 100 years, fills the hemisphere in about 1,700 years (Table 1). As group range or initial founding population size is increased, and population doubling time decreased, these times drop markedly; the most liberal scenario fills the hemisphere in about 600 years. Assuming population growth rates were comparable to modern foraging populations, just over 2,000 years would be needed to fill the hemisphere. Roughly similar spans, supporting rapid landscape filling, have been obtained in a number of analyses exploring this problem (e.g., Belovsky 1988; Hassan 1981:201–203; Martin 1973; Mosimann and Martin 1975; Steele et al. 1996, 1998; Whittington and Dyke 1984:458; Wobst 1974:153; Young and Bettinger 1995).

Of course, these types of analyses have a number of obvious problems. The assumption that unoccupied territory would be available for each new group, for example, is unrealistic (unless long-distance movement is assumed), since initial groups themselves continue to double and quickly come to be surrounded by their offspring. Likewise, it is unrealistic to expect that population growth rates or territory/mobility ranges could have been the same everywhere in the varied environments making up the New World (e.g., Dillehay 1991:251, 253). Finally, demographic rates in Late Pleistocene populations may have been lower than observed among contemporary foragers, particularly if a "low-technology" or generalized foraging adaptation was in place instead of the "high-technology foraging" adaptation assumed to be characteristic of terminal Pleistocene Clovis and related colonizing adaptations (c.f. Butzer 1988, 1991; Kelly and Todd 1988). A low growth rate is, in fact, inferred for much of the period of early human settlement in Australia, the only other continental landmass for which colonization by anatom-

Table 1. Hypothetical Colonization Scenario, Illustrating the Rapidity with which the Americas Could Have Been Filled.

Elapsed Time in Years	Founding Population = 25 people	Number of Separate Groups	Area Occupied Range Size 25 km Diameter	Area Occupied Range Size 50 km Diameter	Area Occupied Range Size 100 km Diameter	Area Occupied Range Size 200 km Diameter	Area Occupied Range Size 400 km Diameter
0	25	1	491	1,963	7,850	31,400	125,600
100	50	2	982	3,925	15,700	62,800	251,200
200	100	4	1,964	7,850	31,400	125,600	502,400
300	200	8	3,928	15,700	62,800	251,200	1,004,800
400	400	16	7,856	31,400	125,600	502,400	2,009,600
500	800	32	15,712	62,800	251,200	1,004,800	4,019,200
600	1,600	64	31,424	125,600	502,400	2,009,600	8,038,400
700	3,200	128	62,848	251,200	1,004,800	4,019,200	16,076,800
800	6,400	256	125,696	502,400	2,009,600	8,038,400	32,153,600
900	12,800	512	251,392	1,004,800	4,019,200	16,076,800	64,307,200
1000	25,600	1,024	502,784	2,009,600	8,038,400	32,153,600	*
1100	51,200	2,048	1,005,568	4,019,200	16,076,800	64,307,200*	*
1200	102,400	4,096	2,011,136	8,038,400	32,153,600	*	*
1300	204,800	8,192	4,022,272	16,076,800	64,307,200*	*	*
1400	409,600	16,384	8,044,544	32,153,600	*	*	*
1500	819,200	32,768	16,089,088	64,307,200*	*	*	*
1600	1,638,400	65,536	32,178,176	*	*	*	*
1700	3,276,800	131,072	64,307,200*	*	*	*	*

North America (unglaciated): 24,398,000 square kilometers
South America (unglaciated): 17,793,000 square kilometers
Total Area: 42,191,000 square kilometers
* exceeds available land area in the New World

Founding Population Size = 25 people, Group size = 25 people
Population Doubles Every 100 Years
Group Fissioning Occurs when Group Size Reaches 50
Group Range Diameters = 25 km, 50 km, 100 km, 200 km, and 400 km

