

GIS Modeling of Paleo-Indian Period Caribou Migrations and Viewsheds in Northeastern Lower Michigan

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Abstract

A geographic information system (GIS) was used to develop a cartographic model of caribou movement during the Paleo-Indian and Early Archaic periods [ca. 11,000 to 9,500 years before present (y.b.p.) and 10,000 to 8,000 y.b.p.] from digital elevation data and ancillary digital data sets. Cartographic surfaces depicting the friction of movement for migrating caribou were generated for a study area in Presque Isle County, Michigan. Alternative optimal pathways, based on minimizing energy of movement for north-to-south and south-to-north migration, were simulated using cumulative cost surface calculations. Spatial relationships between viewsheds from three archaeological sites and the simulated pathways indicated that these sites were suitable locations for hunting caribou during the Early Holocene.

Introduction

This paper presents a cartographic model of caribou (*Rangifer tarandus*) movement to illustrate the potential of geographic information systems (GIS) for archaeological research. The model was compared with an archaeological database, possibly dating to the Paleo-Indian or Early Archaic periods, which contains few diagnostic tools and no faunal remains. Physiographic features deemed significant to Paleo-Indian and Early Archaic subsistence patterns were simulated in the cartographic model.

Early Archaic cultures are extensions of, and very similar to, Paleo-Indian cultures (Cleland, 1992). The Early Archaic period has also been termed the Plano and/or Late Paleo-Indian period. Since the early to mid 1980s there has been a wealth of anthropology literature focusing on Paleo-Indian (ca. 11,000 to 9,500 y.b.p.) cultures throughout eastern North America (Ellis and Lothrop, 1989). Much of the research has attempted to describe life ways. Throughout the Great Lakes region, the lack of organic and faunal remains, due to soil and climatic conditions and the scarcity of early sites, have limited the potential for definitive conclusions. Despite the lack of archaeological evidence, GIS can provide a powerful spatial analysis "tool-box" for understanding early settlement systems.

GIS is often used to produce cartographic models of unsurveyed regions by depicting areas of highest archaeological site potential - models which are derived from knowledge of previously observed site locations (e.g., Carmichael, 1990; Hasenstab and Resnick, 1990; Hunt, 1992; Kvamme, 1992). GIS also enables the creation of computer databases for fast

and flexible data entry, revision, and display (Green, 1990). In addition, it can be a powerful research tool, aiding in the study of spatial relationships among relicts of human activity and their physical environments on known archaeological sites (Savage, 1990a). For example, GIS can provide insights into the age and function of sites. Despite these advantages, few researchers have employed GIS as a sophisticated explanatory tool for archaeological research and spatial analysis (Savage, 1990b; Green, 1990; Williams *et al.*, 1990).

The principle goal of this research was to develop and apply GIS methods for explaining and understanding prehistoric environmental and cultural patterns. Movements of migrating caribou were simulated using a GIS. Caribou may have been a principal food source for Late Pleistocene and Early Holocene peoples of the Great Lakes. With the aid of the model, the possibility that migrating caribou could be hunted from three known archaeological sites was examined to further determine the potential for Paleo-Indian or Early Archaic human activity along the North Branch of the Thunder Bay River in northeastern Michigan (Presque Isle County). The relationships between site viewsheds, terrain, and modeled caribou movements were examined to understand site locations and their usefulness to Paleo-Indian people.

All aspects of Paleo-Indian and Early Archaic lifeways were not explored. Instead, caribou hunting, which was a significant segment of early subsistence patterns, was modeled. This limitation was not intended to imply that lifeways of early peoples were simple. The models were used to demonstrate the potential power of GIS for archaeological investigations where remains are scarce.

Prehistoric Environment of Northern Lower Michigan

By 11,200 y.b.p. the entire Straits of Mackinaw were deglaciated, separating the Upper and Lower Peninsulas of Michigan and connecting the Lake Huron and Lake Michigan basins (Larsen, 1987). This newly formed and probably largest of all the glacial Great Lakes is known as the Main Algonquin stage of Michigan (also called Lake Algonquin). The level of Lake Algonquin remained stable from approximately 11,200 y.b.p. to 11,000 y.b.p., at 198 metres above mean sea level (a.m.s.l.). Crustal rebound has raised the Lake Algonquin shore to a present level of 238 metres a.m.s.l. in the project area (Leverett and Taylor, 1915). The waters were

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permanently drained from the study area through a succession of lower outlets, resulting in a series of lower water levels which left formations known as the Upper Group Beaches, from 11,000 to 10,300 y.b.p. (Eschman and Karrow, 1985; Larsen, 1985; Larsen, 1987).

Retreating glacial ice was replaced by tundra, which persisted for 250 to 500 years (Cleland, 1966; Delcourt and Delcourt, 1991). Lake Algonquin existed for approximately 200 years after the retreat of glacial ice and its shoreline was probably bordered by a periglacial environment (Larsen, 1987). Tundra gave way to mixed-boreal forest while Lake Algonquin rapidly receded (Shott and Welch, 1984). This "spruce parkland," consisting of widely spaced and sometimes stunted growth forms of spruce, would have provided an excellent habitat for grazing animals such as Barren-ground caribou and for Paleo-Indian and Early Archaic activity in the region (Fitting, 1975; Peers, 1985). Views of the landscape from upland positions would have been rarely obstructed by vegetation. Lowland regions were rapidly colonized by black and white spruce, alder, willow, and birch (Cleland, 1966). Woodland caribou may have resided in the densely forested lowlands. By the end of the Early Archaic, Barren-ground caribou probably began to abandon Northern Michigan and move northward.

