A GIS Approach to Archaeological Settlement Patterns and Predictive Modeling in Chihuahua, Mexico

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A GIS Approach to Archaeological Settlement Patterns
and Predictive Modeling in Chihuahua, Mexico

Haylie Anne Ferguson

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Arts

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ABSTRACT

A GIS Approach to Archaeological Settlement Patterns and Predictive Modeling in Chihuahua, Mexico

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Master of Arts

In this study I analyzed the pattern of settlement for known Medio period (A.D. 1200–1450) sites in the Casas Grandes region of Chihuahua, Mexico. Locational data acquired from survey projects in the Casas Grandes region were evaluated within a Geographic Information Systems (GIS) framework to reveal patterns in settlement and site distribution. Environmental and cultural variables, including aspect, cost distance to nearest ballcourt, ecoregion, elevation, local relief, cost distance to nearest oven, cost distance to Paquimé, slope, soil, terrain texture, topographic position index, cost distance to nearest trincheras, vegetation, vegetation variety to 100 meters, vegetation variety to 500 meters, cost distance to nearest intermittent lake, cost distance to nearest intermittent stream, cost distance to nearest perennial lake, and cost distance to nearest perennial stream were calculated for each site in this region. It was expected that the relationships of correspondence between known sites and these variables would provide a quantitative framework that could be used to model the locational probability of unknown sites in the region. Through the use of GIS and statistical analyses, the results of this study were used to produce an archaeological site sensitivity map for this region of northern Mexico.

Keywords: GIS, Predictive Modeling, Binary Logistic Regression, Casas Grandes
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1 Introduction

The Casas Grandes region of Chihuahua, Mexico has been an area of intense archaeological focus for over 100 years. For most of that time, research efforts in the area have been geared primarily toward the documentation of the UNESCO World Heritage site of Paquimé, which lies at the heart of this cultural region, as well as the documentation of sites on the surrounding landscape. This site, as well as the broader cultural region, is distinguished from other significant sites across the southwest not only because of the strong architectural and cultural ties to Mesoamerican practices to the south, but also for strong evidences in the archaeological record that suggest Paquimé played a preeminent role in the trade and production of goods that reached across the southwest. During the Medio period, Paquimé and the Casas Grandes culture rose to ascendency among prehistoric southwestern communities. While many explorers, geographers, and archaeologists have conducted survey and excavation projects since the 1530s, it is only recently that these findings are being converted from paper-based documentation to digital, georeferenced formats. Additionally, the various datasets have never been brought together into a single digital geodatabase.

This study focused on the prehistoric residential sites dating to the Medio period (A.D. 1200 – 1450) which are located within a 75-kilometer radius around Paquimé in present-day Chihuahua, Mexico (Figure 1.1). This study was comprised of four distinct phases. The first was the collection, digitization, standardization, and compilation of site and environmental
Figure 1.1. Overview map of the study area in relation to the Greater Southwest.
data into a flexible and dynamic geodatabase. The second phase was the performance of spatial analyses for 291 site and 299 non-site locational data within a GIS framework. The third phase was the performance of a binary logistic regression analysis to the site data that examined the relationships between known site locations and the 26 environmental and cultural variables analyzed within the GIS, as well as production of a site locational predictive model and site sensitivity map for the study area. The use of binary logistic regression made it possible to empirically demonstrate the correlation between the location of sites on the landscape to the variables selected for analysis in this study. The statistical approach used in this study was drawn from similar studies undertaken in archaeological predictive modeling (see Heilen et al. 2013, Holton 2014). The fourth and final phase was model testing and evaluation.

The objectives of this study were two-fold. The first goal was to collect and georeference as much of the available archaeological data for the Casas Grandes region as possible, and to compile it all into a single geodatabase that would allow researchers to have access to data on a regional scale. The second goal was to use these datasets to conduct a Geographic Information Systems (GIS) based analysis of residential site locations and to perform a binary logistic regression analysis as the means of creating a site location predictive model for the study area. This study utilized available settlement data for Medio period (A.D. 1200–1450) residential sites in the Casas Grandes cultural region to evaluate the quantitative relationships between site locations and specific environmental and cultural variables. For the purposes of the binary logistic regression analysis, site and non-site locations are termed “dependent variables,” while the environmental and cultural variables are termed “independent variables.” These designations will be discussed in greater detail in Chapter 3. Once the values for the independent variables were calculated and added as attributes for each dependent variable, they were used to carry out a binary logistic regression analysis using statistical software. Finally, the results of the logistic regression analysis were used to create a predictive model and site sensitivity map in ArcGIS that
illustrates the probability values of site presence across the landscape. The resulting probabilities are based on the relationship between the dependent variables and eight statistically significant independent variables.

Initially, site and survey data from Sayles (1936), Di Peso et al. (1974a), Whalen and Minnis (2001a, 2003), Kelley et al. (2012), and Pitezel and Searcy (2013) were collected for inclusion in the geodatabase. Once collected, site locations provided by Whalen and Minnis, as well as a dataset of arbitrary non-site locations were used to carry out the rest of the analysis and predictive modeling. The independent variables selected for this study included elevation, ecoregion, topographic aspect, slope, local relief, cost distance to perennial water, cost distance to intermittent water, soil, terrain, topographic positioning, vegetation, vegetation to 100 meters, vegetation to 500 meters, distance to ballcourts, cost distance to ovens, cost distance to check dams (trincheras), and cost distance to Paquimé.

The ESRI ArcGIS software was used to evaluate the data within a GIS framework. The values of environmental and cultural variables associated with both site and non-site locations were calculated using this software. It was expected that as these data were brought together and spatial and multivariate analyses were performed, it would be possible to empirically demonstrate relationships of correspondence, or association, between site/non-site locations and environmental and cultural features in the area. The creation of this predictive model will assist in future survey efforts to identify those areas within the region that have a statistically high probability for containing Medio period residential site locations.

This project was the first to bring together much of the archaeological settlement and survey that has been conducted in the Casas Grandes region into an integrated and dynamic geodatabase. The creation of this geodatabase, along with the geospatial, statistical, and modeling analyses undertaken, has advanced our knowledge and understanding of the settlement patterns of those who lived in the Casas Grandes region during the height of Paquimé. This
study has revealed previously unexamined correlations and patterns related to Medio period site location and the environmental and cultural features throughout the region.

Chapter 2 is an overview of both the people who have occupied the Casas Grandes region, as well as the environment. The debate over the origins of the builders and inhabitants of Paquimé is discussed. A temporal chronology for the region, including its original definitions and subsequent revisions, is also included. The extent of what has come to be known as the Casas Grandes cultural area is identified. Finally, there is a discussion of the environmental setting of the region. This discussion includes information regarding ecoregions, climate, common vegetation, annual precipitation averages, and regional elevation.

Chapter 3 is a literature review of the archaeological work that has been conducted in the Casas Grandes region since the discovery of Paquimé in the early 1500s. The aim of this chapter was first, to provide a brief history of the archaeological work that has been done in the region, and, second, to elucidate the gaps in the literature regarding settlement research. The overview of archaeological research is discussed chronologically, beginning in A.D. 1450 at the decline of Paquimé, and ending with the most recent archaeological work conducted in the spring of 2017.

Chapter 4 is a discussion of methods for each phase of this study. From data collection to digitization and georeferencing, as well as the methods used to conduct each of the GIS analyses. A discussion of methods for both the logistic regression analysis and predictive modeling and mapping is also included.

Chapter 5 outlines the results obtained through this study. Paying particular attention to the independent variables that were shown to be statistically significant in the logistic regression analysis. The results of the predictive model, and subsequent site sensitivity map are also discussed.

Chapter 6 provides a discussion of the benefits of this study, as well as some of the limitations of the data. There is an evaluation of those aspects of the model that can be improved
as more information is added to the geodatabase, as well as the need for particular types of datasets that will allow for broader evaluation of site locational modeling in the future.
This chapter provides a cultural, temporal, and environmental overview for the Casas Grandes region and the narrower study area used for this thesis. The chapter begins with a summary of the longstanding debate regarding the origins of the cultural group responsible for building Paquimé. Following this discussion, a temporal chronology for the region, including its original definitions and subsequent revisions, is addressed. Additionally, the extent of what has been identified as the Casas Grandes cultural area is outlined. The chapter concludes with a discussion of the environmental setting of the cultural area.

**ORIGINS OF PAQUIMÉ**

The origins of the builders of Paquimé has been a topic of discussion since reports of the site were first published in 1536 (Di Peso et al. 1974a:58). Ever since that time, questions regarding which cultural group should be affiliated with the creation of the city, as well as their place of origin, have been debated. Some postulate that the group responsible was from Mesoamerica to the south, some argue for an origin from the Puebloan culture to the north, and some have argued that their roots are local (see Di Peso et al. 1974a; Lister 1946; Lekson 1999, 2000, 2002, Whalen and Minnis 2003, 2009). In 1922, American archaeologist Edgar Lee Hewett visited the ruins of Paquimé and wrote, “I can think of but one region that answers fairly well to the conditions of the Aztec legend. It is improbable that the tradition can ever be positively verified, but I should offer no objection if the people of the Casas Grandes region should name
their charming basin the Vale [sic] of Aztlan” (Hewett 1923:50). While Aztec connections are not promoted in the literature of today, Mesoamerican connections have been at the heart of interpretations since researchers first encountered Paquimé.

Di Peso was convinced of a central Mexican influence at Casas Grandes, and argued for a “handful of traders, or perhaps artisans, who traveled from their home base to specific points in the Gran Chichimeca [Casas Grandes] without leaving en route evidence” (Di Peso et al. 1974b:59). He asserted that these traders and artisans, or Puchteca, were the driving force behind the rise and prosperity of Paquimé. On the opposing side of the debate, Gladwin and Sayles argued against a Mesoamerican influence in the development of Chihuahuan culture and claimed instead a “Chihuahua Branch” of the Pueblo cultures from the Southwest (Sayles 1936:86–87). Lister and Lekson have also argued for a Puebloan rather than Mesoamerican influence at Paquimé (Lister 1946; Lekson 1999, 2000, 2002).

In more recent debates, Whalen and Minnis (2003, 2009) have postulated a third possibility and argued against the long-held assumptions that the Casas Grandes region was underpopulated before the rise of Paquimé, as well as the assumption that there was little continuity between the earlier Viejo period and subsequent Medio period of the region. Whalen and Minnis proposed that there is evidence of continuity in architecture and ceramic production between these two periods, as well as other material culture continuations, including aviculture, copper, shell, and mortuary evidences. They have argued that although the Viejo period remains poorly understood, there are significant indications that support the claim that continuity can be seen through the Viejo to Medio transition (Whalen and Minnis 2003, 2009).

In the southern portion of the Casas Grandes cultural area, Stewart et al. (2005) reported findings from 122 sites with Viejo and/or Medio components and conducted an analysis of the radiocarbon chronology for this southeastern area. Thirty samples were taken from mostly charred materials recovered during their excavation, as well as one float sample. While the
authors focused on aspects of the Viejo period which differed from the Medio period, including architecture, ceramics, and radiocarbon sampling, they concluded that the transition between the Viejo and Medio periods demonstrate a continuity of cultural tradition between these two time periods as well.

**CHRONOLOGY OF CASAS GRANDES**

Di Peso was the first to develop an archaeological chronology for Casas Grandes. The chronology was segmented into six distinct periods. Respectively, they were the Preclassic Horizon, Plainware, Viejo, Medio, Tardio, and Españoles periods. As this study is focused on sites dating to the Medio period, a more in-depth summation of the distinct characteristics for that period will be given. The remaining five periods will be briefly outlined to provide context.

Di Peso argued that hunters must have been in the Casas Grandes valley no later than 10,000 B.C., which marks the beginning of the Preclassic Horizon and extends to A.D. 1 (Di Peso et al. 1974b:63). This period was marked by the hunting of megafauna as evidenced by several Clovis projectile points and other Paleo-Indian tools that were recovered from the Casas Grandes basin (Di Peso et al. 1974b:63).

Following the Preclassic Horizon, Di Peso identified the period between A.D. 1 and A.D. 700 as the Plainware period. This period has been characterized as the beginning of sedentary village life and maize-based gardening (Di Peso et al. 1974b:86). The inhabitants of these villages are characterized as “central based wanderers” who came together during the wet seasons to participate in farming and then who divided into family units for the remainder of the year (Di Peso et al. 1974b:87).

Di Peso designated A.D. 700–1060 as the Viejo period. He further subdivided the period into three phases: Convento (A.D. 700–900), Pilon (A.D. 900–950), and Perros Bravos (A.D. 950–1060). He argued that the Chichimecs left their cave dwellings to build houses-in-pits during the Convento phase of the Viejo period (Di Peso et al. 1974b:107). He argued that the inhabitants
of these Convento phase villages were seasonal farmers and that this phase was marked with low population densities, with individuals concentrating in a small number of independent villages (Di Peso et al. 1974c:118). An analysis of Convento phase ceramic decoration by Di Peso and his colleagues revealed six different techniques for the period. These include corrugated, scored, incised, tool punched, painted, and textured and painted (Di Peso et al. 1974b:127).

The Pilon phase of the Viejo period spanned from A.D. 900 to A.D. 950. This period saw architectural changes in size and construction of pit-houses over and around the previous Convento phase architecture (where present). Red-on-brown and polychrome designs are indicative of the ceramics of this phase. The Perros Bravos phase is the final phase in the Viejo period and extended from A.D. 950 to A.D. 1060. Di Peso noted that this phase marked an abrupt change from house-in-pit architecture to rectangular surface rooms built around plazas (Di Peso et al. 1974b:180).

The close of the Viejo period at A.D. 1060 and the start of the Medio period marked an explosion of architecture, settlement, agriculture, and goods. The Medio period spans the rise and fall of Paquimé, and its impact on the surrounding region. According to Di Peso, this period spanned from A.D. 1060 to A.D. 1340. He further divided the Medio period into three phases: Buena Fe (A.D. 1060–1205), Paquimé (A.D. 1205–1261), and Diablo (A.D. 1261–1340). Following the Medio, Di Peso identified the Tardio period as the time between A.D. 1340 and 1660, and concluded his chronology with the Españoles period which extended from A.D. 1660 to 1821.

Shortly after the Di Peso chronology was published, others suggested revisions to the dating of Casas Grandes, and the debate over the chronology of Casas Grandes has continued ever since (see Braniff Cornejo 1986; Dean and Ravesloot 1993; Doyle 1976; Harmon 2005; Kelley et al. 1999; Larkin et al. 2004; LeBlanc 1980; Lekson 1984; Stewart et al. 2005; Whalen and Minnis 2003; Wilcox 1986; Wilcox and Shenk 1977). Among the critics were Dean and Ravesloot...
(1993), who re-examined dendrochronology samples from Paquimé and reassigned Di Peso’s original dates for the Medio Period to A.D. 1200 – A.D. 1450. These dates are used by most researchers today.

In 2009, Whalen and Minnis re-evaluated the chronology of the Medio period based on dendrochronology samples taken from four sites excavated during their 1996–field seasons. Based on the results from those samples, and the previous work done by Dean and Ravesloot (1993), Lekson (1984), and Larkin et al. (2004), Whalen and Minnis support the division of the Medio Period into just two phases, an early phase which dates from A.D. 1200–1300, and a late phase dating from A.D. 1300–1450 (Whalen and Minnis 2009:68). Whalen and Minnis examined changes in ceramic production and function during the Medio period to supplement the early and late designations to the Medio period. They classified thirteenth century settlements as “early” Medio and determined that fourteenth century polychrome wares can be distinguished from those that were present in the early thirteenth century as well as those that have been dated to post-1300 (Whalen and Minnis 2009:44–45, 260; see also Whalen and Minnis 2003).

ARCHAEOLOGICAL SPACE DEFINED

As part of the extensive Joint Casas Grandes Expedition (JCGE), Di Peso and his colleagues identified the greater Casas Grandes archaeological zone. They started at their research center in the Casas Grandes drainage to survey the extent of the Casas Grandes influence. They determined borders based on the material culture found during this survey and used the term “Casas Grandes” to signify both the city itself and the “culturally associated villages” in the surrounding area (Di Peso et al. 1974c:328). They argue that this area contained thousands of “satellite” villages (Di Peso et al. 1974c:328). Di Peso argued that the northern border included the southernmost portions of Arizona and New Mexico, while the eastern border extended to the Samalayuca Dune Fields, also known as Los Medanos, in the northeastern area of the contemporary state of Chihuahua (Di Peso et al. 1974b:6). Di Peso identified the Aros River
as the southernmost marker of Casas Grandes influence, with the western border reaching the Bavispe Basin on the edge of the contemporary Chihuahua/Sonora border (Di Peso et al. 1974b:7). Di Peso and his colleagues concluded that, “the dominion of Paquimé…grew to include more than 85,000 sq. mi. of land located in the northwestern portion of Chihuahua and the northeastern sector of Sonora” (Figure 2.1; Di Peso et al. 1974c:328).

Whalen and Minnis (2001a:52) corroborated with the square kilometers originally given by Di Peso in 1974. They identified several prehistoric cultures that were contemporaneous and shared cultural traits with Medio period Casas Grandes, including the Salado cultures from the southeastern portion of Arizona and the southwestern area of New Mexico, the Black Mountain-phase culture from the south-central area of New Mexico, the El Paso-phase culture of south central New Mexico and western Texas, as well as several unnamed cultures to the south and west. Whalen and Minnis (2001a) argued that “all of these cultures lie within about 170 km of Casas Grandes, and the radius of 170 km produces the area of about 88,000 sq. km that Di Peso saw as under the domination of the center” (Figure 2.2). Whalen and Minnis (2001a:46) call this broader area the “Casas Grandes Hinterland.” The term “hinterland” has been defined as “generally lacking large concentrated populations and communities, but…significant in the economies of ancient societies…often contain[ing] raw materials for craft production, consumable food resources, and arable land” (Bayman and Sullivan III 2008:6). “Region” has been described as “expansive areas that share socio-political ties, creating greater interaction within the region than outside it” (Douglas 1995:241).

The Casas Grandes cultural region is broader than the study area used in this thesis. Whalen and Minnis (1996) identified a smaller, more concentrated zone of influence and interaction between Paquimé and the settlements within a 75 km radius around the site. Whalen and Minnis have given various distances for this intensive zone since they originally published their findings in 1996. They reaffirmed the 75 km radius zone in their 2001 book. However, several years
later they argued for a radius of 90 km (Whalen and Minnis 2001a:193, 2009:3). Subsequently, Whalen and Pitezel have stated that the intensive zone reached a radius of 80 km (Whalen and Pitezel 2015:115). It has also been argued that the influence reached a limit of approximately 130 km north and south of Paquimé (Minnis 1984, 1989; Whalen and Minnis 1996). Summaries of these studies can be found in greater detail in Chapter 4 of this thesis. Because there is some variability in the understood boundaries of the influence from Paquimé, for the purposes of this
settlement analysis, the study area was restricted to the most conservative estimate of a 75 km radius surrounding Paquimé (Figure 2.3).

**ENVIRONMENTAL SPACE DEFINED**

The remainder of this chapter will focus on the study area in terms of its environmental setting. Topics such as climate, regional elevation, ecoregions, common vegetation, and annual
Figure 2.3. Overview map showing the extent of the study area boundary.
precipitation averages will be discussed. This summary of the environment will introduce and provide context for several of the independent variables selected as part of the settlement analysis and predictive model.

Climate

In the Casas Grandes region, and throughout North America, there were dramatic changes in climate during the Viejo and Medio periods. Approximately at the midpoint of the Viejo Period, in A.D. 900, there was a shift from the Early Medieval Cool period to the Medieval Warm period which was characterized by a warmer, wetter climate (Foster 2012:15). Various authors have commented that the Medieval Warm period is associated with increased productivity in crop cultivation, the spread of complex societies based on agriculture, changes in pottery style, and an explosion of monumental architecture (Anderson 2001; Foster 2012; LeBlanc 2003; Lekson 2006). Foster (2012) noted that native groups throughout the Southwest experienced exceptional changes in the cultivation of crops, population growth, economy, and culture. This is certainly true for the inhabitants of the Casas Grandes region. This period marks the transition from pithouses to pueblos, changes in agricultural practices, notably the shift to irrigated farming, the appearance of polychrome pottery, and the impressive growth of Paquimé. Interestingly, the rise of Paquimé in the A.D. 1200s coincided with a climatic transitional period between the Medieval Warm period and the Little Ice Age. This transition is characterized by variations between the dry, hot conditions of the Medieval Warm period and the chillier, wetter conditions of the Little Ice Age (Foster 2012:64). Foster (2012) postulated that compared to other Southwest regional centers, the latitudinal position of Paquimé, as well as its location on a floodplain, may have reduced the effects of the climate changes that were happening at more northern locations such as Chaco Canyon. Through this climatically transitional phase, the Medieval Warm period lasted through the Viejo to Medio transition, and the rise of Paquimé, before changing again in A.D. 1300 with the advent of the Little Ice Age (Foster 2012:15).
The fourteenth century marked the beginning of what has been termed the Little Ice Age. Foster explained that globally this was a period of drastic swings in temperature from decade-long periods of cool temperatures, short periods of warmer temperatures, and then a shift back to cooler temperatures (Foster 2012:87). Foster noted that some archaeologists have argued that the occurrence of droughts during the Little Ice Age also impacted agricultural settlements in the Southwest and the combination of the two led to the collapse of these communities (Foster 2012:88). It is significant to note that while great upheaval and collapse were occurring in other regions of the Southwest during the Little Ice Age, Paquimé experienced the period of its greatest architectural, population, and economic growth (Foster 2012:93; Whalen and Minnis 2009:261). This era of growth, along with the decline and subsequent abandonment of Paquimé, all occurred during the Little Ice Age, which lasted until A.D. 1850 (Foster 2012:15).