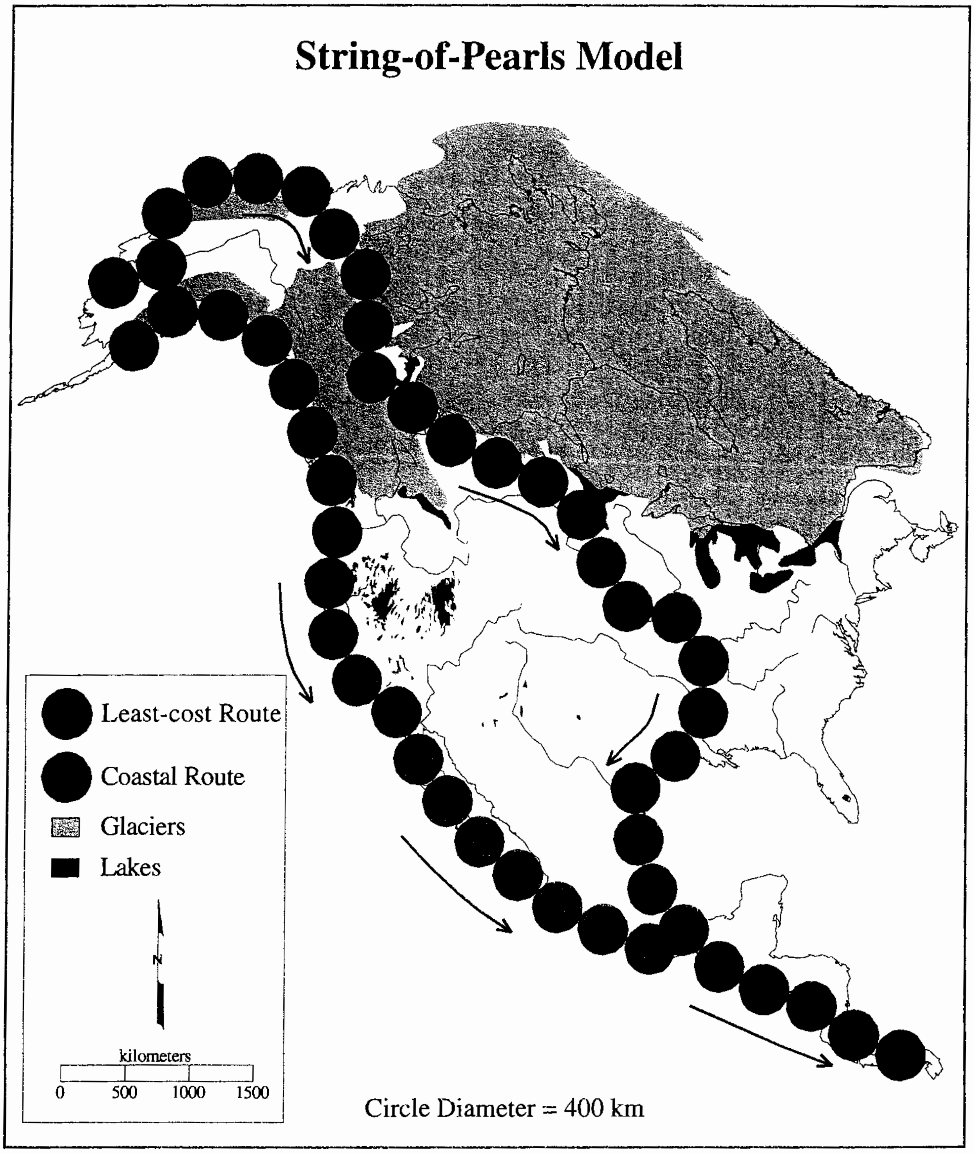


Figure 6. String-of-pearls model for Paleoindian colonization and movement through North America.

ically modern human beings has been explored archaeologically (Beaton 1991:218).