As climatic conditions gradually began warming, the uplands were taken over by fir, jack pine, black spruce, and white pine (Cleland, 1966; Delcourt and Delcourt, 1991). Maple and a few other deciduous species were also present in limited numbers during this low water period from 10,300 to 9,000 y.b.p. (Cleland, 1966; Eschman and Karrow, 1985; Larsen, 1985; Larsen, 1987; Delcourt and Delcourt, 1991).

Early Holocene Lifeways in the Great Lakes

Caribou were a dependable food resource, due to their predictability and large numbers (Spiess, 1979). As a result, caribou predation probably played a major role in subsistence patterns of the early peoples across the Great Lakes (Peers, 1985). This is consistent with the discovery of caribou remains in association with Paleo-Indian artifacts at the Holcomb Beach site near Detroit, Michigan (Cleland, 1965). Caribou remains were also found near Burt Lake in Northern Michigan, approximately 30 kilometres northwest of the study area (Wilson, 1967). Although neither set of caribou remains could be identified as any particular sub-species, the presence of caribou suggests the possibility of an arctic or subarctic hunting environment throughout Michigan (Cleland, 1965; Shott, 1986). Furthermore, the sub-species in Michigan during the Paleo-Indian and Early Archaic periods were likely to have been the same varieties now found in northern North America. These include migrating varieties of Barren-ground caribou and Woodland caribou. The sub-species prefer different habitats, but their ranges overlap and they are both known to migrate through arctic and sub-arctic environments. Barren-ground caribou prefer open environments, such as tundra and parkland. Woodland caribou prefer closed boreal forests (Spiess, 1979).

Historically and prehistorically, whenever caribou behavior and topography allowed, the dominant hunting patterns in arctic and subarctic lacustrine or riverine environments consisted of intercepting caribou at natural traps and from watercraft (Spiess, 1979; Skogland and Molmen, 1979; Gronnow *et al.*, 1983). Applying ethnographic and prehistoric models of caribou predation from Greenland, Norway, and especially Canada to suspected Late Pleistocene and Early Holocene sites in Northern Michigan aids in the

determination of the potential for early cultural activity. Once the most likely location of caribou trail systems is established, hunting patterns across the topography can be inferred.

Lake benches of the former high levels in the glacial Great Lakes were utilized during part of the Paleo-Indian and Early Archaic seasonal round throughout the region (Mason, 1981; Stewart, 1984; Storck, 1984; Peers, 1985; Wendt, 1985; Deller and Ellis, 1992). Some early cultures occupied beaches while they were active, and others utilized them after waters receded (Cleland, 1965; Deller, 1976; Deller, 1979; Ellis and Deller, 1986). Deller and several others suggested that shallow bays and lagoons of Lake Algonquin provided excellent environments in which to hunt caribou (Deller, 1976; Deller, 1979; Storck, 1984; Peers, 1985). Once caribou entered or were diverted into water bodies, they were intercepted easily from watercraft. Rivers and streams entering glacial lakes created crossing barriers for migrating caribou herds (Deller, 1979; Peers, 1985). Crossing barriers were relative barriers which slowed and funneled caribou, narrowing broad herds to single lines in some cases, allowing for easy interception as the herds coursed or crossed the features (Mowat, 1952; LeResche and Linderman, 1975; Deller, 1979). After lake levels began falling in the Lake Huron basin, lakebeds provided a rich micro-environment, with closed canopy forests, lush sedges, and grasses (Deller, 1979). Woodland caribou, moose, deer, and elk frequented these low lying areas (Stork, 1984, Deller, 1976). Waterfowl, muskrat, turtle, giant beavers, and fish may also have been taken from near shore environments during the Paleo-Indian and Early Archaic periods. The attractiveness of environments along abandoned shorelines was also documented for later periods in prehistory (Smith, 1985).

Barren-ground caribou probably preferred moving along shorelines because they offered easy migration paths with lichens in winter and rich vegetation in summer (Peers, 1985). Storck (1982) wrote that some early hunters chose locations along shorelines because they provided visibility of the interior access routes such as ridges and valleys used by migrating caribou. Wendt (1985) found that early sites were often located near higher ground in Dane County, Wisconsin. Higher ground would provide a better view for caribou during their movements along shorelines, bays, lagoons, lakes, lowlands, and at crossing barriers (Harper, 1955).

Several authors have shown that caribou migrational behavior in arctic and subarctic conditions is predictable (Miller *et al.*, 1972; LeResche and Linderman, 1975; Skogland and Molmen, 1979; Spiess, 1979; Gronnow *et al.*, 1983). According to LeResche and Linderman (1975), caribou appear to follow certain geographical principles when they migrate. In hilly terrain, caribou follow contours by traversing hill-sides, ridgelines, the most gentle slopes, and valley bottoms. In other words, with few exceptions, caribou conserve energy by using the most horizontal path possible. Caribou also prefer ridgelines and tend to course natural features (rivers and very steep slopes) before crossing them. However, once trails are established across natural features, caribou follow these. Figure 1 depicts the most favored routes likely to be traversed by caribou over an idealized terrain. The predictability of caribou movements enables the construction of GIS models depicting possible trail locations.