The rise of Paquimé and the formation of settlements within its influence occurred at a time when environmental changes were taking place around the world. The Little Ice Age brought with it cooler temperatures and droughts that affected settlements throughout the Southwest/Northwest. Despite these changes, during the Medio period Paquimé was able to grow into the largest community in the Southwest at that time (Douglas 1995; Lekson 1989; Wilcox 1991).

**Ecoregions**

The Casas Grandes cultural area is comprised of four distinct ecoregions (Figure 2.4). Two large ecoregions account for nearly 88% of the study area, while two smaller ecoregions comprise the remaining land. The Piedmonts and Plains of the Western Sierra Madre Piedmont dominates the eastern portion of the area, while the Sierra Madre Occidental of the Western Sierra Madre comprises most of the western portion. A small section of the Chihuahuan Desert is in the northeastern section of the study area, and a small segment of the Madrean Archipelago of the Western Sierra Madre Piedmont lies in the northwest corner of the study area. A description and discussion of each ecoregion will be discussed below.
Figure 2.4. Overview map of the ecoregions within the study area.
Chihuahuan Desert

The Chihuahuan Desert covers approximately 2,140 km² and accounts for 12.11% of the land in the study area. The climate in this region is classified as a dry desert. According to the Commission for Environmental Cooperation (CEC) this area is cold in the winter and hot in the summer with average temperatures ranging annually from 62 to 68 °F (CEC 2011:94). Frost-free days span from 150 days in the northern, higher elevations to over 320 days in the southern, warmer areas (CEC 2011:94). Most of the precipitation occurs in late summer with an annual average of 340 mm (CEC 2011:94). Local vegetation in the basins include mesquite, striated agave, and yucca, with pinyon pine, oak, and juniper trees occurring at higher elevations (CEC 2011:94). Several prominent rivers are associated with this area. Namely the Rio Grande, Rio Conchos, and Pecos rivers with many additional intermittent streams (CEC 2011:94). The terrain in this region is comprised mostly of valleys and basins that abut sloped terraces (CEC 2011:94). No archaeological sites used in this study are found in this ecoregion. All sites occur farther to the west in the Piedmonts and Plains of the Sierra Madre and the Sierra Madre Occidental regions.

Madrean Archipelago

The Madrean Archipelago divides the Rocky Mountains from the Sierra Madre Occidental and is located along the southern borders of Arizona and New Mexico in the United States, and the northern border of Sonora in Mexico (CEC 2011:97). This ecoregion is the smallest of the four found within the study area. It accounts for only 24 km², or .14% of the total area. It is a region marked by temperate winters and hot summers with annual precipitation averaging 421 mm (CEC 2011:97). The terrain is made up of basins and ranges, with relief on the ranges ranging from 1,000 to 5,000 meters (CEC 2011:97). Vegetation is similar to the Chihuahuan Desert with mesquite, yucca, agave, oak, pine, and juniper found at varying elevations (CEC 2011:97). Very little surface water exists in this area and streams are usually intermittent (CEC 2011:97).
Elevation varies between 800 and 3,000 meters above sea level (CEC 2011:94).

**Piedmonts and Plains**

The Piedmonts and Plains of the Western Sierra Madre Piedmont extends through the center of the study area from northwest to southeast and covers 9,270 km², or 52.46% of the total land area. This large region has average annual temperatures ranging from 54°F to 64°F (CEC 2011:97). Summer rain storms occur frequently, but the climate is classified as predominantly dry (CEC 2011:97). This region has numerous intermittent streams but there is no perennial surface water (CEC 2011:98). The intermittent springs found throughout this area provide substantial amounts of water to the Casas Grandes and Santa María basins (CEC 2011:98). Elevation throughout this region ranges from 1,200 to 2,500 meters above sea level, with an average elevation of 1,900 meters above sea level (CEC 2011:98). The terrain is comprised primarily of plains and hills, and nearly half of the vegetation is naturally occurring grasslands with pine, oak, and mesquite forests also present (CEC 2011:98). The site of Paquimé falls within this ecoregion, as do all but twenty of the 381 sites recorded by Whalen and Minnis during their extensive survey.

**Sierra Madre Occidental**

The Sierra Madre Occidental covers 6,237 km² of the western portion of the study area and accounts for 35.29% of the total area. It is the second largest ecoregion in the study area. Roughly 81% of the Sierra Madre Occidental is covered in pine and oak forests, and the region has an average elevation of 2,400 m above sea level (CEC 2011:101). The terrain of this region is marked by deep canyons, sierras, and plateaus (CEC 2011:102). The climate is classified as semi-humid and temperate (CEC 2011:101). This area experiences dry seasons during the winter and spring months with heavy rains occurring throughout the summer and autumn months (CEC 2011:101). Water from these mountains feed the rivers, streams, and closed drainage basins found in the Chihuahua Desert (CEC 2011:102). The twenty sites recorded by Whalen and
Minnis that are not part of the Piedmonts and Plains all fall within this Sierra Madre Occidental region.

While the ecoregions found within the study area are varied in regard to climate, vegetation, and elevation, sites are concentrated primarily in the Piedmonts and Plains ecoregion with a few sites falling within the boundaries of the Sierra Madre Occidental. Despite the concentration of sites within these two regions, all four ecoregions played a significant role in shaping the predictive model.
This chapter is a literature review of the archaeological, and more specifically, the settlement work that has been conducted in the broader Casas Grandes cultural area. This review is presented chronologically beginning in the early 1500s and concluding with research that has been published within the last five years. The purpose of this chapter is to provide an overview of the settlement research that has been conducted for the area to identify aspects of settlement research that are still lacking for the region. To begin, early accounts of Paquimé as referenced by Spanish, American, and Norwegian explorers in the sixteenth century is discussed. A brief summary of the survey and excavation work of Charles Di Peso follows. The intensive survey and settlement work conducted by Whalen and Minnis in the late 1990s, as well as the work conducted by the Proyecto Arqueológico Chihuahua (PAC) in the southeastern portion of the cultural area, is also discussed. The settlement work that has been conducted for the Medio period in the Casas Grandes area is summarized in detail.

**EARLY ACCOUNTS**

The first historical account of the ruins of Paquimé was written a mere 86 years after the presumed fall and abandonment of the site. At the end of an eight-year excursion, Álvar Núñez Cabeza de Vaca, who led the Narváez Expedition, explored the southern portion of the Casas Grandes area in 1536, and may have been the first European to see the remnants of Paquimé (Di Peso et al. 1974a:58). In 1565, almost twenty years after that first recorded European excursion,
Francisco de Ibarra travelled across the Sierra Madre Occidental on his way to Sinaloa and came across the remains of the site. The locals informed him that the occupants of Paquimé had moved a six-day journey to the north (Hammond and Rey 1928:205–207).

Baltazar de Obregón explored Paquimé in the 1540s and 1560s and recorded a description of the site that would be the last historical account for nearly one hundred years (see Hammond and Rey 1928). It was not until 1663 that the Spanish returned to northwestern Mexico, and they had come to stay. It was in 1663 that they established a settlement and mission near the ruins of Paquimé (Di Peso et al. 1974d:863–864). In 1883, more than two hundred years after that first Spanish mission was established in Casas Grandes, Bancroft (1886) wrote about connections between sites in Arizona and New Mexico to Paquimé as part of his Native Races publications. Following Bancroft, Bandelier (1890) published a description of Casas Grandes in which he speculated on the structures and artifacts at Paquimé.

In 1902 Norwegian explorer and ethnographer Carl Lumholtz concluded a five-year expedition which included a study of Chihuahua and Sonora. He even participated in excavation near Casas Grandes during that time (Lumholtz 1902). The early 1900s saw Paquimé referenced in several publications on Southwest archaeology. While they were not extensively researched, references in publications came from Blackiston (1906, 1909) as well as the 1916 publication by Kidder, “The Pottery of the Casas Grandes District, Chihuahua.” Weissheimer (1917) referenced Paquimé in his analysis of the San Joaquin Valley of California.

In addition to these early accounts of Paquimé, Brand and Sayles conducted extensive reconnaissance research in the 1930s throughout northern Chihuahua. Brand published through the 1930s on the natural landscape, resources, distribution of pottery, extent of the Chihuahuan cultural area, as well as the relationships between the southwest United States and northern Mexico (1933, 1935, 1937, 1943). Sayles (1936) published his work on the archaeological survey he conducted in Chihuahua through the Gila Pueblo Archaeological Foundation. In that
study he focused on the origins of the inhabitants of Paquimé and argued that it was the principal site in the region and had roots in the Pueblo cultures of the Southwest. These early accounts provided the foundation of research for the ruins of Paquimé and many of the surrounding sites that Di Peso and others would use to conduct more intensive and extensive survey and excavation work as well as research in the following years.

**DI PESO AND BEYOND**

The time between 1958 and 1961 marked the most extensive project that had ever been undertaken in the Casas Grandes region. In September 1958, with Charles C. Di Peso representing the Amerind Foundation based in Dragoon, Arizona, and Eduardo Contreras representing the Instituto de Antropología e Historia (INAH) of Mexico, the Joint Casas Grandes Expedition began. This effort focused on the excavation of the ruins of Paquimé, but additional research was carried out at the Convento Site and surrounding areas north of Paquimé one year later (Di Peso et al. 1974b:40). In addition to excavation work at Convento and Paquimé, a reconnaissance survey was undertaken during the summer of 1959. These efforts were led by M. Harvey Taylor of Brigham Young University and resulted in the recording of over 1,000 sites (Di Peso et. 1974b:38). Using local informants as guides, Taylor and Di Peso drove across the Casas Grandes area and without ground truthing the locations they recorded sites on a large-scale topographic map. This “dashboard survey” resulted in a map published as part of a multi-volume publication on the work conducted in the Casas Grandes area. Whalen and Minnis (1996:733) conducted an extensive study to locate records and exact locations for these sites, however nothing finite was found.

After excavations were competed on the Joint Casas Grandes Expedition, and for the next thirteen years, the crew at the Amerind worked tirelessly to analyze the artifacts that had been collected during the three-year excavation period. This work culminated in an eight-volume publication by Di Peso et al. in 1974 that is considered to be the seminal work for the Casas Grandes area.

During the 1990s, archaeological work in the Casas Grandes region continued to expand. Whalen and Minnis, archaeologists from the University of Tulsa and the University of Oklahoma respectively, conducted extensive survey work in the area in the late 1980s and early 1990s. As their survey and analysis of settlement make up much of the settlement work conducted for this region, and as the site information used in this thesis comes from these early surveys, a more extensive overview of their work will be given in the coming pages. In addition to the work done by Whalen and Minnis, Kelley et al. (1999) began work on the Proyecto Arqueológico Chihuahua (PAC) project. Their excavations and study focused on the southeastern edge of the Casas Grandes area including the Babicora Basin, the upper Rio Santa María, and upper Rio Carmen areas. Their research has included both Viejo and Medio period sites. As mentioned above, Dean and Ravesloot (1993) wrote a chronology of cultural interactions for the “Gran Chichimeca” for the Amerind Foundation.

From 2000 to 2013 a new generation of archaeologists began working in the Casas Grandes region. Bradley (2000) published “Recent Advances in Chihuahuan Archaeology” for the University of Utah. VanPool and VanPool (2002), both from the University of Missouri, began their work analyzing and interpreting iconography, as well as social, ritual, and religious beliefs at Paquimé. Stewart et al. (2005) reported on the documentation of 122 sites with Viejo and/or Medio period components in the southeastern portion of the Casas Grandes cultural area and
their survey in the valley of the Casas Grandes river, close to Ignacio Zaragoza (Stewart et al. 2005:176).

Todd Pitezel directed the Cerro de Moctezuma Prehistoric Trails Survey in 2006 and in 2011 he also completed his dissertation from the University of Arizona on the Medio period hilltop site of El Pueblito (Pitezel 2007, 2011). In 2012 Pitezel and Searcy (2013) co-directed the Viejo Period Preliminary Survey south of Paquimé where they identified five Viejo period sites. In 2015 Searcy and Pitezel (2017) excavated a Viejo period site near Paquimé and recorded and documented a basalt quarry. Ure and Searcy (2016) documented and mapped several sites in the Casas Grandes region using unmanned aerial vehicles (UAVs).

Since 2005, several archaeologists working in the area have focused on examining the Viejo period and resolving issues with chronology, site distribution, subsistence, architectural variation, social identity, and trade (see Kelley et al. 2012; Kelley and Searcy 2015; Pitezel and Searcy 2013; Searcy and Pitezel 2017; Stewart et al. 2005). Research focused on the Medio period has continued as well, with focus being given to ecology, production of goods at Paquimé, religion and cosmology, settlement, regional social identity, and the fall of Paquimé (see Douglas and MacWilliams 2015; Kelley and Burd-Larkin 2003; Minnis and Whalen 2015; Punzo and Villalpando 2015; Rakita and Cruz 2015; VanPool and VanPool 2015; Whalen and Pitezel 2015). Additionally, a number of archaeologists have argued that the area being studied by the Proyecto Arqueológico Chihuahua that lies southeast of Paquimé was beyond the influence and control of the local power at Paquimé during the Medio period (see Kelley et al. 1999:76, Kelley and Phillips 2017:77; Whalen and Minnis 2001a:53). Several of these works will be discussed in the coming pages.

WHALEN AND MINNIS SETTLEMENT SURVEYS

In an article on the production of goods at Paquimé during the Medio period, Whalen and Minnis (1996) argued that it was necessary to examine the artifacts and architectural styles
within an area that are shared among the communities in order to define a regional system. To conduct a regional study of that kind, Whalen and Minnis used the occurrences of eight Medio period polychrome wares across four areas surveyed in 1989 (Figure 3.1). The first area was a tract of land, approximately 30 km long, extending west of Paquimé to the Sierra Madre mountain range, which they named the Casas Grandes unit. The second area was 50 km south of Paquimé and was identified as the Santa Maria unit. The third area was located 50 km north of Paquimé which they termed the San Pedro unit. The final area, the Carretas unit, was located 100 km north of Paquimé. These survey units were selected because they are located in between Paquimé and the farthest reaches of its influence to the west and north, where much of the regional interaction analyses had been focused (Whalen and Minnis 1996:175). In subsequent years, Whalen and Minnis (2001a:318) conducted intensive surveys in select portions of the original 1989 survey (Figure 3.2).

Whalen and Minnis recognized that one assumption of their study was that the more alike ceramic assemblages were between two areas, the stronger the level of interaction would have been between them as well (Whalen and Minnis 1996:175–176). Based on this assumption, as well as the polychrome ceramic distributions across the four survey areas, Whalen and Minnis concluded that the most intensive interaction occurred in the area between Paquimé and the San Pedro river, approximately 60 km to the north, with comparatively less interaction between Paquimé and either the Santa Maria unit or the Carretas unit (Whalen and Minnis 1996:177). Additionally, they determined that macaw cage entryway stones were only recovered from surface collections gathered at sites with distances less than 30 km from Paquimé. They argued that the absence of these macaw stones from areas beyond 30 km did not indicate that the raising of macaws was limited only to the area surrounding Paquimé, but that the production of macaws was considerably less in the other zones (Whalen and Minnis 1996:180). They noted that as early as 1991, the PAC project was reporting the existence of macaw cage entryways 150 km southeast
of Paquimé. They argued that these occurrences denote that at that distance, the communities in that region were beyond the influence of Paquimé (Whalen and Minnis 1996:180).

They also argued for the possibility of using the distribution of shell and other imports as an indicator of interaction between Paquimé and the surrounding communities. They claimed that in order to see that level of interaction more completely, excavation work at those sites was needed (Whalen and Minnis 1996:179). They did find a “faint pattern” in their regional analysis of shell recovered from their 1989 surface collections (Whalen and Minnis 1996:179). Findings on shell distribution were similar to the findings on the distribution of polychrome ceramics, with an apparent higher frequency of distribution in the area between Paquimé and the San Pedro River 60 km to the north (Whalen and Minnis 1996:179).

Whalen and Minnis subdivided the more intensive zone of influence around Paquimé into
two levels of interaction. The 30 km zone surrounding Paquimé was identified as being “more tightly integrated than outlying areas,” based on percentages of stone circles, ballcourts, and macaw stones compared to the other zones (Whalen and Minnis 1996:180). In subsequent publications, Whalen and Minnis have modified the geographical extent as well as the terms used to identify the zones of interaction, which will be discussed in detail below (Whalen and Minnis 2001a, 2009).

In their 2001 book Whalen and Minnis subdivide this more integrated area into several distinct zones (Whalen and Minnis 2001a:82). They use a core-periphery model in their identification and designation of these zones. They described the core-periphery model in these terms:
The core is the system’s best-organized part, where interaction, integration, and cultural homogeneity are all at their highest levels, and from which emanates such political and economic power as the society can generate…Peripheries, in contrast, are areas of variable size and composition that lie outside the core’s zone of intense interaction and integration. Peripheries are characterized by lower levels of political and economic development and organization than are found in the core, and peripheral people may speak other languages and have different cultural traditions. Peripheries are affected by their cores in different ways and to variable degrees, the precise situation depending on the nature of the regional system in question [2001a:15-16].

They saw the Inner zone radiating outward from Paquimé as the “core,” and an area beyond the core to the northwest as a “near periphery” to the core that they called a Middle zone (Whalen and Minnis 2001a:193–194). Furthermore, they distinguished an inner core zone extending 15 km from Paquimé, and an outer core zone 15–30 km beyond the inner core zone (Figure 3.3, Whalen and Minnis 2001a:82, 194). Additionally, they identified a middle zone that ranged from 30–75 km to the northwest of Paquimé and conclude that “in this near periphery…we may be seeing the farthest extent of a political economy centered on Casas Grandes” (Whalen and Minnis 2001a:82, 193).

These zone designations were made using site information collected by Whalen and Minnis in 1989, 1990, 1994, and 1995 for more than 380 sites in the region. Most of these sites fell within the Middle zone (210), while 171 sites were found in the Inner zone. Based on this core-periphery model Whalen and Minnis identified seven classes of features with which to gauge functionality and integration for the three hundred Medio period sites identified in their surveys. These seven classes included: small ovens and fire pits (small scale domestic facilities), large ovens (used for food processing on a large scale), check dams (trincheras), stone alignments,
Figure 3.3. Intensive zone of influence as outlined by Whalen and Minnis (2001a), with Inner Core (15 km), Outer Core (30 km), and Middle (75 km) zones illustrated.
trash middens, I-shaped ball courts, and macaw cages (2001a:125–129). The authors analyzed the frequencies of these features for each zone. They concluded that the Inner zone had presence of all seven features whereas the Middle zone lacked trash middens, I-shaped ball courts, and macaw cages. Additionally, the features found in the Middle zone were often simpler and occurred half as frequently as those found in the Inner zone. They also analyzed mound height, mound shape, assemblages, and proximity to other structures for both the Inner and Middle zones. This was all done in an effort to reexamine Di Peso’s Casas Grandes culture area and to determine the functionality of both the site of Paquimé, and the extent of its surrounding hinterland.

Whalen and Minnis attempted to arrange a hierarchy for the sites in their study. Central Place Theory was utilized to interpret settlement hierarchies, size, and distribution patterns. They concluded that this theory was inefficient to cope with the elements of the dataset and used instead a Rank-Size Analysis model to give a more comprehensive interpretation. According to this model, settlements are ranked in a descending order by size. A numerical value is established for each site, the first being the largest and so forth. Based on these numerical assignments, a graph is utilized to illustrate the relationships between the sites. Two different types of graphs were represented in the model. The first graph was concave and represented a disparity between the first ranked settlement and all other sites. The second-ranked sites were smaller than what the rank-size rule predicted, based on the size of the first ranked site which is often termed the “Primate” site (in this case, Paquimé). The second graph was a convex graph which showed that all sites ranked below the first-ranked site were larger than the rank-size predicted based on the size of the first-ranked site. This graph represented a reduced level of settlement system organization.

In their study, Whalen and Minnis (2001a:161) concluded that the Inner zone shows a concave or primate pattern, with the site of Casas Grandes being six times larger than the largest
site in the Inner zone. They determined this settlement pattern to have a dendritic distribution, where the smaller sites share a connection to the Primate site but are independent of each other. Analysis of the Middle zone resulted in a convex graph, where the secondary sites were larger than was expected in the model and suggests a decrease in settlement organization. Whalen and Minnis conclude that while the ceramic assemblages and architecture for both zones are similar, the Middle zone settlements are smaller, simpler, lack core features, and possessed less intercommunity organization. These findings reflect the Core-Periphery model (2001a:176).