Even given these caveats, it is clear that large numbers of people could have been scattered over appreciable parts of the New World within a span of no more than one or two thousand years. The dramatic increase in the visibility of sites after 12,000 B.P. has, in fact, long been assumed to reflect expansion shortly after initial entry. When sites are found at or near the extremities of migration pathways that predate this time, such as Little Salt Springs, Warm Mineral Springs, and Page-Ladson in Florida (Clausen et al. 1979:611; Dunbar et al. 1988) at just prior to 12,000 B.P., or Monte Verde in Chile at ca. 12,500 B.P. (Dillehay 1997), however, the questions that immediately arise are how people got there and the nature and locations of antecedent and contemporary populations.

Two simple migration scenarios can be used to explore these questions—here called the "string of pearls" and "leap-frog" models (Figures 6–8). These analyses proceed by estimating group ranges at

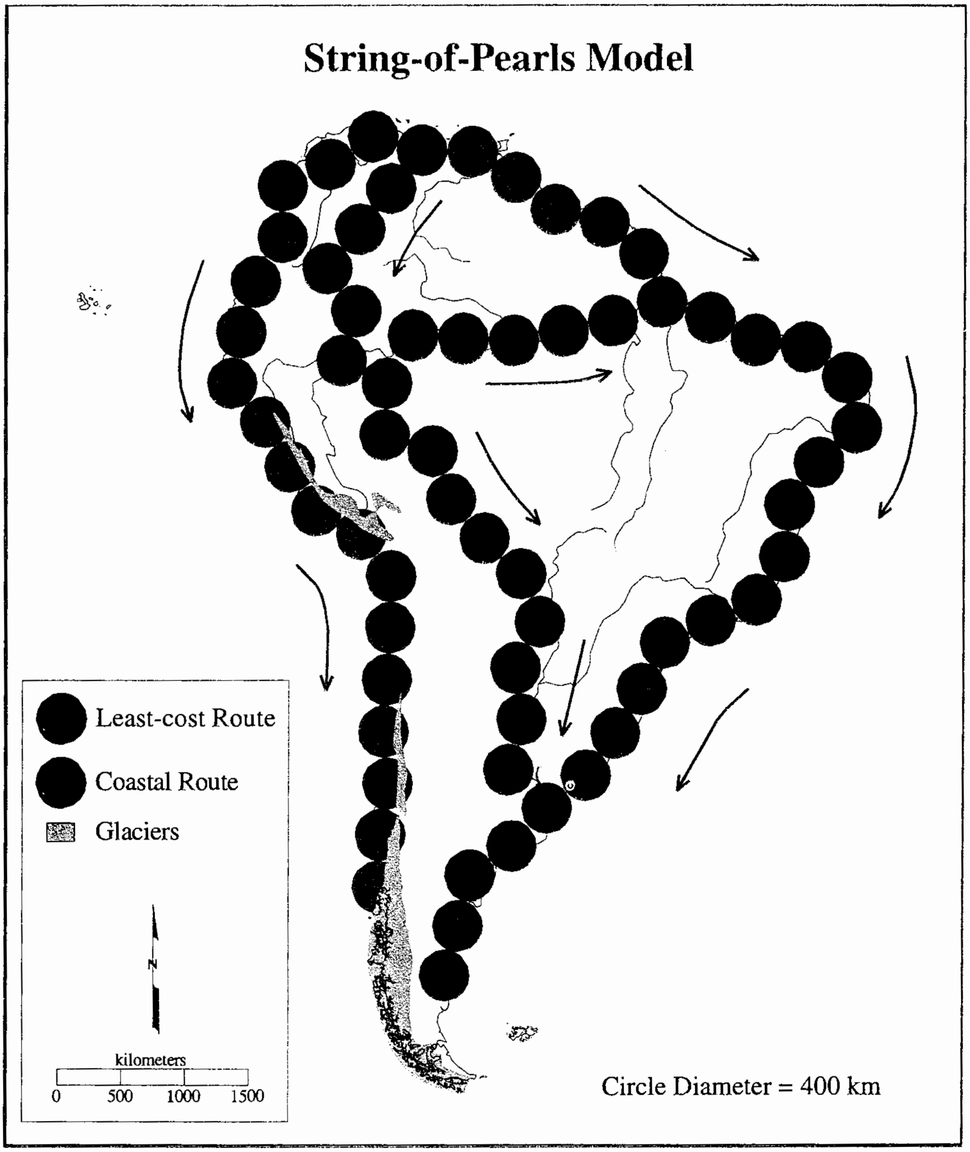


Figure 7. String-of-pearls model for Paleoindian colonization and movement through South America.