Study Area

This study was conducted for an area of approximately 6,400 ha in Presque Isle County, Michigan (Figure 2). The study

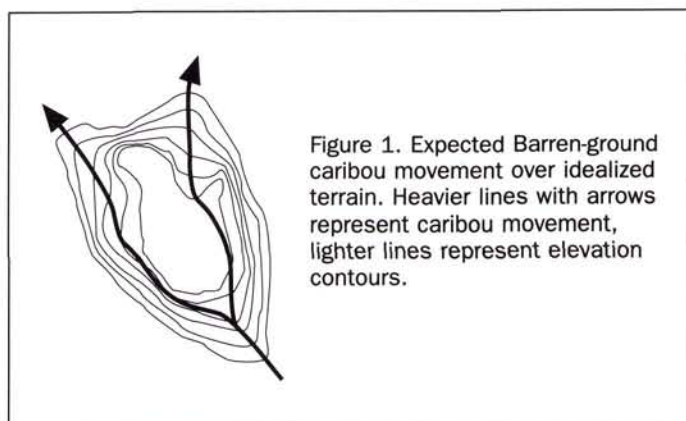


Figure 1. Expected Barren-ground caribou movement over idealized terrain. Heavier lines with arrows represent caribou movement, lighter lines represent elevation contours.

area rests at the northern end of a long isthmus of ground moraine with occasional drumlins (Burgis, 1984). The region is bordered by the Long Swamp on the west and the former Lake Algonquin shoreline on the east. The North Branch of the Thunder Bay River entered a large, shallow bay with numerous lagoons and islands in the southeastern corner of the area. Terrain in the study area ranges from nearly level to very hilly. Soils are loamy to sandy, moderately well- to well-drained, belonging primarily to the Cheboygan-Emmet-Onaway and Emmet-Onaway-Omena associations (Knapp, 1993). The basin of the North Branch of the Thunder Bay River and the surrounding terrain probably took on much of its present form during the retreat and melt of the Greatlakan ice sheet around 11,200 y.b.p.

An archaeological reconnaissance survey of Presque Isle County was initiated in 1989. As part of the survey, an upland area along the North Branch of the Thunder Bay River, in the southeastern part of the county, was investigated during 1992 and 1993. Ten archaeological sites were located, yielding diagnostics of the Paleo-Indian, Late Archaic, Early

Woodland, and Late Woodland periods. Three sites were selected for GIS analysis (Figure 2). Site I was chosen on the basis of an artifact assemblage which suggested that early occupation (i.e., Paleo-Indian and Early Archaic) was likely. Sites II and III, lacking any clear diagnostic artifacts, were selected on the basis of their location above the Lake Algonquin shoreline and their topographic situations, with the intent of assessing their potential for early occupation based on location.

Site I

Site I was located on a ridge seven metres above the northeastern bank of the North Branch of the Thunder Bay River and was near two areas of higher ground for viewing. The best evidence, thus far, for Late Pleistocene or Early Holocene human activity in Presque Isle County's upland environment was located at this site. Three graves were recovered from the northeastern corner of the site. A graver is a small, flat, thin, flaked tool with a needle-like spur or spurs on one end, used for scribing bone or wood (Mason, 1981). Gravers are rare at later archaeological sites and are considered diagnostic of the Paleo-Indian period (Stewart, 1984; Deller and Ellis, 1992). The gravers and other lithics found in the northeastern corner of the site consist primarily of a brownish chert that is available at the site.

Site II

Lithics at Site II, consisting of one retouched flake and a quartzite flake, were not diagnostic of any particular time period. Site II lies on a flat upland, approximately nine metres above the river surface. A swamp borders the site to the north and west. The river borders the eastern side of the site. A drumlin, 0.25 km to the west, provided access to higher ground.

Site III

Site III contains two concentrations of lithics (called scatters). The site is on a ridge 0.75 kilometres from the river mouth at Lake Algonquin. The site is 10 metres above the river and allows for a good view, but slightly higher ground is available within 0.4 kilometres.

Methods

Archaeological Data Collection

All cultivated fields within 0.8 km of the North Branch of the Thunder Bay River were walked using five-metre transects (Figure 2). All cultural materials were collected on the first visit. During subsequent visits, only diagnostic tools were collected. On public lands, all areas with surface disturbance, (two tracks, eroded areas, etc.) were examined. No cultural materials were collected on public lands.