In their 2009 book, The Neighbors of Casas Grandes, Whalen and Minnis again investigated the regional system around Casas Grandes. In this publication they abandon the use of the terms “inner core” and “outer core” and designate the 30 km area around Paquimé as simply the Core/Inner zone. They determined that the largest average site size in the region was found in this Inner zone, and that an average distance between small or medium sized sites from the larger sites was 2.5 km (Whalen and Minnis 2009:3). The authors state that the Middle zone, or near-periphery, extended from approximately 30–90 km from Paquimé. They note the absence and/or differences in features between the Middle and Inner zones. Notably, the distance between the smaller and larger sites, simpler settlements, and the absence or rarity of ballcourts, terrace systems, and large ovens (Whalen and Minnis 2009:4). Whalen and Minnis reiterated that there was an increased level of organization and control within the Core zone by the elite population of Paquimé. They used Timothy Earle’s 1997 analysis of power sources among mid-level societies to argue that the elite of Paquimé derived their power from both a political economy as well as a regional ideology (Whalen and Minnis 2009:5). Evidences for each of these power sources included the distribution of prestige goods, long-distance trade, the production and construction of large terrace systems, and the presence of ritual architecture in the form of ballcourts.

They examined community complexity within this broader framework of regional and power systems by excavating four Medio period sites within the Core zone. These sites varied in size
and included a large community, small village, and a small ritual and administrative center. They evaluated Medio period architecture by comparing architectural characteristics between Paquimé and residential sites throughout the region. Characteristics included construction techniques, room size, room shape, room function, and wall thickness. They also analyzed elements such as doorways, wall niches, platforms, stairways, columns, and hearths. In addition to the architectural characteristics Whalen and Minnis also examined changes in ceramic production and function during the Medio period (Whalen and Minnis 2009:110–182).

ADDITIONAL RESEARCH

In addition to the settlement research carried out by Whalen and Minnis, Douglas (1995) included Paquimé in his regional systems examination of the Southwest. He discussed the organizational scale of sites throughout the Southwest and argued that site size should not automatically be equated with community size. He examined the core-periphery model utilized by Minnis in the early 1980s and the distribution of exotic goods in the peripheries of Paquimé influence. He argued that there were three problems with Minnis’s analysis. Douglas first questioned the expectation that integration leads to greater amounts of prestige goods. Second, Douglas did not consider the excavation data for the region to be adequate for the comparisons made by Minnis. Douglas argued that it was inappropriate to compare the Animas phase with the Classic Mimbres (Douglas 1995:246). Douglas noted that rather than the core-periphery model, Minnis has also suggested a peer-polity interaction as an alternative approach (Douglas 1995:248). Douglas suggested that the 1995 settlement data by Whalen and Minnis, which is based on settlement hierarchy, the distribution of goods, integrative features such as ballcourts and hilltop sites, and stylistic integration, does not support the Animas phase area as a periphery of Paquimé (Douglas 1995:248).

Fish and Fish (1999) reviewed the studies undertaken to examine what they termed the Casas Grandes-Borderlands interaction and they also examined the outer limit of the Casas Grandes
periphery. Specifically, they studied the Animas sphere and the Malpais Borderlands. The authors insisted that “the scale and shape of the Casas Grandes systems in the north must be understood in terms of dynamics and interactions within [the] area” (Fish and Fish 1999:27). They affirmed that across the Southwest late prehistoric peoples were gathering in locations that were favorable for irrigation (Fish and Fish 1999:28). They discussed chronology for the region and noted the reevaluation of tree-ring dates for the site of Paquimé that show major occupation between A.D. 1200–1250 and 1450, or even a possible late date of A.D. 1500 (Fish and Fish 1999:29). In a discussion of settlement hierarchies, they acknowledged the use of site size rankings in many of the analyses performed for the area, as well as the presence and absence of ritual features in identifying “communal nodes” (Fish and Fish 1999:36). They also discussed the presence of traits such as architecture, ceramics, and prestige goods to highlight the debates regarding the level of influence and control from Paquimé over the Animas area and regional integration and interaction.

Swanson (1997, 2003) assessed the hilltop platform features in the area around Paquimé to determine if the features had been used as communication networks. He referenced other signaling systems in the Southwest, including sites near Chaco Canyon, in the Río Sonora Valley of Sonora, and in the Kayenta Region of Arizona, and argued that his analysis provided important information for the interpretation of regional integration and interaction for the Casas Grandes area. He employed GIS-based intervisibility analysis to conduct his study. In all, 107 hills were surveyed, and 24 features were recorded. Line-of-sight analysis was performed using GIS techniques and he cross-examined his analysis with field observations. Ethnographic examples were given of fire-signaling systems to argue that the system in the Paquimé area may have been multifunctional. Swanson argued that the most common feature types for these signaling systems were pyramidal, rectangular, or oval/circular platforms, and that they were only found on hilltops or crests of ridges (Swanson 2003:757–758). Swanson assumed Medio
period use for the 23 platform features and an additional atalaya. He used 60 km as the maximum signal distance and “established 101 lines-of-sight between the 24 recorded platform locations” (Swanson 2003:760). He argued that the hilltop platforms were ideally located for the purposes of fire-signaling and that the intervisibility was statistically higher than a random sample. Minnis (1984), Di Peso et al. (1974a), and Douglas (1995) have also considered these atalayas as signaling locations. Unfortunately, the site information collected by Swanson for these hilltop features is not included in this predictive model, as it is currently unavailable.

In an article Minnis et al. (2006) examined the size of upland agricultural fields in comparison to the size of associated sites to argue for administrative control of agricultural production from the elite of Paquimé. It was Di Peso who first claimed that there was military control over agricultural production in the Casas Grandes area (Minnis et al. 2006:708). Schmidt and Gerald (1988) argued that rather than control coming from a centralized political power, the construction of upland fields was carried out by individual families. Minnis et al. (2006) argued that there was at least some control of agricultural production by the elite of Paquimé.

Minnis et al. (2006) argued that the foundation of the economy in Casas Grandes was likely farming and that upland farming probably had lower and less predictable yields. They note the presence of water control systems as evidences of irrigation, which included lithic mulching, stone alignments, and check dams to support their claim for centralized control over the production of agriculture. The authors also stated that one of the goals of their 2005 survey was to acquire more information on upland field locations, particularly those that seemed to be associated with larger sites and ritual or administrative locations (Minnis et al. 2006:711). They divided the locations of the upland field locations into three types: special, administrative/ritual sites in sparsely populated locations, large sites, and a category for all other types that they designated as “other” (Minnis et al. 2006:712).

They recorded and mapped a total of 183 fields, with all but six being relatively small. They
found that check dams were located on “gentle slopes, ranging from two to eight degrees” and that most were a “single course of stones” (Minnis et al. 2006:712). One significant observation made during this study was that the larger agricultural fields were not located near the larger residential sites, but to the smaller sites. The authors suggested these smaller sites “played special administrative and/or ritual roles” (Minnis et al. 2006:715). These fields have not been included in the current predictive model due to the unavailability of the data at the time of the analysis.

A summary of settlement pattern information for the region was given by Whalen and Pitezel (2015) who divided the information into four different time intervals beginning with the preceramic and ending with the post-Paquimé period. In discussing the Medio Period, the authors remarked on mound size estimations, site size comparisons, population densities, room block sizes, architectural features, site clustering, and the relationship between Paquimé and the Core and Middle zones as outlined by Whalen and Minnis in their 2001a and 2009 publications. Whalen and Pitezel provided geographical site location descriptions for the Core and Middle zones and stated that the sites were found clustered near arable land and water in primary and secondary drainages (Whalen and Pitezel 2015:115). They also observed settlement clustering in the Outer Core zone. Each of the clusters were located 20 km from Paquimé and 20 km from one another (Whalen and Pitezel 2015:117). Clustering was not observed in the Middle zone, and this factor (as well as presence of certain features/artifacts) was used to argue for a lower level of structure and organization in the Middle zone than in the Core zone.

The prehistoric features that have been found in the region surrounding Paquimé have been explored and researched for nearly 500 years. Extensive archaeological work has been conducted throughout the Casas Grandes region, with much being published regarding the social, political, economic, and geographical influences of the Casas Grandes culture. Studies regarding settlement and site distributions at a regional scale have added to our understanding of Medio period occupation in the Casas Grandes area. This thesis focuses on features of settlement that
have yet to be studied for this area of northern Mexico. Specifically, cost to traverse distances
to major environmental and cultural features, including the cost to traverse to the central site
of Paquimé is an avenue of inquiry that has yet to be analyzed. Additionally, the regional
relationships between Medio period sites and environmental features such as topography,
ecoregion, elevation, aspect, and slope have yet to be published. These relationships, along with
others used in this thesis, will not only add to our understanding of Medio period settlement, but
will assist in future reconnaissance efforts.
In *Ancient Paquimé and the Casas Grandes World*, editors Minnis and Whalen outlined six critical issues for the archaeology of the Casas Grandes region. They listed among the priorities: (a) more fieldwork, survey, and excavation, and (b) determination of settlement patterns and regional comparisons (2015:14). They argued that these issues are of particular concern, and are needed, as archaeological work continues in the area (2015:14–15). This thesis addresses these critical issues in part by refining survey methods through predictive modeling, as well as examining aspects of Medio period residential settlement patterns at a regional level, and in ways that have not been previously attempted.

This chapter begins with a summary of the functions and capabilities of a geodatabase as it was applied to this study. A discussion of the power, uses, and components of predictive modeling follows. Binary logistic regression as it applies to predictive modeling is addressed, including the methods to set up the analysis and the necessary datasets to carry it out. The remainder of the chapter is dedicated to a description of the dependent and independent variables used in the GIS, binary logistic regression analyses, and the predictive model, and includes such information as site data, non-site data, environmental and cultural variables, and the resulting datasets from the GIS analyses. Where applicable, variable file and attribute names are given in parentheses.
GEODATABASE

Geodatabases allow GIS data files to be stored, managed, edited, and analyzed in a single, dynamic collection comprised mainly of feature classes and raster datasets (ESRI 2018a). Over 50 datasets were collected and standardized for inclusion in the geodatabase created in this study. The data brought together represent the most comprehensive geodatabase for the Casas Grandes cultural area and represent 60 years of archaeological work conducted in the region. Currently, site location information for more than 1,600 sites has been added to the geodatabase. These sites are spread across the broader Casas Grandes cultural area. The Di Peso (1974a) map shows site locations for over 1,000 sites in the Casas Grandes River valley alone (Figure 4.1). While descriptive information for the sites in the Di Peso map is nonexistent, several researchers agree that the densities of sites represented on the map are likely to be accurate (Lekson et al. 2004; Whalen and Pitezel 2015). If the site densities illustrated by Di Peso are indeed correct, then by implementing the results of this predictive model to the survey efforts in the Casas Grandes area it will be possible to increase the number of sites that are currently in the geodatabase.

PREDICTIVE MODELING

Warren and Asch (2000) have stated that predictive modeling applies known site patterns and relationships to places where those patterns are unknown. The advancement of computer-based GIS platforms has made the identification and study of archaeological settlement patterns and predictive modeling a more cost- and time-efficient endeavor. The capabilities of a GIS to manage large geospatial datasets has allowed researchers to bring together vast quantities of data to incorporate into predictive modeling research. In addition, the implementation of computer-based statistical programs has allowed for quantitative analyses of geospatial data to be conducted at an unparalleled rate. By applying GIS and computer-based statistical analyses, modeling settlement patterns can be done at a larger scale and at a higher resolution than ever before.
Figure 4.1. Section of Di Peso map showing site densities for the Casas Grandes river valley (Di Peso 1974).
Predictive modeling is one tool that is frequently used to identify locations within a research area that have a high probability of containing previously unrecorded archaeological sites. Stančič and Kvamme (1999) detailed the two approaches, inductive and deductive models, of predictive modeling in archaeology. Inductive models are built using basic archaeological data and are based on patterns from that data (Stančič and Kvamme 1999:231). Deductive models, on the other hand, begin with theory and knowledge of the culture being studied and attempt to arrive at conclusions regarding settlement (Stančič and Kvamme 1999:231). This thesis implements an inductive approach to predictive modeling through binary logistic regression methods. Stančič and Kvamme affirmed that logistic regression methodology is usually applied to inductive modeling and is a powerful approach that can elucidate the relationships between sites and the variables used in the analysis (Stančič and Kvamme 1999:2013). Heilen et al. (2013) explained that inductive models are built on the observed relationships between site locations and cultural and environmental variables. They argued that during the testing phase of inductive modeling this type of model often outperforms deductive approaches as the former is based on associations and the latter is based on interpretation (Heilen et al. 2013:87). Others have suggested that “a good case can be made that all archaeologists wishing to build models for locational behavior should work within a predictive framework rather than applying their theories post hoc” (Kohler and Parker 1986:398).

Since the 1988 publication of Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling, edited by Judge and Sebastian, many archaeologists have used predictive modeling in their research (Finke et al. 2008; Ford et al. 2009; Heilen et al. 2013; Hill et al. 2006; Holton 2014; Kvamme 1992a; Stančič and Kvamme 1999; Warren and Asch 2000; Wright et al. 2014). The application of this method is predominantly used for site locational modeling and has been conducted within a GIS framework. Predictive modeling has been a commonly used tool for cultural resource
management companies in the United States in identifying areas of focus for surveys that spread over vast tracts of land (Heilen et al. 2013; Hill et al. 2006; MNDOT 2018).

Even before Judge and Sebastian published their influential book, Custer et al. (1986:584) used LANDSAT data and logistic regression techniques to determine quantitative links between environmental variables and site locations in the coastal plains of Delaware. Custer and his colleagues (1986:573–574) examined the environmental variables associated with known site locations as well as known non-site locations and used the data to produce a predictive model for the area. To generate the predictive model they examined several combinations of environmental variables at a regional level that demonstrated statistically significant relationships with known site locations.

A review of the literature on predictive modeling in archaeology revealed that while there have been numerous publications on the results of these studies, very few publications have outlined the specific methods researchers have used to construct and carry out their predictive models. Several notable exceptions include a technical report written by Heilen et al. (2013) in which they discussed effective tools and models in archaeological sensitivity modeling, a master’s thesis by Holton (2014) who created a predictive model for archaeological sites in northeastern Arizona, and a study conducted by Warren and Asch (2000) who created a predictive model for site locations in the Prairie Peninsula of Illinois.

In a settlement pattern study conducted by Ford et al. (2009), Ford and her colleagues used GIS and Bayesian methods to model settlement patterns for Late Classic Maya sites in the southern Yucatan Peninsula. The authors claimed that site location decision-making was heavily influenced by environmental factors such as slope, soil fertility, and soil drainage. In their study, Ford and her associates used a weights-of-evidence statistical technique on known archaeological site data. This weights-of-evidence method is another approach to predictive modeling and is a probabilistic spatial model that uses known site locations to classify the study
The weight-of-evidence method was used because the weights, or degrees, to which each environmental factor impacted the location of each site was considered variable. Each weight was classified into distinct categories, for example from low to high or one to four. They first used existing survey data to identify an application zone and to develop a model. They then expanded the original model to include a validation zone, which was then verified through fieldwork. In ground-truthing their predictive model, the team found and recorded 315 previously unknown/unmapped sites predominantly located in the very high and high-probability areas as calculated by the model. In all, they determined that four geographic and environmental factors predicted 82 percent of sites in the high-probability areas.

The methods used in my thesis are drawn from a study conducted by Holton in 2014. In that study Holton used predictive modeling within a GIS framework to aid in survey efforts to identify archaeological site locations across a large region in northeastern Arizona. Holton created a predictive model to categorize areas of varying probabilities for site locations across the landscape, which allowed researchers to focus their survey efforts on the high-probability areas (Holton 2014:1). Holton also used a logistic regression approach in creating the predictive model for his study area.

**BINARY LOGISTIC REGRESSION ANALYSIS**

Binary logistic regression examines the mathematical relationship between a dichotomous, dependent variable and any number of independent variables. The dependent variable is represented in a binary expression and is typically indicated as “presence” or “absence.” In the case of this study, the dependent variable is signified as either site or non-site, or in other words “site presence” or “site absence.” It is important to note that while the dependent and independent variable values calculated in the GIS analyses are extracted to a point feature class for use in the binary logistic regression analysis, the predictive model itself is raster-based. The
objective of this study was to examine the pattern of site presence for the raster cells that contain sites in the study area, and to demonstrate statistically the probability of site presence to the rest of the raster cells within the study area based on those patterns. Thus, the presence or absence of a site is a reference to the raster cell in which the site or non-site is located, and not the site/non-site location points themselves.

In this study the binary logistic regression analysis tested the predictive power of each independent variable in a forward stepwise sequence and selected only those variables that combined to be the strongest predictors for the presence of a site. The independent variables used in the binary logistic regression analysis were the same environmental and cultural variables used for the GIS spatial analyses mentioned above. The forward stepwise technique applied to the logistic regression analysis added each independent variable in turn to the model which allowed the model to test the predictive power of each independent variable and ultimately selected only those variables that were the strongest predictors for the dependent variable “site presence” (Warren and Asch 2000:14). Once the predictor variables were identified through the logistic regression analysis, an equation was produced for the probability of site presence. This equation is based on the relationship between the dependent variable and the significant independent variables. It is expressed in terms of a coefficient for each independent variable selected for the model (Holton 2014:12). The equation is expressed as:

$$P(Y) = \frac{1}{1 + (1 + \frac{1}{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \epsilon_1}})}$$

“where $P(Y)$ is the probability of $Y$ occurring, $e$ is the base logarithm, $\beta_0$ is the constant…$\beta_n$ is the regression coefficient corresponding to the independent variable, $X_n$ [and] $\epsilon_1$ is the residual term” (Holton 2014:13).

This equation was then applied to the corresponding statistically significant raster datasets in the GIS to produce a predictive model and probability map of the study area (Warren and Asch 2000:8). The predictive model illustrates the probability value that is assigned to each raster cell
in the study area and denotes the strength of probability for the presence of a site. The probability values range from zero to one, with values near one representing high probability locations and values near zero representing low probability locations for site presence (Holton 2014:13). These values are classified into distinct classes and are represented by a discrete color scale which clearly illustrates which cells are more likely to have the presence of sites, specifically Medio period residential sites.

DEPENDENT VARIABLE

Sites

A dichotomous, dependent variable is required for the binary logistic regression analysis to be carried out. As mentioned, the dependent variable for this study was “site presence”/%”site absence.” Site presence information came from known site locations identified in survey efforts in the Casas Grandes area. Site locations and survey information from Sayles (1936), Di Peso et al. (1974a), Whalen and Minnis (2001a, 2003), Kelley et al. (2012), and Pitezel and Searcy (2013) were collected for inclusion in the geodatabase, and the original design of the project was to utilize all datasets from the various survey projects for the binary logistic regression analysis and predictive model. However, site information acquired from the surveys done by Sayles, Di Peso, and Kelley contained only site location information with limited to no descriptive data. As there was no way to determine site type from these datasets, they were added as files in the geodatabase but were left out of the binary logistic regression analysis and predictive model. Additionally, when the Proyecto Arqueológico Chihuahua data were uploaded into the GIS, all but two of the 211 sites fell outside of the study area boundary used in this project. Site information provided by Whalen and Minnis, Searcy and Pitezel, as well as the Proyecto Arqueológico Chihuahua was already in a digital format. The Sayles and Di Peso site information, as well as the Whalen and Minnis intensive survey boundaries, were acquired from paper-based maps that had to be scanned and georeferenced. The project study area lies across
two separate UTM zones in the WGS84 coordinate system; zones 12 North and 13 North. As a result, site information provided by Whalen and Minnis as well as the Proyecto Arqueológico Chihuahua that was collected in zone 13N had to be reprojected to zone 12N before being included in the geodatabase. This was done using the calculate geometry function within the GIS, which gave each site location situated in zone 13N a false easting and northing based on the 12N projection and allowed all the site information to be combined in to one dataset. This dataset was then saved in the geodatabase as the GIS layer “wm_sites.” GIS layer names generated in this study will be designated in parentheses in the discussions of independent and dependent variables that follow.

While all site location information from the various survey projects was included in the geodatabase, only Medio period residential sites collected by Whalen and Minnis were used for the binary logistic regression analysis and predictive model. These site locations were located during surveys that were conducted as part of their 1989, 1990, 1994, and 1995 field seasons. Efforts from these surveys resulted in the recording of more than 380 sites. Preceramic, Viejo, Medio, and Viejo/Medio period sites were recorded, and site type was listed as either “residential” or “not residential.” The designation of “residential” appeared to be based on the presence of at least one instance of visible surface architecture (i.e. foundations, pueblos, or mounds). Without any additional information regarding site type beyond “residential” or “not residential” there was no way to determine the nature of the site types. As such, sites in the analyses were limited to residential sites with a Medio period component to refine the predictive model. While several predictive models have included sites that dated to multiple time periods (see Campbell 2006; Finke et al. 2008; Heilen et al. 2013; Hill et al. 2006; Holton 2014), the sites in this analysis were limited those that date to the Medio period, again to refine the predictive model and focus in on a single period of occupation in the Casas Grandes area. This approach follows similar studies in predictive modeling (see Custer et al. 1986; Ford et al. 2009;
Preceramic, Viejo period, and non-residential sites, were removed from the dataset for the regression analysis and predictive model. Additionally, two Medio period sites were listed as “residential,” however, neither had any record of architectural features, and the reason for the designation of “residential” could not be determined, so they were also removed from the dataset. Once these sites were removed, a total of 291 residential sites remained for analysis (Figure 4.2). No site size information was available for the sites recorded by Whalen and Minnis. Consequently, only site locational points, rather than polygonal data, were used in this study. The site locational points were assumed to be the site centroids. Furthermore, it was assumed that all Medio period sites represented in this study were contemporaneous, as no designation of early or late Medio was available in the site data. The attribute of “site presence” within the shapefile was designated by the number one to be consistent with the binary logistic regression probability results.