annual, generational, or longer scales, and using these values to delimit circular group "territories." To this is added the assumption that, given population growth, once group size reaches a certain level, fissioning occurs, and either the parent or daughter group relocates into a new area. Adjusting population growth rates and range sizes, it is possible to generate rough measures of the time needed to traverse the least-cost pathways, at least for the string-of-pearls model, where movement into an adjacent territory is assumed. The leap-frog model, in contrast, proceeds by assuming groups move appreciable distances upon fissioning (Anthony 1990:902–903).

Using the string-of-pearls movement scenario, and assuming group ranges were a generous 400 km in diameter, movement down the ice-free corridor along the primary least-cost pathway would have required 30 territories or "pearls" to span North America, with another 24 required to reach the southern cone of South America, at Los Toldos (Figures 6 and 7). Assuming fissioning occurred as often as once a century, it would still take over 5,000 years

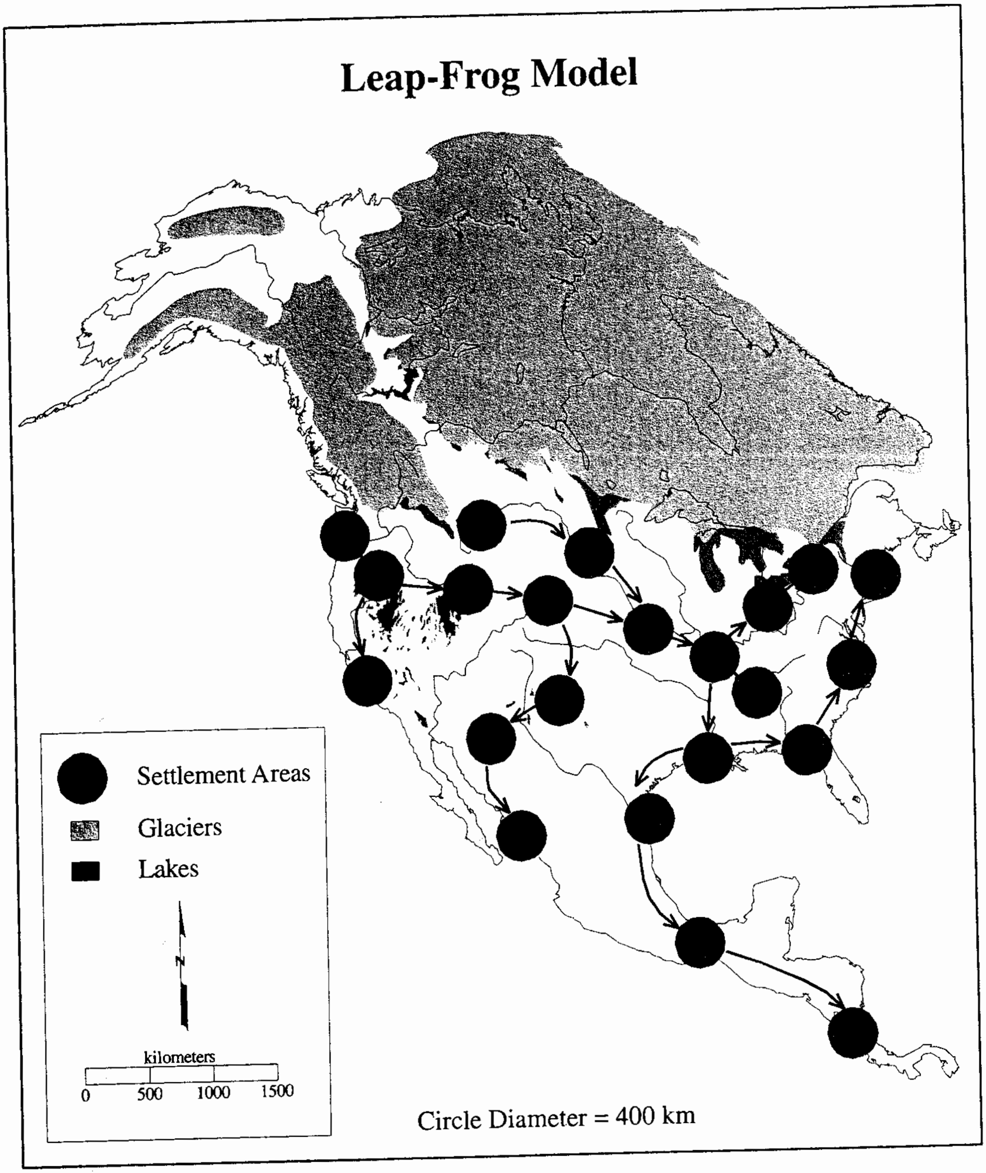
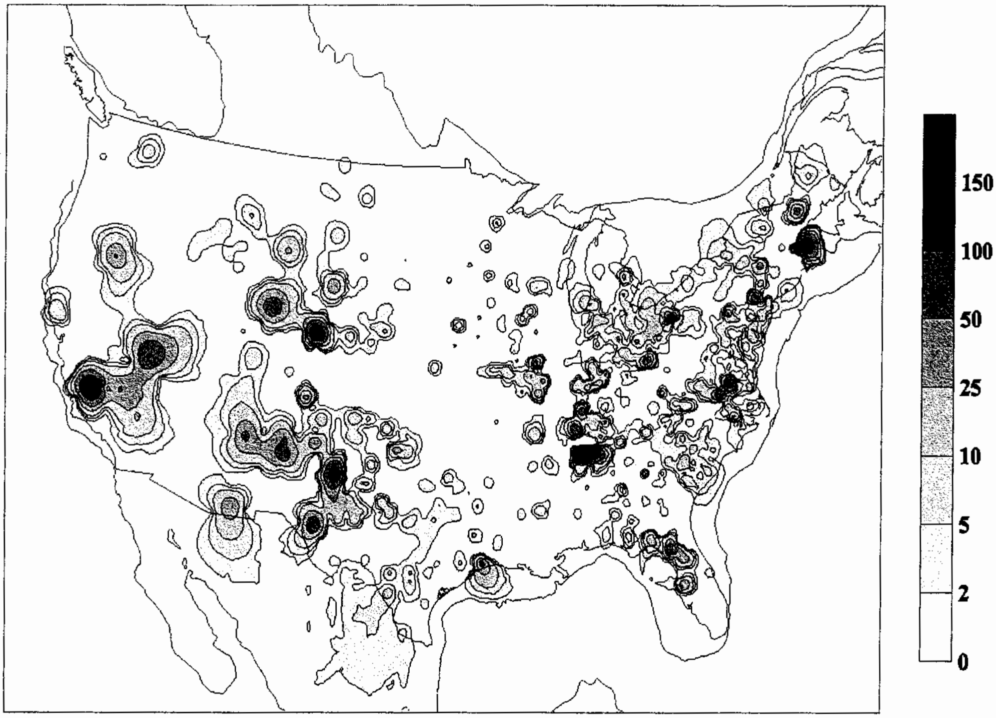


Figure 8. Leap-frog model for Paleoindian colonization and movement through North America.