Digital Data Entry

Because of the paucity of digital data from Presque Isle County, all data sets were digitized from USGS 7.5-minute quadrangles (Hillman NE, Metz, Polaski, and Posen). Physiographic features including lakes, swamps, creeks, marshes, and lake inlets or outlets were interpreted from 7.5-minute quadrangles. Topographic contours, archaeological site locations, and hydrography were digitized using the ERDAS software and converted from the vector to raster data structure. A pixel (grid cell) size of 30 by 30 metres was used for all raster layers, as a conservative estimate of the resolvable de-

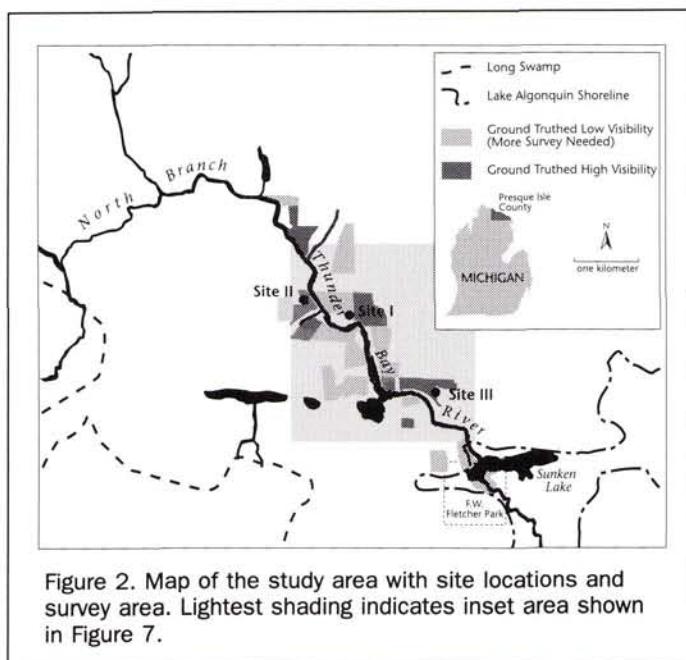


Figure 2. Map of the study area with site locations and survey area. Lightest shading indicates inset area shown in Figure 7.

tail from the topographic maps. All data were imported into IDRISI v4.1 for further manipulations (Eastman, 1993).

A digital elevation model (DEM) was created by interpolating from the digitized contours, which had a contour interval of 10 feet (Figure 3). Slope angle and slope aspect surfaces were calculated from the DEM using the SURFACE routine in IDRISI. Slope angle values were reclassified into 15 classes and slope aspect values into ten classes. The location of Lake Algonquin and its bottom lands were approximated through a reclassification of elevation values in the DEM. All elevations below 238 metres a.m.s.l. were reclassified as under water. Several swamps not shown on the Hillman NE provisional quadrangle were identified on the soil survey as muck soils (USDA, 1993) and were digitized on-screen through IDRISI.

Caribou Migration Pathways (Trails)

The first step in simulating migration routes was to generate a weighted representation of the relative cost of traversing each pixel (i.e., unit costs). All unit costs were integer values assigned on the basis of slope angle, slope aspect, hydrography, and the assumed direction of travel (i.e., northwest to southeast or vice versa). Higher unit cost values were assigned to locations less likely to be traversed by caribou and lower values to terrain more likely to be crossed. The general nature of the relationship between slope angle, slope aspect, and unit cost is listed in Table 1. A base friction value of 5 was assigned to flat surfaces. A pixel with a value of 2.5 required half the effort of a pixel with a value of 5 to traverse.

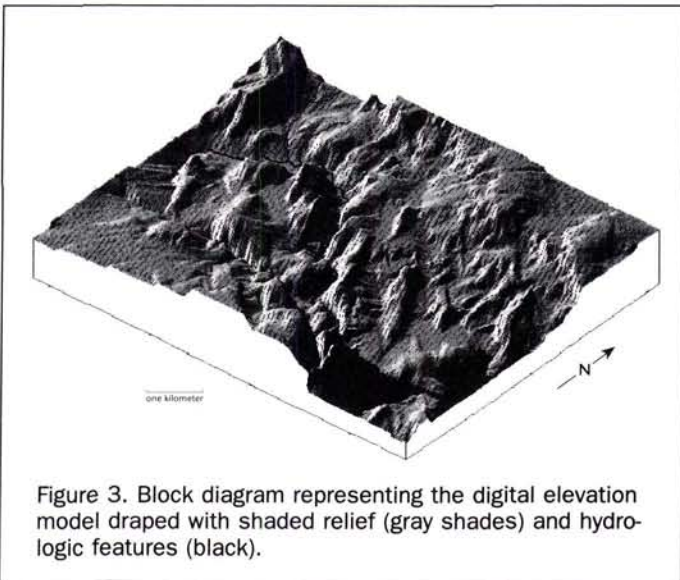


Figure 3. Block diagram representing the digital elevation model draped with shaded relief (gray shades) and hydrologic features (black).

A weight of 10 required twice the effort. Because of the orientation of glacial Lake Algonquin and its subsequent stages, migrating caribou were assumed to be traveling northwesterly or southeasterly. This assumption governed the unit cost values assigned to different slope aspect classes (i.e., uphill, downhill, and side slope). Steep slope angles (5 to 8 degrees) with southwesterly or northeasterly orientations (i.e., side slopes) were assigned the lowest friction value (1) because of the observed preference of caribou for walking perpendicular to steep slopes (LeResche and Linderman, 1975). Moderately steep side slopes (0.5 to 4.9 degrees) were assigned values ranging from 2 to 16, with lower values assigned to lower slope angles. Gentle side slopes (0.09 to 0.49 degrees), which would likely be traversed, were assigned a weight of 8. Slopes with aspects to the northwest or southeast were uphill or downhill grades, depending on the assumed direction of travel. Weights for ascending slopes progressed from 7 (for slope angles from 0.5 to 0.99 degrees) to 80 (for slope angles from 7 to 7.49 degrees). Gently to moderately descending slopes were assigned values less than the base friction. Steeper descending slopes (greater than 3 degrees) were given values above the base friction, because of the energy expended resisting gravity. Slopes of 8 degrees or steeper in all directions were treated as absolute barriers to movement and given a value of -1, meaning that the features could not be crossed. All of the steepest cells represented the walls of a sinkhole. Figure 4 graphically depicts the friction values assigned to each combination of slope angle and slope aspect classes, assuming northwest to southeast travel. Crosstabulation (CROSSTAB in IDRISI) was used to map each combination of slope angle and slope aspect classes.