**Non-sites**

Non-site locations were also needed to distinguish characteristics of “site absence” from “site presence” in the binary logistic regression analysis. In order to create the non-site location points, 26-meter buffers were created around each known site within the GIS and exported out as a polygonal feature shape file (wm_buffers). This buffer distance was determined using the shortest distance observed between any two known sites in the survey data. This wm_buffers layer was used in conjunction with the study area polygon shapefile to create a new shapefile of the study area that excluded the 26-meter buffer areas (Figure 4.3, buffers_26). This new polygon of the study area was then used as the extent to create a random points shapefile of non-site locations across the study area. Three hundred individual non-site points were created, and points that fell on the study area boundary line and produced no sampled field values or fell within a lake boundary were deleted. Once these non-site locations were removed from the dataset, 299
Figure 4.2. Medio period residential sites within the study area.
Figure 4.3. Study area with 26-meter buffer zones around each known site removed.
non-site location points remained (Figures 4.4 and 4.5). For each of the non-site locations the attribute value for “site presence” within the shapefile was designated with the number zero to be consistent with the binary logistic regression probability results.

**Training and Testing Datasets**

The construction of both training and testing datasets for binary logistic regression analyses and predictive modeling have been utilized in other archaeological studies (Custer et al. 1986; Holton 2014; Warren and Asch 2000). The 590 site and non-site locational points implemented in this study were divided into two separate sample datasets to be used as training and testing datasets in this study. The first dataset was made up of 394 locational points for both site and non-site locations to be used as a training dataset for the binary logistic regression analysis (Figure 4.6). Of these training sites, 195 were known site locations and 199 were non-site locations. The second dataset was made up of the remaining 196 locational points that were withheld to test the predictive model (Figure 4.7). This testing dataset was comprised of 96 known site locations and 100 non-site locations. This division of datasets was carried out within the GIS and was a random sampling of points. Two thirds of the site locations and two thirds of the non-site locations were randomly selected and combined into a shapefile that would be the training dataset (sites_training). The sites_training file was then exported out of the GIS as a text file to be used in the logistic regression analysis. The remaining one third of site locations and non-site locations were also combined into a shapefile that was used later to test the predictive model (sites_testing).

**INDEPENDENT VARIABLES**

The independent variables used in a binary logistic regression analysis can be either continuous or categorical, which allows for a robust analysis of variable relationships. The independent variables included in this study were: aspect, cost distance to nearest ballcourt, ecoregion, elevation, local relief, cost distance to nearest oven, cost distance to Paquimé, slope,
Figure 4.4. Non-site locations generated within the GIS.
Figure 4.5. Non-site locations in relation to the Whalen and Minnis intensive survey boundaries.
Figure 4.6. Training dataset of site and non-site locations.
Figure 4.7. Testing dataset of site and non-site locations.
soil, terrain texture, topographic position index, cost distance to nearest trincheras, vegetation, vegetation variety to 100 meters, vegetation variety to 500 meters, cost distance to nearest intermittent lake, cost distance to nearest intermittent stream, cost distance to nearest perennial lake, and cost distance to nearest perennial stream. A discussion of the cultural variables included in the analysis (i.e. cost distance to nearest ballcourt, cost distance to nearest oven, etc.) will be included in this chapter.

Two different data types were used in the GIS analyses: primary datasets and secondary datasets. Primary datasets represent those layers in the geodatabase that were not derived within the GIS from other sources. These primary datasets include the digital elevation model (DEM), ecoregion shapefiles, elevation, hydrological shapefiles, Paquimé shapefiles, soil shapefiles, and vegetation shapefiles. All primary datasets had varying coordinate system projections and had to be transformed to ensure an accurate overlay in the GIS. The Project tool in the GIS was used to transform all primary datasets to WGS84 zone 12N. Secondary datasets represent those layers within the geodatabase that were derived from either the primary datasets or from previously existing GIS data. These datasets include aspect, cost distance to nearest ballcourt, elevation, local relief, cost distance to ovens, cost distance to Paquimé, slope, terrain texture, topographic position index, cost distance to nearest trincheras, cost distance to nearest intermittent lake, cost distance to nearest intermittent stream, cost distance to nearest perennial lake, and cost distance to nearest perennial stream. All secondary datasets were projected to the appropriate coordinate system and then added to the geodatabase. The Extract Values to Points tool was used to obtain the raster values for each of the independent variables for all site and non-site locations. As a DEM of 1-arc second was used in this study, each raster cell represents 30 square meters. The raster values extracted within the GIS are attributes for each of the 30 square meters within the study area.
Environmental Variables

Many studies have been conducted on the influence of environmental variables in the selection of site location (see Anderson and Neff 2011; Ford et al. 2009; Heilen et al. 2013; Hill et al. 2006; Holton 2014; Kohler and Parker 1986; Kvamme 1989, 1990; MNDOT 2018; Schermer and Tiffany 1985; Warren and Asch 2000; Wright et al. 2014). Schermer and Tiffany (1985) have stated that “if archaeological sites are in fact strategically located for access to natural resources considered to be important by a particular group, it would be of research value to demonstrate this phenomenon statistically in settlement pattern studies” (Schermer and Tiffany 1985:216). The environmental variables selected for the GIS analyses and the binary logistic regression analysis in this study were chosen to assess the quantitative relationship between known sites and environmental resources in the Casas Grandes area, as well as to statistically demonstrate these patterns in settlement. It is important to note that like all other archaeological predictive models, this study assumes that modern ecological settings are similar to the prehistoric environmental conditions that existed during the Medio period in the Casas Grandes area. As such, the environmental datasets used in the GIS analyses all come from modern records.

Primary Datasets

Digital Elevation Model

One-arc second (30-meter resolution) DEM tiles for the state of Chihuahua were obtained from the Shuttle Radar Topography Mission, an international project led by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) in the United States (NASA 2016). As the research area was comprised of multiple DEM tiles, the tiles were mosaicked to form a single raster image within the GIS. Cell size, band, pixel depth, and native coordinate system information were carried over from the original DEM tiles to the mosaicked raster. The resulting image was then reprojected to the appropriate coordinate
system and clipped to the study area and added to the geodatabase (buffer_12N). This DEM of the study area was subsequently used for elevation values as well as in the generation of several secondary datasets (Figure 4.8).

**Ecoregions**

The use of ecoregions in predictive modeling can be found in a number of different studies (Anderson and Neff 2011; Custer et al. 1986; Heilen et al. 2013; Ortman et al. 2007; Warren and Asch 2000). The ecoregions in the study area differ dramatically and range from dry desert valleys to temperate forests and even dry desert plains (Figure 2.4). With such varied ecological resources in a 75 km radius, ecoregion data was included in the predictive model to assess the statistical significance of its relationship to Medio period site locations.

Ecoregion data for this study was downloaded from the Commission for Environmental Cooperation website (ces.org). The dataset was downloaded as a shapefile and was imported into the GIS. Once the data was projected to the appropriate coordinate system, the 75 km buffer shapefile was used to clip the ecoregion data to the study area (see Figure 2.4). The shapefile was then converted to a raster format to allow for the use of the data in calculating the predictive model. The ecoregion data was added to the geodatabase and raster values were extracted and added as an attribute for site and non-site locations (ecoregion).

**Elevation**

Elevation is one of the standard variables used in archaeological predictive modeling. This environmental variable has been used in many predictive modeling and settlement studies in the United States (see Anderson and Neff 2011; Heilen et al. 2013; Hill et al. 2006; Holton 2014; Kohler and Parker 1986; MNDOT 2018; Schermer and Tiffany 1985; Warren and Asch 2000; Wright et al. 2014). Elevation information was acquired for both the site and non-site locations using the SRTM DEM raster (see Figure 4.8). Elevation values were given in meters above sea level and were extracted as the elevation attribute for site and non-site locations (elevation).
Figure 4.8. The digital elevation model of the study area.
Hydrology

It is difficult to find an archaeological settlement analysis or predictive model that does not incorporate hydrological data in some form. Whether it is present in the form of flood zones, a watershed analysis, or proximity to hydrological resources, the study of water in relation to archaeological sites has been a topic of research in most settlement modeling studies. The relationship between prehistoric site locations and their proximity to water resources can also be found in numerous predictive modeling studies (see Anderson and Neff 2011; Judge and Sebastian 1988; Heilen et al. 2013; Hill et al. 2006; Holton 2014; Kohler and Parker 1986; Schermer and Tiffany 1985; Schwartz et al. 1980; Warren and Asch 2000).

Hydrology data for this study was acquired through the web-based database platform diva-gis.com. This platform was created by the International Potato Centre based in Lima, Peru, and is part of the Consultative Group of International Agricultural Research. Polyline and polygonal data for all of Mexico was downloaded and reprojected to the correct coordinate system within the GIS. Perennial lakes were double checked with historical records to ensure that none of the water bodies were of modern construction. The datasets were then clipped to the boundary of the state of Chihuahua and the file was exported out as separate shapefiles according to water resource type. The four feature shapefiles created were: intermittent streams, intermittent lakes, perennial streams, and perennial lakes (Figure 4.9). These files were subsequently used in the cost to traverse analyses for each of the four water resource types. This analysis was the only one that was not restricted to only those occurrences within the study area. In order to account for the continuation of streams and lakes beyond the defined study boundary, and to reflect a more real-world cost distance analysis, stream and lakes that extended beyond the study area were also included.

Paquimé Centroid

A polygonal graphic shape representing the extent of the Paquimé archaeological zone was
Figure 4.9. Hydrology data by type across the study area.
created in the GIS using basemap satellite imagery. The graphic shape was then converted to a geographic feature shapefile and projected to the appropriate coordinate system. The centroid of the Paquimé archaeological zone was determined using the polygon shapefile in the GIS. Columns for the northing and easting coordinate values were added to the shapefile table and the calculate geometry function was used to find the coordinate values of the centroid. This record was imported back into the GIS as a separate file and converted to a point shapefile representing the centroid of the Paquimé archaeological zone (Figure 4.10; paq_cent_12N).

Once the centroid of Paquimé was determined, the representative point shapefile was used as the input feature to create buffer zones around the site according to Whalen and Minnis’s (2009) and Whalen and Pitezel’s (2015) interaction zones at 15 km, 30 km, and 75 km. Two separate shapefiles were created in the GIS. The first shapefile was a buffer zone that extended to the 75 km extent of the Paquimé influence (Figure 4.11; paq_buffer). The second shapefile contained separate rings of buffers that represented the 15 km, 30 km, and 75 km interaction zones (Figure 4.12; paq_buffers). These shapefiles were added to the geodatabase, and the 75 km buffer shapefile was used to clip many of the primary and secondary datasets to the extent of the study area.

Soil

Soil characteristics have been used in multiple settlement pattern and predictive modeling studies (see Ford et al. 2009; Heilen et al. 2013; Hill et al. 2006; Holton 2014; MNDOT 2018; Schermer and Tiffany 1985; Warren and Asch 2000). Soil information was downloaded from the Instituto Nacional de Estadística y Geografía (INEGI) website in the form of 25 separate shapefile tiles at a scale of 1:250,000. The shapefiles were loaded into the GIS and transformed to the WGS84 12N projection and then mosaicked together and clipped to the study area boundary (Figure 4.13; soil_gp1). The soil type for each site and non-site location was extracted as an attribute to each point shapefile within the GIS (soil). Sixteen different classifications were
Figure 4.10. Map of Paquimé centroid.
Figure 4.11. Map of 75 km buffer around Paquimé.
Figure 4.12. Map of 15 km, 30 km, and 75 km buffers around Paquimé.
present in the study area and all but one classification (NA) were based on the dominant soil group. These groups included leptosol, phaeozem, vertisol, regosol, cambisol, fluvisol, luvisol, calcisol, solonchak, kastañozem, planosol, solonetz, arenosol chernozem, and umbrisol (INEGI 2009:28). The classification of NA represented areas comprised of water bodies or towns (INEGI 2009:iv).

Vegetation

Vegetation, and vegetation variety is often incorporated into predictive modeling and settlement analyses (see Bayman and Sullivan III 2008; Heilen et al. 2013; Hill et al. 2006; Holton 2014; MNDOT 2018; Schermer and Tiffany 1985; Warren and Asch 2000). As with each of the environmental variables selected for inclusion in this analysis, vegetation is one of the variables that is considered to influence site location selection (Allen 2000; Hill et al. 2006). Vegetation information for the study area was obtained through the Instituto Nacional de Estadística y Geografía website in the form of 27 separate shapefile tiles at a scale of 1:250,000. These tiles were mosaicked, reprojected, and clipped to the extent of the study area within the GIS before the file was added to the geodatabase (buff_veg). The three most prevalent vegetation groups were natural grassland, desert scrub, and oak forest. However, 18 distinct plant community classifications were present in the study area (INEGI 2014). The vegetation classification for each site and non-site was extracted and added as an attribute to the respective shapefiles (Figure 4.14; veg). Following similar predictive modeling studies two additional vegetation variables were included in this study. The number of vegetation types, or vegetation variety, within 100- and 500-meter radii from each site and non-site location was also calculated within the GIS (Figures 4.15 and 4.16; Heilen et al. 2013; Holton 2014). These variety counts were added to the site and non-site shapefiles as veg_100 and veg_500 attributes.
Figure 4.13. Map of soil groups within the study area.
Figure 4.14. Map of vegetation within the study area.
Figure 4.15. Map of vegetation variety to 100 meters.
Figure 4.16. Map of vegetation variety to 500 meters.
**Secondary Datasets**

**Aspect**

Aspect, as it applies to GIS, refers to the horizontal direction of the slope of a raster cell in terms of the degrees of a compass (ESRI 2018b). This environmental variable appears in several settlement pattern and predictive modeling studies (see Schermer and Tiffany 1985; Heilen et al. 2013; Holton 2014; Warren and Asch 2000). A DEM of the study area was used as the input surface raster in the GIS to generate the aspect raster. The aspect raster represented the directional degree of the slope for each raster cell. As degree values are based on compass directionality, values such as 0° and 360° both represent a northern aspect. To compensate for this duplicity in degree directionality, the aspect raster was reclassified so that the slope values from north to south ranged in degrees from 0 to 180 (Figure 4.17; aspect_ns). A second raster was calculated so that the slope values from east to west also ranged in degrees from 0 to 180 (Figure 4.18; aspect_ew). Once the aspect raster was reclassified based on these north-south and east-west ranges, values were extracted and added to the site and non-site point shapefiles as aspect_ns and aspect_ew attributes.

**Cost to Traverse**

Numerous environmental and cultural variables used in this study represent a proximity estimation from site/non-site locations to environmental or cultural features. Several options were available within the GIS to calculate the distances. Euclidean distance measures the shortest straight line between two features, however it does not take in to account terrain or cost to traverse across the landscape. For this reason, a cost surface raster was created to account for terrain variability between the site/non-site locations and the environmental and cultural variables to which they were measured. When a cost surface raster is calculated, a cost distance value is given to each cell that represents the cost to traverse through that cell (ESRI 2018c). The cost to traverse value for each cell increased with steeper slope values and/or more drastic
Figure 4.17. Map of north-south aspect.
Figure 4.18. Map of east-west aspect.
relative elevation changes. The cost surface, when used in a cost distance analysis calculates the cost distance value as a weighted distance and represents the least accumulated cost to travel from one location to another (ESRI 2018d). According to ESRI (2018d) the cost distance value is “a unitless system that derives its meaning relative to the cost assigned to other cells.” A cost distance raster is often used to construct a least-cost path between two locations (ESRI 2018e).

Using slope and elevation data, a cost surface raster was created within the GIS to account for terrain texture and slope (Figure 4.19, cost_surface). This method was taken from Heilen et al. (2013), who outlined the process for creating a cost surface raster in their study. The minimum cost value of the cost surface raster was 7.12 while the maximum cost value was 12.24. The cost surface file was used as the input cost raster for generating the least cost distance analyses from site/non-site locations to Paquimé, the nearest known ballcourt, the nearest intermittent lake, the nearest intermittent stream, the nearest oven, the nearest perennial lake, the nearest perennial stream, and the nearest trincheras.

*Cost Distance to Water Resources*

The importance of water in settlement and predictive modeling research has already been discussed in this chapter. In order to perform a proximity analysis from site and non-site locations to the nearest water resource, a cost to traverse analysis was performed. This analysis incorporated four different water types: intermittent lake, intermittent stream, perennial lake, and perennial stream. Four separate cost distance analyses were conducted using the cost_surface raster and each of the water resource shapefiles as the input raster datasets (Figures 4.20–4.23). This analysis was performed to identify the least cost distance to each of the nearest water resource types for site and non-site locations. The cost to traverse values were then extracted as attributes for the site and non-site point locations (int_a_cd_1, int_l_cd_1, per_a_cd_1, per_l_cd_1).
Figure 4.19. Map of the cost to traverse raster.
Figure 4.20. Map of the cost to traverse distance to intermittent lakes.
Figure 4.21. Map of the cost to traverse distance to intermittent streams.
Figure 4.22. Map of the cost to traverse distance to perennial lakes.
Figure 4.23. Map of the cost to traverse distance to perennial streams.
Local Relief

Local relief is a method for measuring terrain roughness and is carried out by calculating the elevation range in a defined area around each raster cell (Heilen et al. 2013:91). The larger the cell value, the greater the change in elevation within that predefined radius (Heilen et al. 2013:91). Local relief rasters for this study were derived using a neighborhood analysis and utilized the slope raster of the study area as the input raster. Rectangular neighborhoods of three by three, six by six, 12 by 12, and 24 by 24 raster cells were used to produce local relief statistics for 90-meter, 180-meter, 360-meter, and 720-meter neighborhoods across the study area (Figures 4.24–4.27). Range was used as the statistic type to calculate the difference between the smallest and largest cell values within the predefined neighborhoods. The local relief rasters were added to the geodatabase and 90-meter (relief_90), 180-meter (relief_180), 360-meter (relief_360), and 720 meter (relief_720) local relief values were extracted for all site and non-site locations.

Slope

Slope refers to the steepness of the surface within a raster cell. This variable is ever present in settlement analysis and predictive modeling studies (Finke et al. 2008; Ford et al. 2009; Heilen et al. 2013; Hill et al. 2006; Holton 2014; Warren and Asch 2000). The DEM of the study area was used to create a slope raster within the GIS (buffer_slope). The cells in this raster were assigned a value in percent for the gradient of each cell. Flat surfaces were assigned a zero percent gradient, 45-degree surfaces were assigned a 100 percent gradient, with the highest gradient in the study area being 128 percent (Figure 4.28). Slope values for all site and non-site locations were extracted within the GIS and added as attributes to both shapefiles (slope).

Terrain Texture

Terrain texture is similar to local relief in that it is a way to measure surface variability across a neighborhood of raster cells and has been used in several archaeological predictive modeling analyses (Heilen et al. 2013; Holton 2014). This variability based on the standard deviation in
Figure 4.24. Map of the local relief to 90 meters within the study area.
Figure 4.25. Map of the local relief to 180 meters within the study area.
Figure 4.26. Map of the local relief to 360 meters within the study area.
Figure 4.27. Map of the local relief to 720 meters within the study area.
Figure 4.28. Map of slope values in the study area.
elevation within defined cell neighborhoods (Heilen et al. 2013:91). As the standard deviation within the neighborhood increases, so does the terrain roughness (Holton 2014:43). For this study, terrain texture was calculated with the same rectangular neighborhoods of three by three, six by six, 12 by 12, and 24 by 24 raster cells. This created terrain statistics for 90-meter, 180-meter, 360-meter, and 720-meter neighborhoods across the study area (Figures 4.29–4.32). Where “range” functioned as the statistic type in the local relief analysis, “standard deviation” functioned as the statistic type for the terrain texture analysis. The terrain texture rasters were added to the geodatabase and 90-meter (terrain_90), 180-meter (terrain_180), 360-meter (terrain_360), and 720-meter (terrain_720) terrain texture values were extracted for all site and non-site locations.