to traverse the hemisphere. Following the Pacific coastline would cut the time required to just over 4,000 years, but this is still a far greater span than suggested by all but the most conservative demographic analyses. Of course, if group ranges were smaller or reproductive rates lower, the time required to traverse the hemisphere would increase markedly. As populations occupying the territories founded early in the string continued to grow and fission, furthermore, the new groups would radiate outward, filling in areas away from the primary solution pathway. Thus, by the time the end of the string of pearls was reached, large numbers of peoples and groups would seemingly have to be present in the areas near the beginning points, in North America and northern South America. This is not at all indicated by the New World archaeological record, which suggests populations were extremely low or absent in many areas prior to about 11,500 B.P.[7]

More intuitively satisfying results (i.e., capable of explaining a thin scattering of early sites) are obtained when long-distance movement is assumed to have



ALL FLUTED POINTS (Count Data as of 3/99, N = 12,163 Points)

Figure 9. Fluted point incidence in the Lower 48 United States, based on data in the North American Paleoindian Database (Anderson and Faught 1998).

occurred after fissioning (Figure 8). This "leap-frogging" pattern results in the rapid dispersal of peoples over large areas (Anthony 1990:902–903). Movement could have followed the least-cost pathways documented here, only with individual circles or territories widely separated from one another. In the absence of information about how far groups could have moved upon fissioning, however, it is difficult to estimate how quickly the extremities of the continents could have been reached. Moving rapidly, colonizing groups could have reached the southern tip of South America in a few generations (Beaton 1991:222), far faster than the time required in Martin's overkill model, which has populations sweeping through the hemisphere in about 1,000 years, albeit in a wave of advance rather than a leap-frog pattern (Martin 1973:972). A leap-frog strategy would leave vast unoccupied areas behind the advancing groups, which would help explain why the early archaeological record in the Americas is so sparse and dispersed. Such a strategy would also leave plenty of area for subsequent generations to fill in.[8]

Anthony (1990:902–903) has suggested that leap-frogging migrations tend to be associated with focused subsistence/procurement strategies, and reflect the movement of peoples from areas where resources are exhausted to areas where they are prevalent. Likewise Beaton (1991:220–222), in an examination of colonizing logic, or the reasons behind possible movement strategies by early populations, has suggested that optimal foraging concerns were likely important, specifically a selection for what he calls "megapatches" or unusually favored combinations of biotic and other resources. Such strategies would certainly favor a leap-frog pattern of movement, and would help to explain the existence of possible Paleoindian staging areas or marshalling sites in some areas (Anderson 1990; Dincauze 1993b).

The distribution of fluted points in the lower 48 states, in dense but widely separated clusters, many occurring in resource rich locations, coupled with a more widespread low density distribution, in fact, suggests early populations did use a leap-frogging movement strategy (Anderson and Faught 1998)(Figure 9). Whether fluted assemblages themselves reflect the remains of a founding population has, however, seen increasing challenge in recent years, notably through the discovery of contemporary assemblages in North America such as Nenana and Mill Iron/Goshen, and the acceptance of the contemporaneity or ancestral position of early South America assemblages at places such as Caverna da Pedra Pintada and Monte Verde (Bonnichsen 1991; Dillehay 1997; Roosevelt et al. 1996). The appeal of the Clovis colonization model was, in part, because it subsumed a technological organization and foraging adaptation that helped to explain its rapid spread, namely, the use of a highly curated toolkit made on high-quality lithic raw materials by groups characterized by extensive range mobility in the pursuit of patchily distributed large animal prey (Kelly and Todd 1988). Whether such a subsistence strategy was actually practiced by these peoples in all areas has, of course, been questioned (Meltzer and Smith 1986; Meltzer 1988), along with the idea that they were a true founding population. The fluted point distribution, accordingly, probably better represents the process of population in-filling and the spread of a specific adaptation, than the locations where the first peoples settled.

The least-cost movement solutions, however, highlight the possibility that initial colonization could have occurred in some parts of the New World well before it did in others. Thus, Clovis could still be a founding population in some areas, although it no longer appears to be the founding population across the hemisphere. The primary pathways in all of the least-cost analyses, regardless of the entry point, however, have people passing near at least some of the dense fluted point concentrations in the Plains and in Eastern North America. Thus, even if the first Americans were more prosaic and archaeologically less visible broad spectrum foragers, their movement patterns south of the ice sheets appear to have taken them into areas where fluting technology may have emerged and spread.