Hydrographic features were overlaid on the terrain-based unit cost surface. It was assumed that hydrographic features acted as relative barriers (i.e., could be crossed with some effort), and that deeper features were more difficult to cross. A

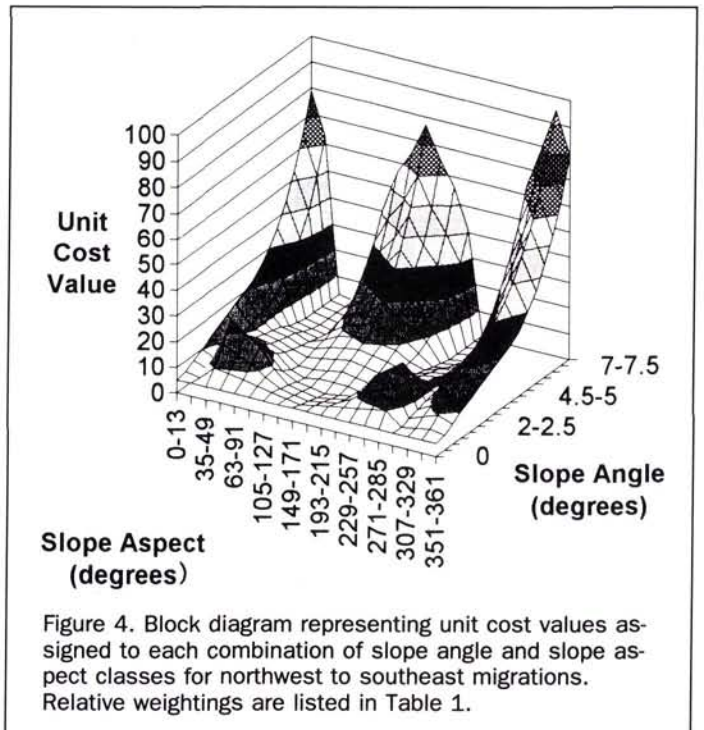


Figure 4. Block diagram representing unit cost values assigned to each combination of slope angle and slope aspect classes for northwest to southeast migrations. Relative weightings are listed in Table 1.

TABLE 1. RELATIVE UNIT COST VALUE ASSIGNED TO EACH RELATIVE SLOPE ANGLE AND SLOPE ASPECT. VALUES ARE DEPICTED GRAPHICALLY IN FIGURE 4.

		Aspect		
		Uphill	Downhill	Side Slope
	0.0 (flat)	Low	Low	Low
Slope Angle (degrees)	0.0 - 2.5	Low	Very Low	Medium
	2.5 - 5.0	Medium	Low	Low
	5.0 - 8.0	High	High	Very Low
	> 8.0		absolute barrier	

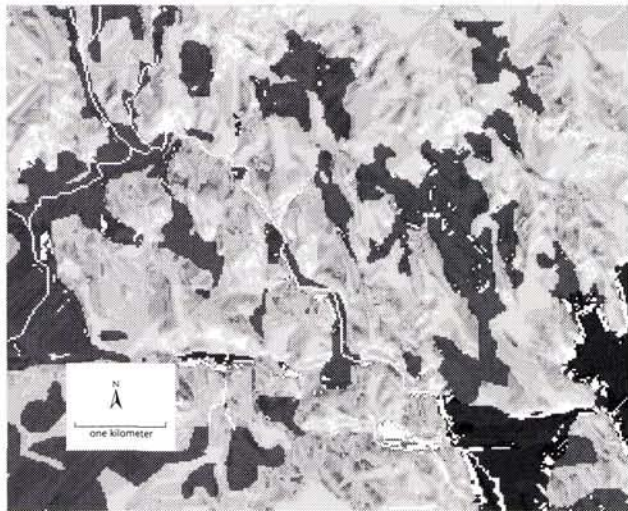


Figure 5. Map of relative friction values (i.e., unit travel costs) for northwest to southeast travel through the study area. Darker shades represent higher friction values.

value of 80 was assigned to swamps. Lakes were assigned a weight of 120 because waterbodies require more effort to traverse than swamps. The deepest portions of Lake Algonquin, where Sunken Lake presently rests, were assigned a weight of 240. Caribou would have to swim long distances to traverse this portion of the former bay. The region of intermediate depth, in which swamps are now located, were given a value of 200, while the shallower areas, where caribou would swim and walk, were assigned a weight of 120. Because the river is one pixel wide throughout the majority of the friction surface, it was assigned a value twice that of the steepest ascending slopes (160). The weight assigned to the creeks (107) was roughly a third less than that of the river because the creeks are usually narrower and shallower. The difference in lake levels between Paleo-Indian and Early Archaic periods was accounted for by calculating the unit cost surfaces without the higher Lake Algonquin shoreline (i.e., for the Paleo-Indian period). The results of the analysis were the same for both periods and, therefore, were not dependent on the level of Lake Algonquin. The unit cost surface generated for caribou traveling from the north side of the study area to the south side is displayed in Figure 5. A similar surface was generated for south to north travel.