**Topographic Position Index**

The Topographic Position Index (TPI) compares the elevation of each cell in a DEM to the mean elevation of a predefined neighborhood surrounding the cell (Holton 2014; Weiss 2018). Focal statistics were used to calculate the minimum and maximum elevations based on the study area DEM. These rasters were then used in conjunction with the DEM to generate the TPI raster (Figure 4.33). A description of the process to create the TPI raster can be found in the study conducted by Holton (2014). Positive TPI values represent locations that are higher than the average of their surrounding raster cells as defined by the neighborhood and are considered ridges. Negative TPI values represent locations that are lower than their surrounding raster cells and are considered valleys. TPI values close to zero represent flat areas when the slope is also zero, or areas of continuous slope if the slope value is greater than zero (Weiss 2018). The output of the TPI analysis gives a range of values between zero and one, with values near zero representing low areas and values close to one representing higher areas. The TPI values were extracted as attributes for both site and non-site locations (TPI).
Figure 4.29. Map of terrain texture to 90 meters.
Figure 4.30. Map of terrain texture to 180 meters.
Figure 4.31. Map of terrain texture to 360 meters.
Figure 4.32. Map of terrain texture to 720 meters.
Figure 4.33. Map of Topographic Position Index (TPI).
**Cultural Variables**

All independent variables discussed to this point have been environmentally based. However, this study also incorporated a number of culturally based variables in order to examine the relationship between known site locations and known cultural features present within the study area. Ford and her colleagues (2009:514) have argued that variations in the patterns expected from predictive modeling may be explained by religious, political, or economic factors. For this reason, cost distance analyses were calculated from each site and non-site location to Paquimé, the nearest ballcourt, the nearest oven, and the nearest trincheras. Macaw stones, shell, and imports will also be discussed below.

**Secondary Datasets**

*Cost Distance to Ballcourts*

The presence and distribution of ballcourt sites in the Casas Grandes area has been used to examine the degree of interaction and integration among Medio period communities (Whalen and Minnis 1996:743). Additionally, ballcourt distribution within the study area has been used as evidence for competitive rivalry among elites in the inner zone and appears to indicate a lower level of centralized political power than those occurring in other regional systems (Whalen and Minnis 1996:744; Whalen and Minnis 2009:6–7). Due to the limited number of ballcourts found across the survey areas, Whalen and Minnis have suggested that ballcourts did not have a principal role in the broader regional integration, but may have been a component of the political, economic, and ritual activities of the inner zone around Paquimé (Whalen and Minnis 1996:742–744; Whalen and Minnis 2009:6–7).

In an examination of site function within the Casas Grandes regional system, Whalen and Minnis (2001a:150) gave considerable weight to the presence of ballcourts. In their rank-based analysis, they assigned a weighted value of four and five out of six for the presence of either a T-shaped ballcourt or an I-shaped ballcourt respectively (Whalen and Minnis 2001a:150).
Several other researchers have suggested that ballcourt sites were essential to the influence of Paquimé across the region (Douglas 1995; Fish and Fish 1999; Wilcox 1991, 1994). While the number of ballcourts recorded during the mid-1990s surveys were limited in number, they were still included in the binary logistic regression analysis and predictive model based on the weight given to the occurrences of these sites by Whalen and Minnis, and the possible influence they may have had on known site locations.

Twelve ballcourt locations from the Inner and Middle Zones were identified in the Whalen and Minnis survey data. Ten were located in the Inner Zone and two were located in the Middle Zone. Ten of the twelve ballcourt sites were designated as residential sites, which will be reflected in the cost distance calculations for site locations. The twelve ballcourt locations were isolated from the survey point shapefile and exported as a separate shapefile (ballcourts). As three ballcourts are also present at Paquimé, the Paquimé centroid was added to the ballcourt shapefile bringing the total number or recorded ballcourts to 15. All of the ballcourts have been dated to the Medio period and as such were included in the analysis (Whalen and Minnis 1996:737). A cost distance analysis was then conducted using the cost_surface raster and the ballcourt shapefile as the input raster datasets (Figure 4.34). This was done to identify the cost distance to the nearest ballcourt for each of the site and non-site locations. The cost to traverse values were then extracted as attributes for the site and non-site point locations (ball_cd).

Cost Distance to Ovens

It has been suggested that the presence of large ovens at Paquimé, and at multiple sites within the Casas Grandes cultural area, indicate that feasting played an important role in community activities and the political organization of Paquimé (Di Peso et al. 1974a; Minnis 1988; Minnis and Whalen 2005; Minnis et al. 2006; Rakita and Cruz 2015; Whalen and Minnis 2001a, 2003; VanPool 2017). Large pit-ovens excavated by the JCGE at Paquimé indicated evidence of agave roasting practices at an uncommonly large scale for the region (Minnis 1989; Rakita and Cruz
Figure 4.34. Map of the cost to traverse distance to nearest ballcourt.
The excavation and recording of ovens at Paquimé, and across the region, as well as the evidences for large-scale feasting practices, denote an organized and controlled system of production during the Medio period (Rakita and Cruz 2015:71).

Sixty-four Medio period ovens were recorded by Whalen and Minnis over the course of their surveys. The oven locations were isolated from the survey point shapefile and exported as a separate shapefile (ovens). A cost distance analysis was then conducted using the cost_surface raster and the oven shapefile as the input raster datasets to identify the cost distance to the nearest oven across the study area (Figure 4.35). These cost distance values were extracted and added as an attribute to each site non-site location in their respective datasets (ovens_cd).

**Cost Distance to Paquimé**

The importance of Paquimé as a primate center during the Medio period should be considered in any settlement analysis for the Casas Grandes cultural area. As the site of Paquimé is six times larger than the largest site in the Inner Zone, it has been suggested that the comparatively smaller sites in the immediate vicinity of Paquimé (10–15 km), as well as the absence of exotica and ritual architecture and production wares, indicates that these sites were likely connected to the primate center for political, ritual, and social activities (Whalen and Minnis 2001a; Whalen and Pitezel 2015). At a distance just beyond the 15 km radius around the primate center, the recording of ballcourts, ovens, terraces, and macaw cages have been identified as evidence for economic, social, and political control by Paquimé for sites at a distance beyond a day’s journey to the primate center (Whalen and Pitezel 2015:116). Due to the numerous studies outlining the impact, organization, and integration from Paquimé on the sites in the surrounding cultural area, it seemed appropriate to add the cost distance to Paquimé as an additional cultural variable in the logistic regression analysis and predictive model. This analysis was carried out using the cost_surface raster and the Paquimé centroid as the input raster datasets to identify the cost distance to Paquimé for site and non-site locations (Figure 4.36). These cost
Figure 4.35. Map of the cost to traverse distance to the nearest oven.
Figure 4.36. Map of the cost to traverse distance to Paquimé.
distance values were extracted for both location types and the corresponding values were added as an attribute to each dataset (Paq_cd_1).

**Cost Distance to Trincheras**

Minnis et al. (2006) and Minnis and Whalen (2005) have suggested that the occurrences of comparatively large fields and check dam systems in close proximity to smaller sites within the Casas Grandes cultural area suggests that some agricultural production in the region may have been under the control of the Paquimé elite. As such, cost distance to trincheras was added as a cultural variable to the logistic regression analysis and predictive model. Thirty-nine trincheras dating to the Medio period were identified during the Whalen and Minnis survey seasons. Again, a cost distance analysis was performed for the cost distance to the nearest trincheras for the sites and non-sites in the study area. The cost_surface and trincheras rasters were used as the input rasters to produce the trincheras cost distance raster (Figure 4.37). The resulting raster values were once again extracted for each site and non-site location and added as an attribute to each shapefile (trinch_cd).

**Macaw Stones**

Evidence for macaw breeding and trade at Paquimé is well documented (Di Peso et al. 1974b; Minnis 1988, 1989; Minnis et al. 1993; Rakita and Cruz 2015; Somerville et al. 2010; Whalen and Minnis 2001a, 2009). According to Minnis (1989:286) more macaw remains have been discovered at Paquimé than all other contemporaneous Southwest sites combined. These remains, along with the evidences for production, breeding, and trade of macaws at Paquimé have led some to suggest that the Paquiméans may have controlled macaw exchange in the American Southwest (Minnis et al. 1993:270; Rakita and Cruz 2015:79).

Whalen and Minnis (1996) used the presence of macaw cage stones in their early analysis of Casas Grandes settlement to argue for regional influence from Paquimé. However, they later (2001a) assigned a ranked value of one out of six to these stones in their site function analysis.
Figure 4.37. Map of the cost to traverse distance to the nearest trincheras site.
This may be due to the fact that macaw stones were only present at 14 of the more than 300 sites surveyed in the late 1980s and early 1990s. Despite the limited findings of cage stones at sites in the Casas Grandes region, these artifacts have been used as evidence for the production and trade of macaws as well as specialized aviculture and organized husbandry across the Casas Grandes region (Minnis et al. 1993; Whalen and Minnis 2001a, 2009). The presence of macaw imagery and symbolism on Medio period Ramos Polychrome pottery has suggested that these birds and their feathers may have served as ritual and prestige items as well (Di Peso et al. 1974a; Minnis et al. 1993; Whalen and Minnis 2001a; 2009). Whalen and Minnis (2009:245–246) have argued that the presence of macaw cage stones as well as macaw imagery and symbology on Medio period ceramics at sites within the study area indicate a shared belief system with and recognized “ritual authority” at Paquimé. They also maintain that the evidences of macaw production are “signifiers of the archaeology of power” (Whalen and Minnis 2009:246).

Due to the scant data on these cage stones, the presence of the stones at known sites is included in the geodatabase, however this information was excluded from the cultural variables used in this predictive model. As additional research is carried out for Medio period sites, and additional macaw stones are recovered, it may be possible to add them as a cultural variable to the predictive model in the future.

Shell and Other Imports

Over the course of the JCGE excavations millions of shells were recovered at Paquimé (Di Peso et al. 1974b; Whalen and Minnis 2001a:81). Along with other exotica and prestige items, shell represented a good that was traded and controlled through the primate site in unprecedented amounts (Lekson 1999; Whalen and Minnis 2001a). In their analysis of settlement in 2001, Whalen and Minnis excluded shell and other imports from their settlement function analysis due to the limiting findings of these items among the surface collections recovered in the 1989 survey (Whalen and Minnis 2001a:150). Only 11.5 percent of room blocks in the Inner Zone had shell
on the surface, while 26.3 percent of room blocks in the Middle Zone resulted in surface finds (Whalen and Minnis 2001a:117). They determined that these surface finds were too infrequent to include in their analysis. Likewise, in this study shell and import data was included in the geodatabase but excluded from the logistic regression analysis and predictive model due to the scarcity of finds. Once additional information is recorded for shell and other imports for the Casas Grandes area it will be possible to include the datasets in the predictive model.

**NEXT STEPS**

With the completion of the GIS analyses for both the environmental and cultural variables, and with attributes values for each independent variable added to the site and non-site location files, it was then possible to randomly divide the datasets into training and testing files as outlined above. Once those datasets were extrapolated and exported as text files out of the GIS, they were ready to be used in the binary logistic regression analysis and in the creation of the predictive model for the study area. The results of the binary logistic regression analysis, predictive model, and site sensitivity map will be discussed in the following chapter.
This chapter examines the results of the various spatial, statistical, settlement, and predictive analyses performed in this study. To begin, there is a discussion of the logistic regression model and formula outputs, as well as the identification of the eight statistically significant independent variables identified during analysis. In addition to the impact of the significant independent variables to the predictive model, each variable will also be discussed in terms of settlement patterning and statistics. This discussion is followed by an overview of the results from the predictive model and site sensitivity mapping which includes a discussion of the model testing results. The remainder of the chapter is an examination of the settlement patterns for each of the independent variables that were not selected as statistically significant during the binary logistic regression analysis.

More than 15,300 independent variable attributes were calculated during the GIS analyses for both known site and non-site location points. Over 7,600 variable attributes were produced across the 26 variable categories for the 291 known site locations, and over 7,700 variable attributes were assigned across the 26 variable categories for the 299 non-site locations. For all distance calculations, Euclidean distance was also calculated to supplement the cost distance results. Euclidean distance is the shortest straight-line measurement of distance to a feature. This method of measurement does not incorporate terrain variability into the distance calculation. Euclidean distance is determined by calculating the hypotenuse of the maximum distance of y
and the maximum distance of x from the center of each raster cell to the center of the nearest source raster cell (ESRI 2018f). While Euclidean distance does not represent as realistic of a calculation as a cost distance analysis, the measurement results are given in meters, rather an accumulated cost values, and thus provide an approximate distance and value that can be easily interpreted. The Euclidean distance for each independent distance variable was calculated within the GIS and the output raster values for each independent variable were extracted for all known site location points. These values were used to calculate average distances with which to compare the entire known site dataset.

LOGISTIC REGRESSION RESULTS

All of the 26 independent variables used in the GIS analyses were also used as input variables in the binary logistic regression analysis. This was accomplished using a forward stepwise selection process with a significance level (α) of 0.10. The significance level indicates that there is a 10% risk of false associations in the model (Minitab 2017). If an independent variable demonstrated a p-value that was less than or equal to the significance level, that variable had a statistically significant association with the dependent variable (site presence) (Minitab 2017). If the independent variable resulted in a p-value that was greater than the significance level, that variable was not statistically significant in the model (Minitab 2017). A statistically significant model was obtained with eight of the 26 independent variables. These statistically significant variables included: north/south aspect (p=0.00), elevation (p=0.028), local relief to 90 meters (p=0.002), topographic positioning index (p=0.022), cost distance to perennial streams (p=0.00), cost distance to intermittent streams (p=0.00), cost distance to intermittent lakes (p=0.02), and cost distance to Paquimé (p=0.00). In order to access how well the model fit the data, a Hosmer-Lemeshow Goodness-of-Fit test was carried out as part of the binary logistic regression analysis. This Goodness-of-fit test examines “whether the predicted probabilities deviate from the observed probabilities in a way that the binomial distribution does not predict”
(Minitab 2017). If the p-value of the Hosmer-Lemeshow test is below the significance level then the model has deviated from the observed probabilities and is not a good fit (Minitab 2017). The Hosmer-Lemeshow Goodness-of-Fit test for the binary logistic regression analysis in this study had a p-value of 0.145, which showed that there was no lack-of-fit in the model (Minitab 2017).

**PREDICTIVE MODEL**

George Cowgill has stated that “statistical analysis is not a way to arrive at certainty; it is a powerful aid in discerning what your data suggest and how strongly your data suggest it” (Cowgill 2015:5). This statement appropriately describes the purposes of predictive modeling and the creation of site sensitivity maps. Both are methods and tools that quantitatively assess the relationships between known sites and environmental or cultural features and are a means whereby the strength of those relationships can be interpreted and illustrated in a clear and concise manner. This is accomplished through the results of the binary logistic regression analysis and the output of a probability equation for the presence of sites across the study area. This probability is based on the coefficients of the statistically significant independent variables. The equation is represented as thus:

\[
\frac{1}{1 + \left(\exp\left(-\left(\beta_0 + \beta_1 \times \text{"sig. independent variable"} + \beta_2 \times \text{sig. independent variable"} + \ldots + \beta_n \times \text{sig. independent variable"}\right)\right)\right)}
\]

where \(\beta_0\) is the constant and \(\beta_1\)… \(\beta_n\) are the coefficients for the statistically significant independent variables (Apan et al. 2008; Holton 2014). The probability equation in this study was:

\[
\frac{1}{1 + \left(\exp\left(-\left(1.33 - (0.01087 \times \text{"aspect_ns"}) + (0.00298 \times \text{"buffer_12n"}) - (0.0478 \times \text{"relief_90"}) - (3.50 \times \text{"tpi"}) - (0.000113 \times \text{"Per_l_cd"}) - (0.000071 \times \text{"Int_l_cd"}) + (0.000017 \times \text{"Int_a_cd"}) - (0.000023 \times \text{"Paq_cd"})\right)\right)\right)}
\]

and was utilized within the GIS to create a predictive raster of the study area that contained a unique probability value for each raster cell. The probability values ranged from zero to one and
indicated the likelihood of each 30 square meter raster cell containing a Medio period residential site. Values close to zero represented low probability cells and values close to one represented high probability cells. By classifying the probability values in ranges of 20%, the low, mid-ranging, and high probability locations were clearly illustrated (Figure 5.1). There are several factors that impact the relationship between the probability and the coefficient. However, it is common for negative coefficients to signify that the probability decreases as the predictor value increases, while positive coefficients signify that the probability increases as the predictor value increases (Minitab 2017). Thus, it can be concluded from the output equation that as the values for north-south aspect, local relief to 90 meters, topographic position index, cost distance to perennial stream, cost distance to intermittent stream, and cost distance to Paquimé increase, the likelihood of site presence for the raster cells decreases. By the same estimation, as elevation and cost distance to intermittent lake increases, so too, do the probabilities for site presence for the raster cells.

Of the 2,136,475 raster cells that comprise the study area, 1,169,760 cells (54.7%) had a probability value less than or equal to .2 (Figure 5.2). The remaining 966,715 raster cells (45.3%) had probability values greater than .2. A total of 148,903 cells (7%) within the study area had probability values greater than or equal to .8, which indicated a high probability for site presence (Figure 5.3). Precisely 470,738 raster cells (22%) had a probability value equal to or greater than 0.5. Conversely, 1,665,737 cells (78%) had probability values that were less than 0.5 and indicated locations of low probability (Figure 5.4).

**Testing and Assessment**

To assess the predictive power of the model, 196 site and non-site locations were withheld from the binary logistic regression analysis to be used for model testing. For visualization purposes the site sensitivity raster was reclassified to two classes, with the break values set to 0.5 and 1 and the training dataset was added over the predictive model layer within the GIS
Figure 5.1. Probability map with five classes of value ranges.
Figure 5.2. Probability map of the study area highlighting the low value range.
Figure 5.3. Probability map of the study area highlighting the high value range.
Figure 5.4. Probability map of the study area with two classes of equal value ranges.
The probability values from the raster were then extracted from the predictive model for each site and non-site location in the testing dataset. The extracted probability values were then analyzed for each site and non-site location to see how accurately the model gave high probability values to known site locations and low probability values to non-site locations. The model accurately predicted 76% of known site locations to be positioned within raster cells with probability values of 0.5 or higher. Additionally, the model correctly predicted 71% of non-site locations to be situated within raster cells with probability values less than 0.5. Twenty-three known site locations fell within predictive raster cells with probability values below 0.5. Of those 23 sites, nine were located within cells with a probability value ranging from 0–.2, ten sites were located within cells with a probability value ranging from 0.2–0.4, and four sites were located in raster cells within the 0.4–0.5 probability range.

The probability raster was also used to create point locations for the centroids of each of the 2,136,475 raster cells. This point feature class was exported with the probability value for each cell included in the dataset. All points below 0.5 were deleted from the layer and variable values for aspect, elevation, local relief to 90 meters, topographic position index, cost distance to perennial stream, cost distance to intermittent stream, cost distance to intermittent lake, and cost distance to Paquimé were extracted for the remaining 476,849 raster cells. The cell point files were separated into two probability datasets: 0.5–0.75 (n= 273,124) and .75–1 (n=203,725). This process was carried out in order to evaluate the averages of the significant independent variable values for high probability areas in the predictive model. Preceding the discussion of all independent variables, a brief overview of the averages for the significant independent variables will be given based on the site presence probability ranges discussed above.

Of the cells with a probability value range between 0.5 and 0.75 the average value for north/south aspect was 67.1 degrees. Of 273,124 raster cells, 185,378 (67.9%) had a north-south aspect value less than 90. The percentage of cells oriented precisely east or west was
Figure 5.5. Probability map of the study area with two classes of equal value ranges with testing sites and non-sites.
3.6% (n=9,913). The average elevation was 1,514.9 meters above sea level with 64.5% of
cells having an elevation ranging from 1,262 meters above sea level to 1,514.9 meters above
sea level (n=176,127). The cost distance to intermittent lake had an average value of 234,065.0
with 153,507 cells (56.2%) with a cost distance value less than the average. The cost distance
to intermittent stream had an average value of 66,559.7 with 59.1% of cell values less than the
average (n=161,530). The average cell value for the cost distance to Paquimé was 418,431.3
with 119,983 cells (43.9%) less than or equal to the average cost distance. The average value of
cells for the cost distance to perennial streams was 67,598 with 54.2% of cells falling below the
average value (n=148,065). Local relief to 90 meters had an average of 7.0 meters of elevation
change. A total of 201,556 cells (73.8%) had a local relief to 90 meters of seven or less. The
average topographic position index for raster cells with probabilities between 0.5 and 0.75 was
0.45. Topographically positioned cells that fell below the average accounted for 46.9% of the
total (n=128,208).

Of the cells with a probability value range between .75 and 1.0 the average value for north/
south aspect was 59.4. Of 203,725 raster cells, 116,293 (57.1%) had a north-south aspect value
less than 90. The percentage of cells oriented precisely east or west was 3.9% (n=7,903). The
average elevation was 1,484.3 meters above sea level with 59.3% of cells having an elevation
ranging from 1,271 meters above sea level to 1,514.9 meters above sea level (n=120,771). The
cost distance to intermittent lake had an average value of 251,214.5 with 117,412 cells (57.6%)
with a cost distance value less than the average. The cost distance to intermittent stream had
an average value of 41,809.2 with 59.2% of cell values less than the average (n=120,522). The
average cell value for the cost distance to Paquimé was calculated to be 265,860.4 with 117,432
cells (57.6%) less than or equal to the average. The average value of cells for the cost distance to
perennial streams was 52,937.9 with 58.0% of cells falling below the average value (n=118,193).
Local relief to 90 meters had an average of 5.0 meters of elevation change, and a total of 152,123
cells (74.7%) had a local relief to 90 meters of seven meters or less. The average topographic position index for raster cells with 0.75 probability or higher was 0.44. Topographically positioned cells that fell below the average accounted for 45.5% of the total (n=92,752).