Conclusions

These results offer a first look at the potential for modeling group movement at large scales of analysis, and the utility of the large geographic data sets now coming online. This type of research will become increasingly common in the years to come, and should proceed in a number of directions. If information about major lithic raw material outcrops can be assembled at a continental scale, for example, these data could be used as a weighting factor in least-cost analyses. Grid cells representing chert source areas could be assigned values to be subtracted from the roughness layer. The attractiveness of chert could reduce the effects of local roughness, potentially causing movement pathways to be diverted to these areas. Similar weighting schemes can be carried out with estimates of game availability, vegetation communities, and so on. Likewise, positive weighting can be given to presumably attractive landscape features such as river or lake margins, while negative weightings can be accorded deserts or rain forests.

These kind of analyses can, of course, also be conducted on smaller regions than those explored here, to examine movement at a fine scale. This paper was inspired, in part, by Fred Limp's (1990) "Digital DeSoto" study, which made use of a least-cost path analysis to determine routes that Spanish explorers may have taken in Arkansas. The quality of the data, in fact, is typically far better for such focused studies. For instance, DEMs with a horizontal resolution of 90 meters (as opposed to the 1-km scale employed here) are available for all of the United States, and many regions have even finer 30-m resolution data available. When combined with soils, geology, hydrology, aerial photography, satellite imagery, and other remotely sensed data, the potential for modeling environmental influences, site locations, or movement pathways are boundless.

Adoption of this form of analysis will undoubtedly yield many new insights into prehistoric population movement, exchange, and interaction around the world. In eastern North America alone, topics worthy of similar exploration include resolving transport networks for soapstone during the Poverty Point era; copper, shell, and other raw materials by Middle Archaic through Hopewellian peoples; prestige goods during the Mississippian period; and the locations of trails during the historic period.

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Notes

1. This sample includes sites that date from ca. 12,500 to 10,500 B.P. or later, spanning the entire Paleoindian era as it is currently known. The North American sample, for example, includes Pre-Clovis (i.e., Page-Ladson, Topper), Clovis (i.e., Blackwater Draw, Lehner Ranch), and post-Clovis (i.e., Debert, Sloan) assemblages. Some of these sites were repeatedly visited, while others saw only one or a few periods of dramatic use during the Paleoindian era. The sample should not, accordingly, be considered indicative of the exact or even likely settlements of initial colonizing populations, only areas that such peoples *could* have reached at an early date, and that their not-too-distant descendants clearly did reach. While modeling effort could have alternatively used randomly or systematically dispersed destination points scattered across each continent, this was considered unsatisfying in a paper intended to demonstrate the utility of the analytical approach to a broad audience of archaeologists. Many possible applications require site-specific data, furthermore, such as delimiting routes between raw material or finished good source areas and places where they were used and discarded (i.e., reconstructing movement pathways for Hopewellian, Poverty Point, or Mississippian exchange). Finally, while the modeling could have included a great many additional early sites (i.e., Cactus Hill, Meadowcroft Rockshelter, Quebrada Jaguay), some limitations had to be placed on the computational effort. These sites and other locations can, of course, be considered in future applications of the method.

2. Specific data on Arc/Info Grid may be found at Environmental Systems Research Institute Inc., 380 New York Street, Redlands, CA 92373-8100 (This information also is available at http://www.esri.com/).

3. Global scale bathymetric data at 5-minute resolution, the ETOPO-5 data set, is available from the National Geophysical Data Center (1988). Finer-grained data exists for some areas and or is under development and can be obtained from the International Hydrographic Organization's Data Center for Digital Bathymetry located at NOAA/NGDC Mail Code E/GC3, 325 Broadway, Boulder, CO (This information also is available at http://www.ngdc.noaa.gov/mgg/bathymetry/iho.html).