In the second step, cumulative cost surfaces for a number of starting points were estimated with the COSTGROW module in IDRISI, using the unit cost surfaces as input. The cumulative cost surfaces represented the relative amount of energy expended traversing the terrain from a starting point to any other point on the surface, based on geographical principles explaining caribou travel (LeResche and Linderman, 1975). The cumulative cost from the starting point to any location was calculated as the sum of the unit costs of all pixels crossed to get to that location. Five cumulative cost surfaces were generated from the unit cost surface depicted in Figure 5, one of which is shown in Figure 6. Five starting points were identified, where caribou were most likely to have entered the study area from the north, as determined by examining surrounding terrain on the topographic maps.

Three such starting points were identified for caribou entering from the south.

Finally, caribou migration pathways were simulated from each starting point on the basis of the cumulative cost surfaces. A pathway was located, using the PATHWAY routine in IDRISI, where the cost-distance for traversing the terrain from a starting point to any point on the other side of the study area was minimized. In each case, the specified target was a straight line digitized across the side of the study area opposite the starting point. By creating and overlaying eight pathways (five from north to south and three from south to north), using alternative starting points, the most likely position of migration trails was ascertained. In areas where multiple simulated migration routes overlapped, a high potential for caribou activity was inferred.

Viewsheds

The relationships between site locations and caribou migration pathways was likely to be a function of viewshed, not necessarily simple proximity. Sites might have been located where views of terrain over which caribou commonly traversed were easily obtained. A viewshed is all land which is in the line of sight from a defined location (called a viewpoint). Viewsheds were calculated, using VIEWSHED in IDRISI, from the highest point within 0.4 km of each archaeological site at a viewer height of 1.4 metres above the ground.

Wendt (1985) suggested that most Paleo-Indian sites were within 0.4 km of high ground. It was assumed that hunters would choose sheltered sites which were close to look-out points for viewing. All viewsheds were calculated assuming the terrain is devoid of stands of large trees. This assumption is reasonable in a tundra environment which is likely to have existed in the study area during the Early Paleo-Indian period. During the Early Archaic period, small stands of

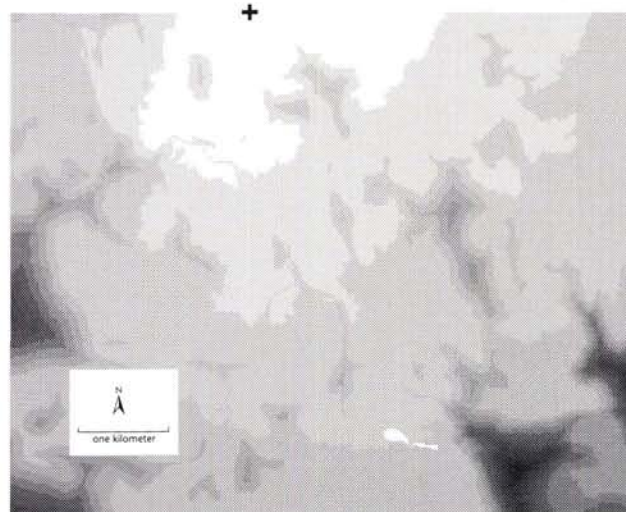


Figure 6. Map of cumulative cost values from one of five starting points on the north boundary of the study area (indicated with a +). Three starting points were determined for south to north travel. A cost surface was generated for each of the eight starting points. Darker shades represent higher costs.

spruce trees may have obstructed the views in the study area.

Results and Discussion

Figure 7 shows all of the simulated caribou migration routes for a subset of the study area around the archaeological sites. Four preferred pathways emerged from the calculation of routes originating from different starting points. Therefore, many of the pathways in Figure 7 represented multiple, coincident pathways. Two of the routes representing southward movement converged to cross the study area along the western edge of Site I while one of the southward trails passed near the eastern edge of the site (Figure 7). All southward migration routes converged to pass near the western edge of Site III. South of Site II, the three northward paths converged to pass just to the west of Site II. Coincident pathways represented likely locations of caribou movement.

Site I

The western shore of Lake Algonquin (near E in Figure 7) and the position at which the river enters Lake Algonquin were not thoroughly visible from high ground southeast of Site I (Figure 8a). However, the northern shore of Lake Algonquin and its lagoon were visible. The viewpoint to the southwest of Site I provided excellent visibility of lowland areas bordering the North Branch of the Thunder Bay River