**SIGNIFICANT INDEPENDENT VARIABLES**

The binary logistic regression analysis identified eight statistically significant independent variables that functioned as indicators in the predictive model and demonstrated relationships with the presence of sites within the study area. These eight variables, along with their corresponding p-values, were mentioned at the beginning of this chapter. In this section, each of the eight independent variables will be discussed in terms of their association, frequencies, distributions, and patterns with known site locations.

**North-South Aspect**

In Chapter 3 it was noted that the original aspect raster generated within the GIS had output values corresponding to 360 degrees of compass directionality and was then reclassified to values ranging from 0° to 180°, in both north-south and east-west directions. Values in the north-south raster between 0° and 89° represented a northern aspect while values from 91° to 180° represented a southern aspect (see Figure 4.17). Precisely east or west directions received a value of 90° (Heilen et al. 2013:91). Of the 291 known site locations, 202 sites (69.4%) demonstrated a north-south attribute value that was less than 90, and as such had a northern aspect. Ten sites (3.4%) had an aspect value of 90°, which signified they were situated in an east/west direction, while 79 sites (27.2%) had an aspect value greater than 90°, signifying a southern aspect (Figure 5.6). Heilen et al. (2013) suggested that topographic aspect has been linked to solar exposure, protection from prevailing winds, and site visibility. Kvamme (1992b) has proposed that a tendency for north-facing aspects may be an attempt to stem the effects of solar radiation on plant growth and evaporation. Additionally, in a study on the impact of aspect and elevation on vegetation, Jin et al. (2008) argued that shadier aspects experience less evaporation from the
Figure 5.6. Map of known sites according to their north-south aspect.
soil, less transpiration from plants, and is optimal for vegetation growth. Conversely, Kvamme (1992a) noted that southern exposures provide increased solar heat. Nearly two-thirds of known site locations are located on northern facing slopes with an average north-south aspect value of 68.5° suggesting that shadier northern exposures were commonly selected for residential site locations.

**Elevation**

Elevation values within the study area range from 1,235 meters above sea level to 2,696 meters above sea level (see Figure 4.8). Elevation values for all known site locations range from 1,337 meters above sea level to 1,810 meters above sea level with an average elevation of 1,529.9 meters above sea level. Of the 291 known site locations, 150 (51.5%) are below the average elevation for known sites (Figure 5.7). The majority of known sites (80.8%) lie on elevations ranging between 1,337 meters above sea level and 1,637 meters above sea level (n=235). Only four known site locations (1.4%) are located at elevations above 1,750 meters above sea level. These four high elevation sites are all to the southwest of Paquimé and include sites 195, 332, 463, and 465. Sites 463 and 465 are approximately six kilometers from Paquimé,
while Site 195 is located at a distance of 22 km away, and Site 332 is approximately 63 km to the southwest. Sites 195, 463, and 465 are all situated on strong slopes, with sites 463 and 465 located on 21% slopes oriented to the northeast and Site 355 situated on a 31% slope oriented northeast. Site 332 has one ballcourt and Site 195 has one recorded oven and one stone circle. Sites 463 and 465 only have one pueblo, or adobe room block, and one surface foundation respectively, however they have the highest elevation (1,810 meters above sea level) for all known site locations in the study area (Figure 5.8). This elevation data suggests that even with these high elevation sites, mid-ranging elevations were predominantly selected for residential site locations.

**Relief at 90 Meters**

Local relief can be a significant factor for site locations as terrain roughness can both affect and limit daily travel and other activities at a site (Heilen et al. 2013:91; Kvamme 1988:333). As each raster cell in the DEM has a resolution of 30 meters, it was determined to analyze local relief in intervals of 30 meters to ensure smooth and equal coverage of raster values across the DEM. The average local relief to 90 meters for all known sites was 7.7 meters, with a maximum elevation change of 60 meters and a minimum elevation change of one meter (see Figure 4.24). Two hundred of the 291 known site locations (68.7%) had a local relief to 90 meters ranging from one to six meters, indicating nearly level to very gentle slopes according to the Slope Steepness Index (Barcelona Field Studies Centre 2018; Figure 5.9). The data suggests that for the 90-meter neighborhood around known sites, a low elevation change was common, with an average elevation grade of 8% for the 90-meter neighborhood, which is classified as a gentle slope (Barcelona Field Studies Centre 2018). Of the total number of known sites, 235 locations (80%) had a local relief to 90 meters that ranged from one to nine meters of elevation change, which represented nearly level to gentle slopes (Barcelona Field Studies Center 2018). Six sites had a 90-meter local relief that ranged from 36–41 meters. Five of these sites are located in the
Figure 5.8. Map of known sites with elevations approximately 1,750 meters above sea level.
Figure 5.9. Histogram of local relief to 90 meters for known site locations.

Tinaja-Tapicitas area one along what is very likely a former perennial stream system (Figure 5.10). Of these five sites, two had recorded trincheras and one had the presence of an oven. The remaining surface architecture was limited to pueblos and a single foundation. A total of four sites had a 90-meter local relief that ranged from 46–61 meters. These sites were also located in the Tinaja-Tapicitas area (Figure 5.11). Three of these sites had the presence of an oven and the remaining surface architecture was limited to pueblos with the exception of a single stone circle at Site 195. The extreme steepness in elevation change in the 90-meter neighborhood around these sites is uncommon for residential sites in the Casas Grandes area, and further survey and excavation work would be required to shed light on why these residential sites are located on such steeply sloping landscapes.

**Topographic Position Index**

Topographic position index results ranged in value from zero to one, with values close to zero representing low areas such as valleys and values near one representing higher areas such as ridges (see Figure 4.33). Of the 291 known site locations, 207 sites (71.1%) had TPI values below 0.50 and represented areas with a relatively low topographic position based on the defined topographic neighborhood (Figure 5.12). A total of 84 sites (28.9%) had TPI values ranging from
Figure 5.10. Map of known sites with local relief to 90 meters ranging from 36–41 meters.
Figure 5.11. Map of known sites with local relief to 90 meters ranging from 46–61 meters.
Figure 5.12. Map of sites with low TPI values.
0.5–0.66 and represented relatively higher locations based on the neighborhood defined during analysis (Figure 5.13). Over two-thirds of known sites have low topographic positions and are spread across all survey zones. While sites with high topographic positions are also found across all survey zones, the results indicate that low topographic areas were predominantly selected for residential site locations. As with the results from the 90-meter local relief analysis, low value ranges for TPI values indicate that level to gently sloping valley locations were selected for residential site placement over more rugged, steeper, ridge-like locations. Low-sloping valley locations, as opposed to the higher sloping locations would provide easier access and travel routes as well as greater ease in daily domestic activities at these site locations.

**Cost Distance to Perennial Streams**

It is worth reiterating that all cost distance analyses were based on the cost surface raster that incorporated slope, elevation, and distance to calculate a cost distance value from each site location to the various independent distance variables. This distance is not a geographic distance, but a weighted value based on terrain texture and slope that calculates the cumulative cost to traverse from each known site location to the source (i.e., independent environmental or cultural variable). These cost distances, when viewed in aggregate, provide comparable averages of cost distances across the study area between sites as well as the independent variables. The results of this cost distance analysis provide quantitative relationships between sites and the environmental and cultural variables in the model that can be used to determine the strength and significance of each variable. The cost surface for the study area had a minimum cost value of 7.1 and a maximum cost value of 12.2 and the average cost values for each of the independent distance variables represent an accumulated value based on the cost values for each of the raster cells traversed to reach the various independent distance variables. The average cost to traverse from known sites to perennial streams was 43,906.8 (see Figure 4.23). Again, this average represents the lowest cumulative path to traverse between known sites and perennial streams. Of the 291
Figure 5.13. Map of sites with high TPI values.
known sites, 164 (56.4%) had a cost distance to perennial streams that was less than the overall average (Figure 5.14). Additionally, 90 known sites (30.9%) had a cost distance that was less than 10,000, while 45 known sites (15.5%) had more than double the average cost distance. All but six of these high cost sites are located in the lower Casas Grandes River Valley and the El Cuervo area (See Figure 3.2). Furthermore, 44 of the high cost sites are located no more than five kilometers from intermittent streams (Figure 5.15).

Regarding Euclidean distance, the average distance to perennial streams for all known sites was 4.9 km with 165 sites (56.7%) located between 90 meters and 4.9 kilometers. At an average pace, 4.9 km can be traversed in approximately one hour. Additionally, a total of 83 sites (28.5%) were located within one kilometer of a perennial stream, and 43 sites (14.8%) were located between one and three kilometers. In a World Health Organization (WHO) report on contemporary domestic water quantity and health, researchers stated that the WHO designates a level of health concern to be “very high” when the nearest accessible water is at a distance of one kilometer or farther (Howard and Bartram 2003:i). Additionally, “reasonable access” to water was defined as the accessibility of at least 20 liters of water within one kilometer from a residence (Howard and Bartram 2003; WHO and UNICEF 2000). Using these modern assessments of water accessibility, the Euclidean distance analysis suggests that Medio period residential sites are well beyond the reasonable access designated by WHO. It has been suggested by several researchers that there is a pattern for prehistoric Southwestern societies to build their villages and towns along perennial water systems and while the data suggests that nearly half of known sites are located within three kilometers of known perennial watercourses, it is possible that Medio period communities were predominantly relying on other water sources, such as springs (Bayman and Sullivan III 2008; Whalen and Pitezel 2015).

**Cost Distance to Intermittent Streams**

The average cost to traverse from known sites to intermittent streams was 65,553.7 (see
Figure 5.14. Histogram of perennial stream cost distances for known site locations.

Figure 4.21). When compared to the cost distance average to perennial streams, that was 49.3% more than the average. Of the 291 known sites, 187 (64.3%) had a cost distance to intermittent streams that was less than the average cost to traverse (Figure 5.16). Additionally, 73 sites (25.1%) had a cost distance of less than 10,000. Sites that had more than double the average cost to traverse (n=66) were no more than six kilometers from perennial streams. Nearly one third of these high cost sites (n=18) look to be aligned along a stream that has either not been recorded, or no longer exists (Figure 5.17).

The average Euclidean distance for known sites to the nearest intermittent stream was 7.4 km with 186 sites (63.9%) situated in locations less than or equal to the average distance. Furthermore, a total of 68 sites (23.4%) were located within one kilometer of an intermittent stream, while 54 sites (18.6%) were located between one and three kilometers. It has been suggested that these settlement locations that are located away from perennial water systems would have used strategies such as exchange and food storage in order to reduce the effects of
Figure 5.15. Map of sites with high cost distances to perennial streams.
rainfall variability (Bayman and Sullivan III 2008:8). Here again, the data suggest that nearly half of known site locations are within three kilometers of known intermittent watercourses.

**Cost Distance to Intermittent Lakes**

A total of 24 intermittent lakes exist within, or no farther than 20 km beyond, the study area (see Figure 4.20). Thirteen of the 24 lakes are located within the study area boundary, and all but one are located in the eastern portion. This distribution of intermittent lakes is reflected in the average cost distance which was calculated at 248,212.7 (see Figure 4.20). Of the 291 known sites, 174 (59.8%) had a cost distance to perennial streams that was less than this average (Figure 5.18). Comparatively, none of the known sites had a cost distance that was less than 10,000.

The lowest cost distance was calculated at 96,833.9. When the averages of the cost distance to intermittent lakes and intermittent streams are compared, the cost distance for intermittent lake is 278.6% more than the average cost distance to intermittent streams (Figure 5.19).

The average Euclidean distance for known sites to the nearest intermittent lake was 26.7 km
Figure 5.17. Map of sites with high cost distances to intermittent streams.
with 181 sites (62.2%) situated in locations less than or equal to the average distance. Compared to the three-kilometer proximity of known sites to perennial stream features, the shortest Euclidean distance between known sites and intermittent lakes was 11.2 km. This is well beyond the definition of reasonable access as defined by the World Health Organization and suggests that other sources of water were preferred among Medio period communities.

**Cost Distance to Paquimé**

The average cost to travel from known site locations to Paquimé was 333,854.31 (see Figure 4.36). Of the 291 known sites, 140 (48.11%) had a cost distance that was less than the overall average. Of these 140 sites, 59 (48.1%) are located within the Inner zone identified by Whalen and Minnis (Whalen and Minnis 2001a:82, 194). A total of 80 of the 140 low cost distance sites are located in the 15–30 km zone, and a single site is located in the 30–75 km zone (Figure 5.20). None of the known sites had a cost distance less than 10,000 as the lowest calculation had a total of 10,007.5. The average Euclidean distance for known sites to the site of Paquimé was 37.7 km with 140 sites (48.1%) located in areas less than or equal to the average distance. Whalen and Pitezel (2015) have stated that between 10 and 15 km is the approximate distance
Figure 5.19. Map illustrating the distances between known site locations, intermittent streams, and intermittent lakes.
Figure 5.20. Map illustrating the known sites with low cost distances to Paquimé.
that an individual can travel and return by foot in a single day, and as such this distance defines the average probable extent of daily contact. This average daily distance has been suggested in several additional studies as well and reflects an average walking speed of 4–5 km an hour depending on terrain, age, and other variables (Liebenberg 2006; Morgan 2008; Murrieta-Flores 2009). According to that average, a total of 59 sites (20.3%) were located within 15 km of Paquimé and were within this area of daily contact. Additionally, 80 sites (27.5%) were located between 15 and 30 km and may have required a two-day journey to reach Paquimé. The farthest Euclidean distance for any known site was 72.3 km which may have required approximately five days of travel, however nearly half of the sites were located within an estimated two-day travel distance from Paquimé.

SETTLEMENT PATTERNS FOR NON-SIGNIFICANT INDEPENDENT VARIABLES

The patterns in settlement for the statistically significant independent variables have been given and the remainder of this chapter will focus on the settlement patterns of the 18 independent variables that were identified as not statistically significant in predicting site presence. These variables include: east-west aspect, cost distance to perennial lakes, cost distance to nearest ballcourt, cost distance to nearest oven, cost distance to nearest trincheras, ecoregions, local relief to 180 meters, local relief to 360 meters, local relief to 720 meters, slope, soil, terrain texture to 90 meters, terrain texture to 180 meters, terrain texture to 360 meters, terrain texture to 720 meters, vegetation, vegetation variety within 100 meters, and vegetation variety within 500 meters. Even though these independent variables were not indicators for site presence in the predictive model, the patterns for these variables provide a better understanding of settlement in the Casas Grandes area.

East-West Aspect

The same process that was used to reclassify the original aspect raster to 180° from north
to south was used to create a raster representing east-west directionality (see Figure 4.18). East-west values also ranged from 0° to 180° with values between 0° and 89° representing an eastern aspect and values from 91° to 180° representing a western aspect. Precisely north or south directions were assigned a value of 90° (Heilen et al. 2013:91). Of the 291 known site locations, 189 sites (64.9%) demonstrated an east-west attribute value less than 90, and as such had an eastern aspect. The average east-west aspect for known site locations was 72.3 degrees. Four sites (1.4%) had an aspect value of 90°, which signified they were situated directly north or directly south, and 98 sites (33.7%) had an aspect value greater than 90° and had a western aspect (Figure 5.21). These data indicate a preference for eastern- rather than western-facing slopes.

**Cost Distance to Perennial Lakes**

A total of two perennial lakes exist within the study area and both are located approximately 10 km northeast of Paquimé (see Figure 4.22). The scant presence of perennial lakes is reflected in the average cost distance from known sites which was calculated at 373,332.9 (see Figure 4.22). Of the 291 known sites, 140 (48.1%) had a cost distance to perennial lakes that was less than this average (Figure 5.22). A total of 24 known sites had a cost distance value that was less than 10,000. When the averages of cost distance to perennial lake and perennial stream are compared, the cost distance to perennial lake is 750.3% more than the average cost distance to perennial streams (Figure 5.23).

The average Euclidean distance for known sites to the nearest perennial lake was 43.2 km with 140 sites (48.1%) situated in locations less than or equal to this average distance. A total of 28 sites (9.6%) were located within 15 km of a perennial lakes, while 84 sites (28.9%) were located between 15 and 30 km. The implications of gaps in the hydrology data in this study, such as springs and well data, will be discussed in greater detail in the following chapter, however it should be noted here that at least one modern spring, El Eje, is located approximately five
Figure 5.21. Map of known sites according to their east-west aspect.
kilometers northwest of Paquimé. At the time of this study, however, no GIS locational data was available for the spring. Additional springs and wells have been recorded in the literature, however locational information for these water sources do not currently exist.

### Cost Distance to Nearest Ballcourt

The average cost to traverse from known sites to nearest known ballcourt locations was 18,712.8 (see Figure 4.34). Of the 291 known sites, 167 (57.4%) had a cost distance to known ballcourts that was less than this average value (Figure 5.24). Additionally, 134 sites (46%) had a cost distance value that was less than 10,000. Ten sites had a cost distance value over 50,000 with the highest cost distance value calculated at 59,499.4. This value is 217.7% more than the average. All ten high cost sites are located at the southeastern leg of the El Cuervo area and are approximately 29 km southeast and 26 km northwest from the two nearest ballcourt sites (Figure 5.25). The average Euclidean distance for known sites to the nearest ballcourt site was 14.3 km with 169 sites (58.1%) situated in locations less than or equal to the average distance. A total of 170 sites (58.4%) were located within 15 km of Paquimé and the time to travel to and from these ballcourt sites would have taken approximately one day. Additionally, 86 sites (29.6%) were
Figure 5.23. Map illustrating the distances between known site locations and perennial water.
located between 15 and 30 km and would have required approximately two-days of travel time. The farthest Euclidean distance for any known site was 49.5 km which may have required just over three days of travel time. The trend for Medio period residential site locations indicates that most sites (88%) were located no more than a two-day journey away from ballcourt locations.

**Cost Distance to Nearest Oven**

The average cost to traverse from known sites to nearest known oven locations was 3,190.7 (see Figure 4.35). Of the 291 known sites, including those sites with the presence of an oven, 202 (69.4%) had a cost distance to the nearest oven location that was less than the average cost distance value. Thirty-five sites had a cost distance value that was double the average cost distance. The highest cost distance equaled 143,636. This value is 4,401.8% more than the average. This site, Site 332, is located approximately 42 km southwest from the nearest known oven location (Figure 5.26). Additionally, a total of 283 sites (97.3%) had a cost distance value that was less than 10,000 (Figure 5.27). The average Euclidean distance for known sites to the nearest oven site was 1.9 km with 195 sites (67%) situated in locations less than or equal to this average distance. Additionally, a total of 287 sites (98.6%) were located within 15 km of the

Figure 5.24. Histogram of cost distances to nearest ballcourt for known site locations.
Figure 5.25. Map illustrating the distances between known site locations and perennial water.
Figure 5.26. Map illustrating Site 332 in relation to site locations with ovens.
Figure 5.27. Map of sites with low cost distances to ovens.
nearest oven location, within the average distance for daily contact. This suggests that activities related to large ovens occurred in locations that were easily accessible by nearly all Medio period communities. Three of the remaining four sites in the dataset were located between 15 and 30 km and may have required two-days of travel from their place of residence and back again. The farthest Euclidean distance for any known site, again Site 332, was 41.7 km which may have required approximately three days of travel there and back again. Again, a total of 287 out of 291 known site locations were located within 15 km, approximately a day’s journey from oven locations. This reaffirms that feasting played an important role in community activities and the political organization of Paquimé (Di Peso et al. 1974b; Minnis 1988; Minnis et al. 2006; Minnis and Whalen 2005; Rakita and Cruz 2015; Whalen and Minnis 2001a, 2003; VanPool 2017).

**Cost Distance to Nearest Trincheras**

The average cost to traverse from known sites to nearest known trincheras locations was 11,303.3 (see Figure 4.37). Of the 291 known sites, 192 (66%) had a cost distance that was less than the average cost distance value (Figure 5.28). Fifty-one sites had a cost distance value that ranged from two to nearly four times the average. This represents a range of 100% to 271.53% more than the average. These 45 sites were predominantly located in the Casas Grandes River and San Pedro River valleys. Six other outlying sites also fell within this high cost category. Site 332 again had the highest cost distance value at 136,305. This value is 1,105.9% more than the average. Site 332 is located 40 km southwest from the nearest known trincheras location (Figure 5.29). Suggesting that farming was not a function or activity of the site, or that no physical evidences for Medio period farming were located during survey or survived in the archaeological record. The average Euclidean distance for known sites to the nearest trincheras site was 9.4 km with 192 sites (66%) situated in locations that were less than or equal to the average distance. Furthermore, a total of 202 sites (69.4%) were located within 15 km of the nearest trincheras, or less than an average of a half a day’s journey. Sixty-one sites (21%) were located between 15 and
30 km from the nearest trincheras, while 28 sites (9.6%) were located between 30 and 42 km. Here again, over 90% of known site locations (n=263) were located within 30 km from recorded trincheras locations, and thus were within the average daily walking distance.