4. If coastal migration was indeed the way many parts of eastern North America were reached, particularly along the Gulf and Atlantic seaboards, this would necessitate a revision to views that major river valleys were the primary movement corridors used by colonizing populations. Areas in eastern North America yielding dense concentrations of Clovis and

immediate post-Clovis Paleoindian sites and artifacts have been hypothesized as possible staging or marshalling areas for colonizing populations, from which groups moved outward (Anderson 1990; Dincauze 1993b). These staging areas tend to be located along the major rivers of the eastern part of the midcontinent, such as the Mississippi, Ohio, Cumberland, and Tennessee. The least-cost analysis suggests, however, that some of these areas may not have been the first reached or traversed by early populations. Once settled, however, the hypothesized staging areas, many of which are rich in biotic, lithic, and other resources, appear to have witnessed extensive subsequent population growth. The Clovis radiation, in fact, may have originated in one of these areas.

5. Recent discoveries of early coastal sites in southern South America (Keefer et al. 1998; Sandweiss et al. 1998), as well as the acceptance of the Monte Verde dating (Meltzer et al.1997; Taylor et al. 1999), however, suggest that the rough coastal terrain may not have been an insurmountable barrier to these early peoples. A similar development is occurring in North America, where initial entry via the Pacific Northwest Coast is gaining increasing support. What is interesting is that the least-cost analysis conducted here complements Sauer's South American routes so closely, particularly since the latter was to some extent intuitively based, and included consideration of both physiography and biotic resource structure.

6. These values are for heuristic purposes. Group territory/range size, population growth rate, overall population, and mobility undoubtedly varied appreciably given the differing environments of the Americas. This is particularly true when comparing movement along the coast versus in the interior, since half the territory of coastal groups is located in the ocean, which in this model is a barrier to movement, and hence inaccessible. Finally, while regular hexagons rather than circular territories could have been used, eliminating problems of lowered "packing efficiency" and voids between neighboring groups, and perhaps giving a more realistic distribution of groups on the landscape (e.g., Wilmsen 1973; Wobst 1974:153–154), in the current analysis circular territories were appreciably easier to compute, map, and describe.

7. The string-of-pearls model is, of course, also a heuristic device and should not be taken too literally. As populations grew behind the leading group, with doubling every few generations, new territories would need to be located and settled. The discussion in the text assumes these groups filled in areas behind the leader. In all likelihood, however, some of the groups forming behind the leader, upon fissioning, would move ahead of that group, either by leap frogging or passing to one side. Likewise, once the landscape behind the leader became completely filled, new strategies would have to be considered (i.e., range reduction, population regulation). Finally, while hunter-gatherer population distributions can be explored using optimal foraging and spacing arguments, the actual occurrence of human groups on the landscape tends to be both uneven and inefficient (e.g., Moore 1981:199; Wobst 1974, 1976). Indeed, how these distributions differ from idealized spacing models can lead to valuable insights.

8. Leap-frogging groups becoming widely separated from one another would also likely be more vulnerable to disease, accident, or other calamity, resulting in failed migrations, and hence leaving behind the sparse assemblages, widely scattered in time and space, that are seen in the pre-Clovis archaeological record. The New World (and also Australia) is frequently portrayed as a hunter's paradise, a setting prompting uninhibited population growth and a rapid dispersal of peoples over the landscape. Given increasing evidence on both continents for early entry, well before sites and assemblages become commonplace, such scenarios are utterly unrealistic and require us to rethink our basic assumptions. If colonizing groups had a difficult time, however, with many groups dying out or struggling along at very low levels, it would take far longer for populations to achieve appreciable archaeological visibility. Negative impacts of disease, fierce predators, and novel biota on human demography have only rarely been considered in research on the colonization of the New World (Dillehay 1991 is a notable exception), but they should be. The colonization of the Americas may have been a far greater challenge and a more epic struggle than we have been lead to believe.

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