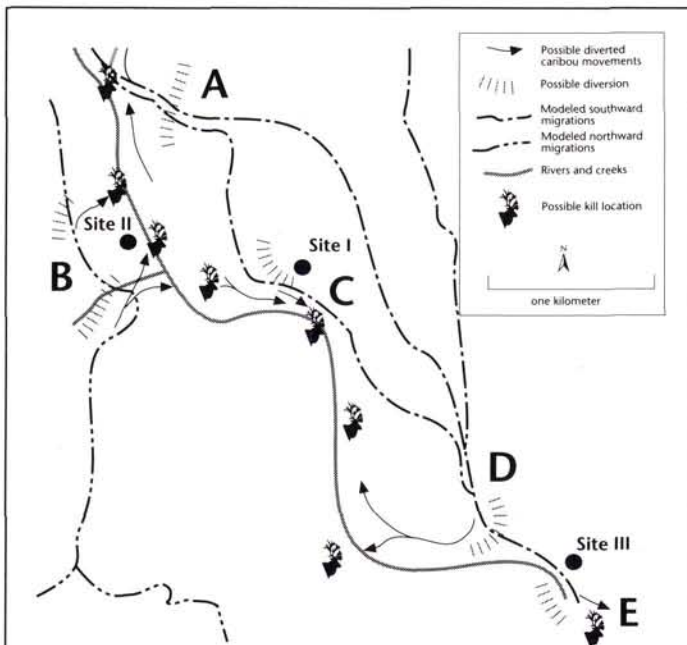


Figure 7. Barren-ground caribou migration routes estimated from cost surfaces for a portion of the study area (see shaded area on Figure 2). All routes are shown. Several of the lines represent multiple routes which converged beyond the extents of the map window. Complete routes are shown in Figure 8. Caribou diversions were interpreted to indicate possible hunting patterns associated with archaeological sites and their spatial location relative to modeled migration routes.

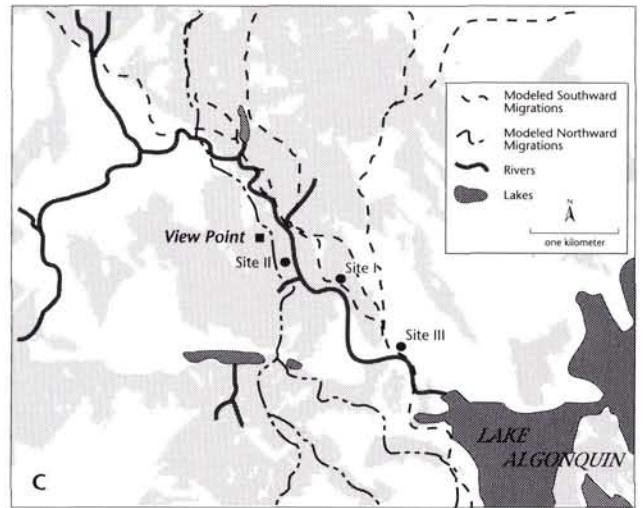
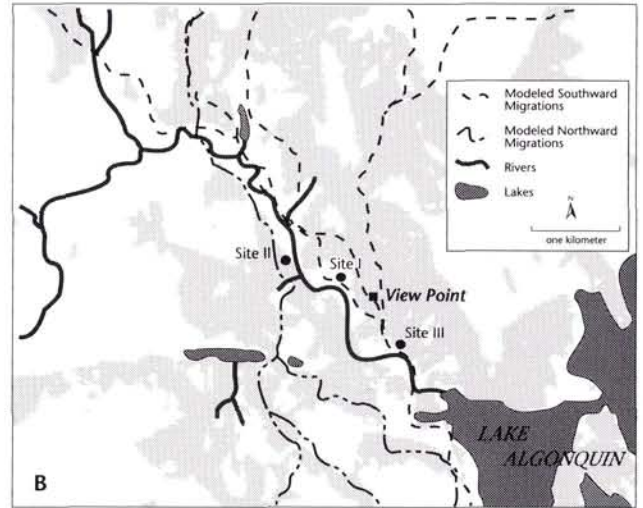
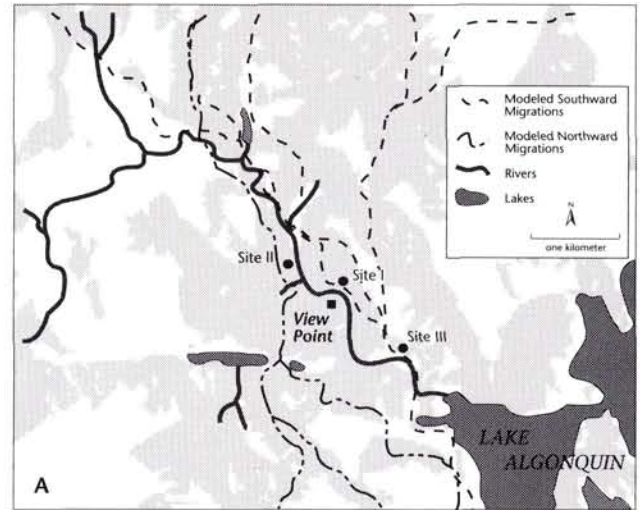


Figure 8. Viewsheds from three higher elevation points within 0.4 km of archeological Sites I and II. Shaded areas are visible from viewpoints. (A) Viewshed from a viewpoint to the southwest of Site I. (B) Viewshed from a viewpoint to the southeast of Site I. (C) Viewshed from a viewpoint to the southwest of Site II.

(Figure 8b). Hunters were probably able to observe caribou that were coursing the River, creeks, and swamps. The southwestern view point provided superior visibility of migrations to the north and south of Site I, while the view from a ridge bordering the eastern edge of the site likely served as a favorable lookout for caribou movements to the east.