**Ecoregions**

Of the total number of known sites, 278 (95.5%) are located in the Piedmonts and Plains of the Sierra Madre Occidental (see Figure 3.2). Twelve of the remaining 13 sites are located less than one kilometer across the western border of the Piedmonts and Plains boundary in the Sierra Madre Occidental ecoregion (Figure 5.30). Site 332 is the exception and lies approximately 40 km southwest of the ecoregion boundary between the Piedmonts and Plains and the Sierra Madre Occidental. The Piedmonts and Plains ecoregion has an average annual temperature of approximately 60°F with frequent summer rains (CEC 2011:97). The lowest elevation of this ecoregion is 1,200 meters above sea level and rises to the highest elevation of 2,500 meters.
Figure 5.29. Map of known sites with high cost distances to trincheras sites.
Figure 5.30. Map of known site locations according to ecoregion.
above sea level, and as the name implies, has a terrain of mostly hills and plains (CEC 2011:98).

The predominance of Medio period residential sites in the Piedmonts and Plains may be attributed to the frequency of summer rain storms, the substantial amount of water provided by intermittent springs and streams, and the large tracts of open grasslands (CEC 2011:97–98). This access to water and open grasslands provides suitable environmental conditions for farming as well as community and residential needs. Obregón (Hammond and Rey 1928:205) and Minnis and Whalen (2015:43) both noted the abundance of water and other natural resources that would have been available to Medio period communities in the Piedmonts and Plains region for irrigation and other subsistence needs.

**Local Relief Beyond 90 Meters**

The average elevation change for known sites within a local relief of 180 meters was 14.4 meters (see Figure 4.25). A total of 214 sites (73.5%) had elevation ranges less than or equal to the average for the 180-meter neighborhoods (Figure 5.31). The data suggest that for the 180-meter neighborhood around known sites, a low elevation change was common, with an average elevation grade of 8% for the 180-meter neighborhood, which is classified as a “gentle slope” according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). Thirty-six sites (12.4%) had elevation ranges that were between two and seven times the average. Two sites had nearly 100 meters of elevation change within a 180-meter neighborhood (Figure 5.32). Site 199 had an elevation range within the 180-meter neighborhood of 94 meters, which represents a 52% grade and is classified as an “extreme slope” according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). Site 195 had an elevation range of 100 meters within the 180-meter neighborhood, which represents a 55% grade and is also classified as an “extreme slope” according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). Site 199 had one pueblo and one mound, with no other architectural features present on the surface of the site. Site 195 on the other hand had one pueblo, two mounds, an oven, and one recorded
trincheras. The extreme steepness in elevation change in the 180-meter neighborhood around the site is unusual for residential sites in the Casas Grandes area, and further survey and excavation work would be required to shed light on why these two residential sites are located on such steeply sloping landscapes.

The average elevation change within a local relief of 360 meters for all known sites was 28.5 meters (see Figure 4.26). A total of 199 sites (68.4%) had elevation ranges at or below the average for the 360-meter neighborhoods (Figure 5.33). This suggests that for the 360-meter neighborhood around known sites, a low elevation change was common, with an average elevation grade of 7.9% for the 360-meter neighborhood, which is classified as a “gentle slope” according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). A total of 34 sites (11.7%) had elevation ranges that were between two and seven times the average. Three sites had nearly 200 meters of elevation change within a 360-meter neighborhood (Figure 5.34). This represents a 56% grade and is classified as an “extreme slope” according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). As with the 180-meter neighborhood, Site 199 had a high elevation range within the 360-meter neighborhood of 190 meters. Sites 463 and 465

Figure 5.31. Histogram of local relief to 180 meters for known site locations.
Figure 5.32. Map of known sites with the highest local relief to 180 meters.
also had high elevation ranges equaling 200 meters within the 360-meter neighborhoods around the sites. Site 463 had one foundation with no other architectural surface features, while Site 465 had one adobe room block. Again, these sites represent considerable outliers to the average gentle sloping landscapes around Medio period residential sites. Further investigation at these sites could illuminate the decision-making process in establishing settlements in these extremely graded locations.

The average elevation change within a local relief of 720 meters for known sites was 52 meters (see Figure 4.27). A total of 189 sites (64.9%) had elevation ranges less than or equal to the average for the 720-meter neighborhoods (Figure 5.35). As with the 180- and 360-meter neighborhood averages, the neighborhood to 720 meters around known sites had gentle slope with little elevation change. The average elevation grade for the 720-meter neighborhood was 7.2%. Thirty-four sites (11.7%) had elevation ranges that were between two and six times the average. The highest elevation changes within a 360-meter neighborhood occurred at three sites and had an elevation change of more than 300 meters. Site 209 had a strong local relief at 720 meters with an elevation change of 310 meters. This represents an elevation grade of 43% and is classified as a “very strong slope” according to the Slope Steepness Index (Barcelona

Figure 5.33. Histogram of local relief to 360 meters for known site locations.
Figure 5.34. Map of known sites with the highest local relief to 360 meters.
Field Studies Centre 2018). This site had one adobe room block, one oven, and three mounds visible on the surface of the site. As with the 360-meter neighborhood analysis, sites 463 and 465 had the highest elevation changes across the 720-meter neighborhood with 322 meters of elevation change (Figure 5.36). This represents an elevation grade of 43% and is also classified as a “very strong slope” (Barcelona Field Studies Centre 2018). Across all local relief analyses, the strongest elevation change was no more than 56 cm per meter with the average elevation change equaling no more than eight centimeters per meter. This indicates that sites were situated on gently sloping, low elevation changing neighborhoods, regardless of the defined radius. The data suggests that the outlier sites, with their extremely sloping neighborhoods at multiple radii, warrant further analysis and investigation to determine the causes of their extreme placement on the landscape.

**Slope**

The slope, or surface steepness across the study area ranged from zero degrees to 56.3 degrees (128.19%) for known Medio period residential locations (see Figure 4.28). The average percent slope value for known site locations was 4.2% (Figure 5.37). According to the Slope...
Figure 5.36. Map of known sites with the highest local relief to 720 meters.
Steepness Index, this signifies a “very gentle slope” average and represents an average of 9.41 degrees of slope for raster cells containing known site locations (Barcelona Field Studies Centre 2018). In summary, a total of 223 sites (76.6%) had a slope value of 0–4.2%. Eleven sites had slope percentages ranging from 20–32% and represent locations of “strong slope” (Barcelona Field Studies Centre 2018; Figure 5.38). Sites 463 and 465 had locational slope values of 21.2%. Site 195, which lies approximately 22 km southwest of Paquimé, had a locational slope value of 31.2%. The remaining eight sites that demonstrated steep slopes are all found in the Tinaja-Tapicitas area. Apart from sites 208, 209, and 241, surface architecture was limited to one adobe room block for all sites with steep slopes. In addition to the presence of an adobe room block, sites 208 and 209 each had the presence of an oven while Site 241 had one recorded trincheras. The average slope for known site locations indicates that within the 30-meter raster squares from which the slope values were taken, relatively flat surfaces were selected for the location of Medio period site locations. This analysis was another method in analyzing landscape slope values and reaffirms the conclusions drawn from the local relief analyses that the majority of sites are situated on gently sloping elevation ranges. Elevation change within a community impacts domestic activities such as construction methods, irrigation strategies, and crop cultivation, as
Figure 5.38. Map of known sites with slope percentages between 20 and 32.
well as the conditions and presence of environmental resources such as water flow, soil, and plant species. These factors are affected by the slope and local relief surrounding communities. An understanding of the physical conditions of the landscape around these communities begins to explain which types of landscapes were selected for habitation and other activities in the Casas Grandes region.

**Soil**

Of the 16 different soil assemblages present in the study area, 10 separate groups were represented for known site locations (see Figure 4.13). The most predominant soil group among the known sites was Phaeozems (PH) which was present at 92 sites (31.6%). Phaeozems are organically rich and dark in color with a high saturation base in the top 100 cm (IUSS Working Group WRB 2015:177). They are fertile and porous soils that are excellent for farming (IUSS Working Group WRB 2015:177). The second most dominant soil group was Regosols (RG) which was present at 57 sites (19.6%). Regosols are common in arid, desert areas and are weakly developed (IUSS Working Group WRB 2015:172). In desert settings Regosols are not agriculturally significant and have a low capacity for holding moisture, requiring extensive irrigation techniques (FAO 2014:172). This type of soil is often used to exploit grazable resources (IUSS Working Group WRB 2015:173).

A total of 56 sites (19.2%) had a dominant soil group of Calcisols (CL), while 34 sites (11.7%) had a dominant soil group of Vertisols (VR). Calcisols are another desert soil group that require careful irrigation techniques, and the naturally occurring grasses and shrubs present on this soil type are used predominantly for grazing (IUSS Working Group WRB 2015:152). Vertisols are comprised of approximately 30% clay in the first meter from the surface (INEGI 2009:38). Because of this high clay content, in combination with dry climatic periods, extensive cracks are formed on the surface (IUSS Working Group WRB 2015:181). While the potential for agricultural cultivation on Vertisols is possible, it requires stringent water control, and like
Calcisols, the natural vegetation covering this soil type is mostly used in the modern era for grazing (IUSS Working Group WRB 2015:181).

The Leptosols (LP) soil group was present at 27 site locations (9.3%). This soil group is very thin at the surface and is followed near the surface by a continuous rock layer, which makes erosion a problem for these soil areas (IUSS Working Group 2015:163–164). While terracing is an option for crop cultivation, the likelihood of erosion is high, and, as such, these soil areas with their naturally occurring vegetation are most often used for grazing during the wet season (IUSS Working Group WRB 2015:164). Planosols (PL) were present at 14 site locations (4.8%) and are characterized as areas that typically experience seasons of waterlogged conditions (FAO 2014:168). Here again, with the naturally occurring shrubs and grasses on Planosol soils, the land use is predominantly used for modern grazing or pasturing (IUSS Working Group WRB 2015:169).

Fluvisols (FL) were present at nine sites (3.1%) and are characterized as fertile deposits of recent fluvial soils (IUSS Working Group WRB 2015:158). Site 469, which is located approximately 35 km north of Paquimé, was the only site to have a soil classification of Cernozems (CH). This soil group is described as a surface layer that is black, thick, and has rich organic and mineral content (IUSS Working Group WRB 2015:153). It has been ranked as one of the best soils in the world for arable crops (IUSS Working Group WRB 2015:154). The last site, Site 283, returned a value of ‘NA’, indicating that it is located within the boundary of a modern town (INEGI 2009:iv).

Only one third of known Medio period residential sites are located in soil areas that are easily conducive to farming, while the remaining 60% of known sites are situated in locations that require extensive irrigation and crop cultivation techniques. When examining the average distance from known sites to available trincheras locations, the data suggests that for 70% of residential site locations farming activities took place within 15 km, with the average distance
to trincheras locations calculated at 9.4 km. Comparing soil results for known site locations to the distance relationship between Medio period residential sites and trincheras locations adds further supports to the notion that farming activities during the Medio period were taking place away from residential locations. In a study of farming techniques in the Casas Grandes region, Minnis, et al. (2006:707, 711) analyzed approximately 200 farming locations identified during a 2005 survey in which they focused on evidences of agriculture. They determined that the largest fields are situated in locations with “few other habitation sites” which also supports the idea that farming practices were taking place away from residential locations (Minnis et al. 2006:716).

**Terrain Texture**

Terrain texture is yet another method to measure surface variability within a defined raster neighborhood using the standard deviation as the means of measurement rather than range, which is used in local relief analysis. As the standard deviation increases, so too does the terrain texture, or surface roughness (Holton 2014:43). As in the local relief analyses conducted for this project, terrain texture was calculated based on four distance scales from each site. This was done for two reasons: 1) to gauge variability across broadening distances, and 2) as a means of analyzing the residential site “area” as no polygon data or site boundaries were available. The results of the analysis showed that the average terrain texture within a neighborhood of 90 meters for all known sites was 2.7 (see Figure 4.29). A total of 215 sites (73.9%) had terrain texture that was less than or equal to the average for the 90-meter neighborhoods (Figure 5.39). Thirty sites (10.3%) had terrain texture that was between two and seven times the average. Four sites had 90-meter terrain texture values between 16 and 20 (Figure 5.40). Site 197 had a 90-meter terrain texture value 17.6 while Site 195 had a 90-meter terrain texture value of 19.1. This trend in terrain texture at 90 meters reflects the findings in both the local relief and slope analyses conducted in this study. Here again, terrain roughness across a landscape impacts architectural construction, irrigation and farming strategies, and environmental resource conditions such as
water, soil, and vegetation that can take place there. The majority of sites, approximately three-quarters, had low terrain texture values, indicating that 90-meter landscape neighborhoods around residential sites demonstrate low surface roughness. As the majority of sites are situated on these low surface roughness, or gently sloping landscapes, patterns emerge regarding the physical conditions of the landscape around these communities, and the types of landscapes that were selected for habitation in the Casas Grandes area.

The average terrain texture within a neighborhood of 180 meters for all known sites was 4.2 (see Figure 4.30). A total of 217 sites (74.6%) had terrain texture that was equal to or below the average for the 180-meter neighborhoods (Figure 5.41). Thirty-three sites (11.3%) had terrain texture that were between two and seven times the average. Ten sites had 180-meter terrain texture values between 20 and 28 (Figure 5.42). Site 195 had the highest 180-meter terrain texture value at 27.6. The high ruggedness of terrain in the 180-meter neighborhood around the site is unusual for residential sites in the Casas Grandes area, and reaffirms that further survey and excavation work is required at Site 195 to identify possible explanations as to why it is located on such a rugged landscape.
Figure 5.40. Map of known sites with the highest terrain texture to 90 meters.
The average terrain texture within a neighborhood of 360 meters for all known sites was 7.2 (see Figure 4.31). A total of 208 sites (71.5%) had terrain texture that was equal to or below the average for the 360-meter neighborhoods (Figure 5.43). Thirty-eight sites (13.1%) had terrain texture that were between two and seven times the average. Four sites had 360-meter terrain texture values between 40 and 51 (Figure 5.44). Site 199 had the highest 360-meter terrain texture value at 50.5. This comparatively high ruggedness value at Site 199 correlates with the extreme slope designation assigned during the local relief analysis. The 360-meter neighborhood ruggedness value for Site 199 is uncommon for residential sites in the Casas Grandes area, and as such this site represents an outlier to the settlement pattern. As with Site 195, further survey and excavation work is required in order to detect reasons as to why it is situated on this highly rugged location.

The average terrain texture within a neighborhood of 720 meters for all known sites was 12.3 (see Figure 4.32). A total of 193 sites (66.3%) had terrain texture that was equal to or below the average for the 720-meter neighborhoods (Figure 5.45). Thirty-six sites (12.4%) had terrain texture that were between two and six times the average. Four sites had 720-meter terrain texture
Figure 5.42. Map of known sites with the highest terrain texture to 180 meters.
values between 70 and 80 (Figure 5.46). Sites 463 and 465 had the highest 720-meter terrain texture values at 78.5. As with the other surface measurement analysis in this section, a relatively low terrain texture was common for known site locations within the study area. However, as relative distances from site locations increased, so too did average terrain roughness values, from 2.7 at 90-meter neighborhoods, to 12.3 at 720-meter neighborhoods. As with the findings for local relief and slope, terrain texture for Medio period residential sites demonstrates a pattern of limited variability in neighborhood topography, which would be more conducive to settlement development than more extreme terrain.

**Vegetation**

Of the 18 different vegetation classes present in the study area, 10 separate classifications are represented for known site locations (see Figure 4.14). The most prevalent vegetation class among known site locations was natural grasslands (n=143). Desert shrub (n=54) was the second most commonly represented vegetation class, with the oak forest (n=12) and salt tolerant vegetation zone (n=2) also present in small numbers. A total of 80 sites returned a vegetation classification of not applicable. No additional information regarding the designation of “not
Figure 5.44. Map of known sites with the highest terrain texture to 360 meters.
applicable was available from INEGI, but may represent areas of modern towns, as was the case with soil designations of the same type.

The natural grasslands, of Chihuahua occupy a transitional zone between the dry climate thickets of the Chihuahuan Desert and the forest vegetation of the Sierra Madre Occidental (INEGI 2014:46). This zone has been identified as the most significant natural grasslands area in Mexico, as it represents the majority of the world’s natural grasslands (INEGI 2014:46). The average altitude range for this zone is 1,100–2,500 meters, with average temperatures ranging from 12°–20° Celsius and annual rainfall averaging between 300 to 600 mm (INEGI 2014:46). This grassland area is dominated by the genus Bouteloua and the Bouteloua gracilis (blue grama) and Bouteloua curtipendula (sideoats grama) species are the most common of the grasses found in this vegetation zone (INEGI 2014:47). The blue and sideoats grama species are two of the most important forage grasses in the Americas and provide highly nutritious feed for livestock and wildlife species including elk, deer, antelope, and wild turkeys (USDA NRCS 2018a, 2018b). These species, namely the mule deer (Odocoileus hemionus), pronghorn antelope (Antilocapra americana), and wild turkey (Meleagris gallopavo) are abundant wildlife species
Figure 5.46. Map of known sites with the highest terrain texture to 720 meters.
found with the Piedmonts and Plains (CEC 2011:98). A total of 49.1% of all known sites are situated in this vegetation zone, which may have been selected in order to exploit the grasses for aviculture or hunting practices.

The desert scrub is a vegetation zone that represents one of the driest regions in Mexico with an average annual rainfall less than 199 mm (INEGI 2014:50). Vegetation only covers approximately 3% of the area and over 90% of that vegetation belongs to the Larrea genus, which contains the creosote bush (Larrea tridentata) species, and the Ambrosia genus, which includes the ragweed species (INEGI 2014:51). A total of 18.6% of all known sites (n=54) are located in this vegetation zone. When compared to soil types present at these sites, only seven are located on Phaeozem soils, which are highly conducive to farming. The remaining 47 sites have predominantly Calcisol or Regosol soil types, where naturally occurring plant species are linked to modern grazing practices (FAO 2014:174; IUSS Working Group WRB 2015:152).

The oak forest is a vegetation zone that has an average annual temperature ranging from 10°–26° Celsius and has an annual rainfall average that ranges from 350–2,000 mm (INEGI 2014:35). As the name implies, this area is dominated by various oak species native to Mexico, with the most prevalent being the Quercus laurina, Quercus candicans, Quercus crassifolia, Quercus rough, and Quercus crassipes species (INEGI 2014:36). Apart from site 332, the remaining 11 sites that lie in this vegetation zone are located no farther than one kilometer from the vegetation boundary between the oak forest and the natural grasslands (Figure 5.47). A total of 4.1% of all known sites (n=12) were located in this oak forest vegetation zone. One of these sites has a ballcourt, four sites have ovens with one also having a trincheras, and three additional sites have trincheras present. This suggests that these sites may have been used for predominantly communal activities.

Sites 494 and 495 were the only two sites located in the salt tolerant vegetation zone (0.7%). This vegetation zone is usually found in arid or semiarid closed basins and is dominated by
Figure 5.47. Map of known sites according to vegetation classes.
low-coverage grasses and shrubs (INEGI 2014:59). Some of the most common species of plants include Suaeda spp. (seepweeds), Altriplex spp. (saltbush), and Limonium spp. (sea-lavender) (INEGI 2014:59). The forms of these species of plants can vary according to salt type, pH levels, water availability, and the permeability of the soil (INEGI 2014:59). The salt tolerant vegetation zone is an isolated area of approximately 310 square acres that is surrounded by natural grasslands on the north, east, and west and a designated as ‘not applicable’ (NA) to the south. No additional information regarding this ‘NA’ designation was available from INEGI. As previously mentioned, 27.5% of known sites returned a value of ‘NA’ for vegetation zone classification.

The vegetation analysis identified that approximately half of known site locations are located in the native grasslands vegetation zone, which is strongly correlated to the findings regarding ecoregions, as nearly half of the vegetation in the Piedmonts and Plains ecoregion is naturally occurring grasslands with some pine, oak, and mesquite forests present (CEC 2011:98).

**Vegetation to 100 & 500 Meters**

The average vegetation variability within a neighborhood of 100 meters for all known sites returned a value of one (see Figure 4.15). A total of 261 sites (89.7%) had only a single vegetation class present within 100 meters of all site centroids. Thirty sites returned a vegetation variety value of two (Figure 5.48). The average vegetation variability value within a neighborhood of 500 meters for all known sites was 1.6 and a total of 147 sites (50.5%) had only a single vegetation class present within 500 meters of the site centroids (see Figure 4.16). A vegetation variety of two was recorded for 124 known site locations (42.6%) while 20 known sites (6.9%) had a vegetation variety of three (Figure 5.49). At these scales, there is a pattern of little to no vegetation variety for known site locations. Broader neighborhood designations, measured in kilometers rather than meters, would reveal higher vegetation class values for known site locations, which would provide additional information as to the types of vegetation resources that may have been available within a day’s travel of these residential sites.
Figure 5.48. Map of known sites according to vegetation variety to 100 meters.
Figure 5.49. Map of known sites according to vegetation variety to 500 meters.
CONCLUSION

The binary logistic regression analysis identified eight strong indicators for the presence of Medio period residential sites in the Casas Grandes area. The results of the statistical model were used to create a predictive model and probability map to identify high probability locations for additional residential sites dating to the Medio period based on the quantitative relationship between known sites and the environmental and cultural variables identified as indicators for site presence.

Results of the predictive model demonstrated that low, northern aspects at an average elevation of 1,500 meters above sea level were high probability locations for Medio period residential site locations. Additionally, distance to water resources proved to be significant for site presence within the study area, with just over half of the known sites situated within five kilometers to perennial streams, and just under half of the known sites located within three kilometers of intermittent streams. Low topographic variability within a 90-meter neighborhood around residential sites was also a significant indicator for site presence. Additionally, as elevation and distance to intermittent lakes increased, the probability of site locations across the landscape decreased. Nearly half of the known residential site locations were located within a two-day journey to Paquimé, and a strong correlation can be seen with eastern-facing aspects and known residential site locations, with 65% of sites situated on an eastern slope. While nearly two-thirds of all known residential site locations were located within a day’s journey to the nearest ballcourt location, only 1.4% of known sites were located beyond a day’s journey to the closest oven location. Furthermore, nearly half of the known sites were located on natural grassland locations with limited vegetation variety within 0.5 km of the sites and the majority of sites were located on soils that require extensive efforts for crop cultivation.

The patterns identified across all 26 independent variables, which examined both
environmental and cultural features across the study area, offer a broader understanding of Medio period settlement. The implications of these results, along with the direction of settlement pattern research for the Casas Grandes cultural area, will be discussed in the following chapter.
This thesis concludes with a summation of the settlement pattern and predictive modeling results of this study as they pertain to future settlement research for the Casas Grandes area. Additionally, an examination of several of the limitations of the datasets within the geodatabase is given, as is a discussion of several facets of the predictive model that could be improved as additional spatial data are added to the geodatabase. I specifically make mention of the types of datasets that if added to the geodatabase, would allow for additional exploration into site locational modeling across the study area.

The amassing of existing spatial datasets, along with the creation of new geospatial information, and the combining of all data into a dynamic geodatabase, has allowed for an evaluation and examination of settlement across the Casas Grandes cultural area. The predictive model created during this project has illuminated not only areas across the landscape where future survey efforts should be focused but has also brought to light several key environmental and cultural variables that played a direct role in the patterns of Medio period settlement within the study area. By implementing a binary logistic regression analysis in the predictive model, quantitatively significant variables were distinguished from non-significant variables and the predictive power of each independent variable for site locational modeling was elucidated. Additionally, the use of training and testing datasets permitted the testing and validation of the predictive model based on existing site data. In all, the settlement analyses and predictive model
carried out during this study have demonstrated patterns in Medio period residential practices and identified locations within the study area that indicate high probabilities for locating additional site locations.

**SIGNIFICANT INDEPENDENT VARIABLES**

Of the 26 independent variables used in the binary logistic regression analysis and predictive model, eight variables were identified as being statistically significant and functioned as indicators of ‘site presence’ within the predictive model. These variables included north-south aspect, elevation, relief at 90 meters, topographic position index, cost distance to perennial streams, cost distance to intermittent streams, cost distance to intermittent lakes, and cost distance to Paquimé.

**North-South Aspect**

A north-south aspect was identified as a significant independent variable and an indicator of site presence. Nearly 70% of all known site locations demonstrated a north-south aspect value less than 90° and represented northern-facing aspect locations. Northern aspect positions are shadier and thus provide protection from evaporation and solar radiation, while promoting vegetation growth (Jin et al. 2008; Kvamme 1992a, 1992b). It is possible that apart from community farming practices, Medio period residential locations were selected for smaller-scale familial farming practices.

**Elevation**

Elevation demonstrated a statistically significant relationship with the presence of sites within the model. Most of the recorded sites (80.8%) are located on elevations ranging between approximately 1,300 and 1,600 meters above sea level. Elevation across the study area ranges from approximately 1,200 to 2,700 meters above sea level, and the results of this analysis indicate that low- to mid-ranging elevations were selected for residential locations during the Medio period. Ancient and modern farming practices on arable floodplain and upland slope
locations within the study area reflect this elevation pattern as has been suggested by Whalen, Minnis, and others (Minnis et al. 2006; Whalen and Minnis 2001a, 2001b, 2001c, 2003).

90-Meter Local Relief

Site locations, and access to those sites are directly impacted by terrain roughness (Heilen et al. 2013:91; Køvsmann 1988:333). As such, local relief and topographic position index values can be a significant indicator of site location, as 90-meter local relief and topographic position was in this study. The average local relief at 90 meters for known Medio period residential sites was 7.7 meters and is classified as a gentle slope according to the Slope Steepness Index (Barcelona Field Studies Centre 2018). Additionally, nearly two-thirds of known sites (68.7%) have nearly level to very gentle slope values.

Topographic Position Index

The topographic position index results echoed these findings with two-thirds of known sites (71.1%) having TPI values below 0.5 which represent low-sloping valley locations. The results of the local relief and TPI analyses indicate that landscapes with low terrain roughness were selected for residential site locations during the Medio period, which would have made daily travel and other domestic activities easier between and around sites.

Cost Distance to Perennial and Intermittent Streams

As cost distance is not a geographic distance, but a weighted cost value that calculates the cumulative cost to traverse across the landscape based on terrain texture and slope, cost distance results for both perennial and intermittent water sources are best understood when compared across the result categories. The average cost distance from sites to perennial streams, which represents the lowest cumulative path to traverse between known sites and the nearest perennial stream, was 43,906.8. Comparatively, the average distance from sites to intermittent streams had a slightly higher cost to traverse value (65,553.7), with the average cost from sites to intermittent lakes having the highest cost to traverse value among the statistically significant
cost distance values (248,212.7). These results indicate that sites near perennial streams had the lowest comparative cost distance for all water resources across the study area. As access to water is a daily necessity for subsistence and other domestic needs, it is logical that proximity to permanent water sources would be a priority in site location selection. These analyses provided a quantitative method for arriving at this conclusion.

**Cost Distance to Paquimé**

The final significant variable identified in the binary logistic regression analysis was the cost distance from known sites to Paquimé. Similar to the environmental variable cost distance results, this cultural variable is best understood when compared to other cultural cost distance values. Several compelling conclusions can be drawn by comparing the average cost distance values between known sites and Paquimé and the cost distance values from sites to ballcourt, oven, and trincheras locations. The average cost distance value from sites to Paquimé was 333,854.31, which is a seemingly high value when compared to the other statistically significant cost distance variables in this study. To explain these results, it is helpful to examine the Euclidean distance results in conjunction with the cost distance results. Of the 291 known sites, 140 had cost distance to Paquimé values ranging from approximately 10,000 to 373,000. All but one of these 140 sites fell within the 35 km zone of interaction around Paquimé. It is possible that despite the average high cost distance from known sites to Paquimé, it was important for Medio period residential sites to be within a one to two day’s journey from the central site.

**NON-SIGNIFICANT INDEPENDENT VARIABLES**

A total of 18 independent variables were identified as statistically insignificant in predicting site presence within the predictive model. These included: east-west aspect, cost distance to perennial lakes, cost distance to nearest ballcourt, cost distance to nearest oven, cost distance to nearest trincheras, ecoregions, local relief to 180 meters, local relief to 360 meters, local relief to 720 meters, slope, soil type, terrain texture to 90 meters, terrain texture to 180 meters, terrain
texture to 360 meters, terrain texture to 720 meters, vegetation, vegetation variety within 100 meters, and vegetation variety within 500 meters. While these variables were not indicators for site presence within the study area, an analysis of the results of these variables provided a better understanding of Medio period settlement patterns.

To summarize, approximately 88% of sites were within two days of travel to the nearest ballcourts. This result may suggest a degree of interaction and integration among Medio period communities for political, economic, and ritual activities. Additionally, 98% of sites were located no more than a day’s travel from oven locations. The presence of large ovens within the Casas Grandes cultural area, and their proximity to nearly all Medio period residential sites may suggest that feasting played an important role in community activities. Finally, nearly 70% of sites were within 15 km, or a half-day journey, of known trincheras locations. The distance relationship between Medio period residential sites and trincheras locations supports the claim that agricultural production during the Medio period was occurring away from residential locations, albeit not at considerable distances.

The abundance of water and other natural resources in the Piedmonts and Plains of the Sierra Madre Occidental made it a profitable ecoregion in which to farm and live. The availability of these natural resource may have contributed to the number of recorded sites found within this ecoregion (95%). Analyses of local relief beyond 90 meters, terrain texture, and slope illuminated which types of landscapes were selected as residential locations—overwhelmingly low, flat, or gently sloping valleys that may have been more conducive to domestic activities than higher, more rugged locations. Approximately 60% of recorded sites were located in areas with soil types that required extensive irrigation and labor-intensive techniques crop cultivation techniques. These results support previous findings by Minnis et al. (2006:711) that varied farming strategies aimed at controlling water were employed during the Medio period. Finally, the vegetation analyses conducted in this study revealed that nearly half of all known sites are
located in a vegetation zone of naturally occurring grassland, which could have been exploited for both avicultural and hunting activities among Medio period communities.

**BUILDING ON THE CASAS GRANDES GEODATABASE**

The heart of this thesis can be summarized by Cowgill (2015) who stated that settlement pattern research is dependent on good maps. This study has brought together, for the first time, an unparalleled amount of geospatial data, both archaeological and environmental, for the Casas Grandes region. These data, combined into a single, dynamic research tool, will facilitate the creation of good maps, broader access capabilities, and analysis of settlement pattern research for the Casas Grandes region. Hearkening back to the critical issues identified by Minnis and Whalen (2015) for the archaeology of Casas Grandes, priority was given to increased fieldwork, survey, and excavation in the Casas Grandes area, as well as additional research regarding settlement patterns and regional comparisons. By bringing together the environmental and cultural data for the Casas Grandes area into one database, the resulting geodatabase and predictive model of this study begin to address these critical issues. Additionally, as the geodatabase and predictive model are made available to Casas Grandes researchers, it will be possible to refine survey methods for the area and examine aspects of regional settlement in new ways. Heilen et al. have stated:

> It is not expected that ancient dwellers…measured the slope of a prospective campsite or the distance between a camp and water resources…We can never reconstruct the exact logic used in the past to guide settlement and land use, but if this logic was replicated over time and space, we can expect to discern regularities in the relationship between site location and environmental and social variables related to settlement and land use [2013:90].

Examining the relationships between site locations and environmental and social variables, and to quantitatively examine the regularities in settlement and the use of land for the Casas Grandes region, has been the aim and the result of this study. While these results have provided additional
understanding of Medio period residential sites, there is still work to be done. The inclusion of additional geospatial datasets to the geodatabase and predictive model will further refine the observed regularities in settlement and the predictive power of the probability model. These data, as well as the impact to settlement research and the predictive model, are discussed below.

**Environmental Data**

*High-Resolution Digital Elevation Models*

Of the geospatial data currently in the geodatabase, the digital elevation model is one of the more important components. It provides the topographic and elevational data for the study area, and was also the means of producing the majority of the secondary datasets used during analysis. As such, the quality and resolution of the DEM is a critical component in this and any other settlement research or predictive modeling. The DEM resolution of 30 square meters per pixel was adequate to perform the geospatial and modeling analyses performed in this study. However, as higher resolution DEMs become available, it will be possible to sharpen the analyses and results of both the spatial information for known sites and the predictive model. This will impact not only the resolution of known site data but will also provide more finite probability boundaries for future survey efforts.

*Hydrology*

One of the limitations of the hydrology analysis conducted in this study was the absence of data on springs and wells. This is an avenue of inquiry that needs to be explored in order to provide a more complete picture of hydrology and water use in the Casas Grandes region. In Chapter 1, it was noted that the intermittent springs that occur in the Piedmonts and Plains of the Western Sierra Madre Piedmont provide significant amounts of water to the Casas Grandes basin (CEC 2011:98). Not only does the site of Paquimé lie in this area, but 361 of the 391 Medio period sites in this study also fall within this ecoregion. The addition of spring data for this area will significantly impact our understanding of settlement in relation to local hydrology and will refine the predictive model.
A few wells and springs in the Casas Grandes area have been noted in several publications; however, their locations were only described and not mapped. Di Peso et al. (1974a) reports two open wells and a spring that were recorded by Schwatka and Withers, who spent the second half of the 1880s exploring northwestern Mexico (Schatka 1977:16). During one of these explorations, Schwatka traveled from Deming, New Mexico, to the town of Casas Grandes and the ruins of Paquimé in 1889 (Schatka 1977:16). Schatka recounts:

While at Corralitos Mr. Davis told me of some ruins situated about halfway between his hacienda and Casas Grandes, near Barranca. I visited them the next day, and found a very noticeable and well-defined road leading straight up a hill to a slight bench overtopped by a higher hill at the end of the bench. Here was an ancient ruin, built of stone, and looking very much like a position of defense…On the top of the hill was a fortification, with a well probably about twenty feet from the summit, overtopped and almost hidden by a hanging mesquite bush [Schwatka 1977:61–63].

Despite this description, Di Peso was not able to locate the well during the JCGE survey, but he stated that it should be located 30 km to the north of Paquimé (Di Peso et al. 1974c:672). In his study of hilltop sites, Swanson (1997) makes no reference to Schatka or the presence of a well at any of the sites recorded during his survey.

Withers communicated to Di Peso the existence of a spring and open well at the Bert Whetten Site No. 6, which is located 60 km southwest of Paquimé (Di Peso et al. 1974c:672). No additional information was available for this site; however, a report of the Elvino Whetten Pueblo site given by Luebben and his colleagues (1986) showed that the Elvine Whetton Pueblo site is in approximately the same geographic location as the Whetten Site No. 6, however no mention is made of either a well or a spring in that study.
In a study of the ichthyology of Mexico, Meek (1902) recorded one spring for the Casas Grandes river system. Meek noted this spring was near the Colonia Juarez railroad station (Meek 1902:64). Beyond the limits of the 75 km buffer zone, Meek also stated that at the time of his visit in late June, Lago de Santa Maria was dry but that near a clubhouse “there were several large ponds fed by many large springs…. [and] the water in the springs and spring brooks was clear…” (Meek 1902:64, 72). If these and other spring and well resources, such as El Eje mentioned in Chapter 5, could be located and recorded across the study area, it would allow for a more accurate picture of the relationship between known site locations and surface water features and would refine the predictive model as well.

_Flood Risk Zones_

Anderson and Neff (2011) examined the possible influence of floods in the Grand Canyon area and the impact of fluvial events on site selection in the area over time. They focused on permanent habitation sites that were contemporaneous with Casas Grandes and found that early sites were located in high risk flood zones and later sites were located in more protected areas farther from the river. They argued that a shift to an even slightly higher elevation would have provided increased safety during a flood event. They used excavation data, and specifically stratigraphic information, to generate a reconstruction of flood events for the time period in question. If the appropriate data were collected in future excavation projects, and the information were added to the geodatabase and predictive model, it would be possible to demonstrate if site selection was influenced by flood zones in the Casas Grandes area.

_Archaeological Data_

The geodatabase created as part of this study is a substantial foundation on which future settlement pattern research for the Casas Grandes area can be conducted. As researchers utilize the datasets already included, and add their own GIS data to the geodatabase, new geospatial and quantitative investigations of settlement will be possible. Below is a discussion of several
existing and possible data files that can and should be added to the geodatabase, as well as a
discussion of how each can contribute to the critical archaeological issues of the Casas Grandes
area.

**Trincheras and Hilltop Sites**

Archaeological data that needs to be added to both the geodatabase and predictive model
includes additional trincheras and hilltop site locations. Reports of the extensive work in the
1960s to record and document trincheras in the Sierra Madre Occidental by geographers from the
University of Denver have been published (Bradley 1993; Herold 1965; Howard and Griffiths
1966; Luebben et al. 1986; Whalen and Minnis 2001a). However, none of the original reports,
or datasets were available to include in this study. Fish and Fish (1999:34) have suggested that
Di Peso also recorded extensive check dam systems in the Playas Valley, but this information
was not found in any of the Di Peso publications. Pitezel (2007) recorded a trincheras system
during a survey of El Pueblito, and survey work to record prehistoric agricultural fields in the
Casas Grandes area was carried out by Minnis et al. (2006) in which they identified a number
of previously unknown trincheras systems as well. This survey resulted in the mapping and
recording of more than 183 prehistoric fields as part an effort to analyze food production in the
Casas Grandes area. They found that the largest fields were located in close proximity to the
smaller sites, and not to the larger communities (Minnis et al. 2006:715). Comparative studies
between these trincheras data and the other independent variables in the geodatabase may shed
additional light on food production in the Casas Grandes area.

Swanson (1997, 2003) has also done considerable GIS work in the recording, mapping, and
analysis of atalaya, or hilltop, sites in the Casas Grandes region. During an extensive survey
of 107 hills, he recorded 35 hilltop sites that he argued were used as a communication network
across the Casas Grandes region. The GIS data for these hilltop sites were not available for
inclusion in this study, but they are important data that, if added to the geodatabase, would
provide valuable information to the regional analysis and would allow for additional geospatial comparative studies to other environmental and cultural features in the area.

During his survey of Cerro de Moctezuma, a widely-visible, hilltop site several kilometers southwest of Paquimé, Pitezel (2007) mapped and recorded a network of prehistoric trails. He concluded that these trail systems were deliberate construction efforts rather than the results of repeatedly utilized access routes (Pitezel 2007:364). If prehistoric trail data were added to the geodatabase, a cost path analysis could be performed to compare the presence of prehistoric trails with the surrounding topography, and could identify areas of high probability for the locations of additional trail network systems within the predictive model.

The site location datasets that were added to the geodatabase for this study could also be improved by the addition of several site characteristics. The foremost issues to be addressed for the Whalen and Minnis survey data is the determination of site types for the ‘non-residential’ sites, as well as the dating of over 50 sites which had unknown dates. If time period and site type could be identified for these sites, it would add information for over 60 sites to the predictive model.

**Site Size Information**

In a similar vein, site size was another limitation in the data used for this study. In one publication, Whalen and Pitezel (2015) measured site sizes for the Whalen and Minnis survey sites according to mound sizes. Small sites were identified as those containing mounds no larger than 2,000 square meters. Medium sites had mounds ranging from 2,001–6,399 square meters. While large sites had mound measurements of 6,400–9,999 square meters, very large sites had mounds ranging in size from 10,000–15,000 square meters (Whalen and Pitezel 2015:114). Two sites from the Santa Clara survey, Ch-318 and Ch-319, both have mound areas over 15,000 square meters, and they were given a designation of ‘super large’ (Whalen and Pitezel 2015:114). Di Peso also gave designations for site sizes on his 1974 settlement distribution map, however,
the sizes are given as population densities and most likely are vastly overestimated (Whalen and Pitezel 2015:113).

In another study focused on modeling settlement patterns in Yucatan, Ford et al. (2009) examined in their predictive model the relationship between site size and probability zones. They concluded that residential sites in high-probability zones were often larger, more complex, more frequent, and in closer proximity to each other than those sites located in low-probability zones (Ford et al. 2009:509). If site size information could be added to the Casas Grandes geodatabase for all site datasets, this is another possible research avenue. Whalen and Pitezel (2015) described a pattern noted in Sayles’s analysis of settlement patterns in the Casas Grandes region of large sites being surrounded by multiple smaller sites. They have argued that Medio period settlement was “headed by the very large center of Paquimé and consist[ed] elsewhere of a few large communities and many small ones” (Whalen and Pitezel 2015:108). It has been suggested by several researchers that clustering of smaller sites around larger community centers in the Casas Grandes region (see Brand 1935; Whalen and Pitezel 2015; Sayles 1936). If site size data were available for known site locations, a cost distance analysis from smaller sites to the larger community centers could be performed in order to better examine this clustering.

Zones of Interaction

Restructuring the predictive model to examine site presence according to the zones of interaction identified by Whalen and Minnis would be an additional approach to evaluating sites within the Casas Grandes geodatabase. In Whalen and Minnis’s evaluation of sites, they found little support to suggest that sites located beyond a range of 30 km from Paquimé were as integrated as those sites located within the 30 km zone (Whalen and Minnis 2001a, 2009). They based this determination on the presence and distribution of ballcourts, craft production, macaw stones, and exotic ceramics. These data are available in the geodatabase and could be quantitatively and geospatially analyzed to assess the integration of sites for each zone of interaction.
Implications

The datasets and aspects of settlement analysis discussed above represent just a few topics of research that are possible through the use of the geodatabase created in this study. The capabilities of having a collection of geospatial data are vast when it comes to settlement research and analysis. This study represents just one way in which GIS information can be applied to quantitative examinations of existing site data. The examination of relationships between site locations and environmental and cultural features has demonstrated correlations between the selection of Medio period residential sites with a variety of environmental and cultural features throughout the Casas Grandes region. These analyses have led to the creation of a predictive model that will provide improvement to the survey efforts in the study area and allow for easier access to the geospatial resources that make these kinds of analyses possible. Whalen and Pitezel (2015) have lamented that studies of Medio period settlement have been few in number for the Casas Grandes area, and the available locational data have been problematic and vague. The efforts of this study have been to address these limitations, to refine the existing data and analyze them in previously unexamined ways, and to provide a solution that will lead to new avenues of settlement research. By implementing the capabilities of GIS, the spatial correlations related to Medio period settlement examined in this study have tested the claim by Cowgill, and demonstrated the veracity that good maps, as well as the data with which they are comprised, are at the center of settlement pattern research.
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