Figure 7 depicts hypothetical hunting patterns undertaken at Site I. Caribou migrating from the northwest, along simulated paths, could be redirected at location **A**. Stone structures and fences, called *inussuit*, and/or hunters themselves would be used to divert caribou into natural traps in arctic and subarctic conditions (Harper, 1955; Spiess, 1979; Skogland and Molmen, 1979; Gronnow *et al.*, 1983). These tactics may have been employed by early hunters to deflect caribou into the lowlands along the North Branch of the Thunder Bay River to the south of **A**. This lowland was probably ponded, aiding in the pursuit of caribou from watercraft. Some caribou could have been intercepted at the narrowest part of the channel, which provided a natural trap near **C**. Caribou may also have been intercepted upon entering the creek and/or River valleys at location **A**.

Site I was centrally located with access to a variety of physiographic features. These features were highly supportive of hunting and gathering subsistence patterns during the Late Pleistocene and Early Holocene (Deller, 1979; Storck, 1984). The pathway and viewshed analyses using GIS indicated the potential for the use of these physiographic features. Based on this evidence and artifacts found at the site, Site I had a high potential for early activity.

Site II

From a point to the northwest of Site II, a limited view of Lake Algonquin (point **E**) and its surrounding features was available (Figure 8c). This higher ground might have enabled hunters to thoroughly monitor suggested caribou movements to the south and north of the site. Lowland regions along the North Branch of the Thunder Bay River, and animals coursing the River and creeks, may also have been visible from this site. Caribou migrating northward could have been diverted along a small creek, at **B**, into the North Branch of the Thunder Bay River (Figure 7). Similarly, caribou could have been diverted into a small swamp to the north of the site. Some caribou may have been diverted into and subsequently intercepted within the lowlands between **A** and **C**. Site II also allows access to small creeks, and to swamps accommodating plant gathering and other forms of hunting (Deller, 1979; Storck, 1984). Despite its very limited assemblage, Site II demonstrated the potential for early activity and warrants additional investigation.

Site III

Despite its closer proximity to Lake Algonquin, visibility of lacustrine features from Site III was similar to that of Site I. The rich environment in and around Lake Algonquin was likely accessible from Site III. Caribou could have been diverted at **D** into a small swampland and/or a low, steep-sided channel. Animals diverted into the channel were probably intercepted from watercraft or at the narrowest part of the channel (**C**). Caribou may also have been diverted into Lake Algonquin (point **E**). Concealed hunters in watercraft could then maneuver from the mouth of the River into the embayment. After the waters retreated, inhabitants at Site III had access to a rich lakebed environment. The area in and around Site III has potential for Paleo-Indian and Early Ar-

chaic activity. However, a portion of this site was destroyed during road construction, perhaps erasing any record of this early activity.

In terms of cartographic models and viewsheds, Sites I, II, and III all had potential for Paleo-Indian and Early Archaic activity. The best evidence for early activity along the North Branch of the Thunder Bay River, archaeologically speaking, has come from Site I. Although there was no definitive evidence for Paleo-Indian activity in northeast Michigan, as the consequence of few surveys, the GIS analyses presented here indicated potential for such activity.

Conclusions

The topographic situation of observed archaeological sites was examined through the use of spatial analysis methods available in many GIS packages. Terrain and reconstructed pre-historic hydrography were used to model caribou migrations through a study site in northeastern lower Michigan. Site descriptions and interpretations were made on the basis of artifacts found and the spatial relationships between potential viewsheds from near the site and possible caribou migration pathways. This research has demonstrated that GIS has potential to support archaeological research, by providing additional evidence of the activities of early peoples.

The analyses indicated that the observed sites might have been Paleo-Indian or Early Archaic in age. Confirmed sites from these early time periods are relatively rare. Early sites are often small and widely scattered across the landscape due to early settlement patterns of Paleo-Indian and Early Archaic peoples in the Great Lakes region. Further testing, in regions where more archaeological data are available, is needed to determine the predictive power of the model for addressing the issue of caribou predation by early peoples. The models should also be tested against modern caribou trails. By improving the models of caribou behavior, the importance of caribou as a food resource for Paleo-Indian and Early Archaic people can be assessed. Furthermore, explanations of the site activities can be improved through spatial analysis. For example, it may become possible to relate site locations (e.g., upland or shoreline sites) to their functions (e.g., as kill sites, base camps, or hunting camps).

A primary restriction for the development of spatially explicit models of pre-historic settlement and land use patterns is the paucity of data. Data limitations, and the necessity of making assumptions about pre-historic environments, affect the certainty of conclusions. However, explanations of the implications of existing data are improved by integrating those data with cartographic environmental models in GIS. These models are useful for encouraging and/or directing additional field work, and they provide an additional line of evidence for evaluating archaeological data sets, large or small. Multiple lines of evidence are crucial for reaching definitive conclusions. GIS model development may provide an alternative to further excavation (i.e., destruction) of archaeological sites. After the excavation of limited regions of an archaeological site, predictive models in GIS might be used to target likely additional sites or to explain those observed. The results of this project might be used to construct a predictive model of site location. This project, however, was explanatory rather than predictive.

Research needs to continue refining and testing spatial analysis methods in support of archaeological research. Models which compare artifact assemblages and occupational intensity of archaeological sites to the surrounding

environment could be developed. Such models can yield valuable information about subsistence patterns at individual sites where archaeological evidence is lacking.

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