A GIS MODEL OF SHELL EXCHANGE BETWEEN COASTAL SOUTHERN CALIFORNIA AND NORTHERN ARIZONA

by

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A Thesis Submitted to the Faculty of the

SCHOOL OF ANTHROPOLOGY

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF ARTS

In the Graduate College

THE UNIVERSITY OF ARIZONA

2022

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

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ACKNOWLEDGMENTS

First and foremost, I want to thank the University of Arizona's School of Anthropology for going above and beyond what is typically expected by M.A. students to support me financially during my pursuit of this degree. I also wish to show my gratitude to my advisors and co-chairs, Dr. Barbara Mills and Dr. Ronald Towner, for their assistance in molding my degree path and topic to better suit the interests I wanted to pursue. I also appreciate the efforts of Dr. Gary Christopherson and Arthur Vokes regarding their input on Geographic Information Systems and shell, respectively, as this paper does not exist without the knowledge they imparted to me. A special thank you goes to John Snow and Bob Hillis. John hosts a website, https://mexican-fish.com/, containing a treasure trove of information and photos on marine life, including some beautiful photos of the shells detailed in this thesis. John kindly put me in contact with Bob, who photographed the shells for John's website and was gracious enough to permit me to use his images in the thesis.

I would be remiss if I did not collectively thank my fellow graduate students starting at the University of Arizona during the Fall of 2020. I may have been the only M.A. student in the wave of Ph.D. pursuers, but I never felt alone thanks to you. I absolutely cherished every moment of time, whether hiking, having group dinners, visiting museums, playing games, meeting up to work, or ranting about graduate school. Dr. Brandon Lewis at Santa Monica College also deserves recognition and appreciation, for I would not be at this point without his introductory archaeology class and insistence on participating in an archaeology field school nearly a decade ago. I also must thank the CRM companies that accommodated the ever-changing amount of time and work I could put forward while pursuing my degree. To the people I trained with for yet another track season while pursuing this degree, specifically Harry Mulenga, Erik Barr Zeilon, and the collective Lucas Tyler Track Club: I appreciate the diversion you provided from the insanity that is academia.

Lastly, to my parents, grandfather, aunt, and uncle and aunt in all but blood: you never wavered in your support of any of my pursuits and always cheered on the highs while listening to the lows and providing support and insight in response. Words alone cannot thank you for all you have done for me.

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ABSTRACT

Shell was traded into the United States Southwest from various areas, one of which was coastal Southern California. Abalone shell, or *Haliotis*, is solely sourced from the Pacific coast and provides irrefutable evidence of this trade. This exchange likely involved many Indigenous groups between the sourcing area and the shell's inevitable endpoints. Historical documentation of trails for facilitating exchange exists, but modeling a route in a spatial analysis program has not been attempted for this transregional exchange. Utilizing least cost path analysis in ArcGIS Pro provides a theoretically most efficient route of abalone shell from the Chumash and Gabrielino Indigenous groups to seven archaeological sites in Northern Arizona and one just across the Utah–Arizona border in Kanab, Utah. The results of the model are mixed. It partially matches with historic documentation in California but is more consistent with the U.S. Southwest trail documentation. Further model refinement is proposed to incorporate hydrographic data, a modified Tobler's hiking function for more accuracy, incorporate more documented sites on the Southern California coast and further inland, and complete additional modeling between destination sites. Still, the model presented here is a first step to further evaluating Southern California–Southwest exchange and shell procurement.

CHAPTER 1: INTRODUCTION

The topic of exchange is heavily studied within the field of archaeology. Exchange between groups within a region can be as simple as acquiring essential resources from a neighbor who has access to something your group does not possess. It can also be more complex, however, involving exchange relations that are more social in nature and potentially carry implications of ideology and power dynamics (Earle 1982:2). It is a small wonder, then, that a strong definition of trade revolves around the movement of goods and materials between individuals, social groups, or organizations (Summerhayes 2015:481).

The Puebloan groups of the United States Southwest are not exempt from archaeologists' attempts to understand the roles played by exchange within the region. For example, Pottery Mound was involved in an exchange that imported ceramic wares from Hopi, Acoma-Zuni, and other Pueblos within closer proximity (O'Donnell et al. 2020). However, the Southwest also connected to other regions via exchange. Mesoamerica, for example, played a significant role as an exchange partner for the U.S. Southwest via networks connecting to the Hohokam, who then redistributed items to peoples having a traditional affiliation with Northern Arizona (Dolan and Schackley 2021; McGuire 2011; O'Donnell et al. 2020:493).

The other major transregional exchange for the Southwest was with Southern California. This exchange between the two locations is highlighted by trade for marine shell (Brand 1938; Colton 1941; Ezell 1937; Farmer 1935; Gamble and King 2011; Gregory and Vokes 2007; Gruner 2020; Merrill 2014; Ruby 1970; Smith 2002; Smith and Fauvelle 2015). This marine shell was desired for various reasons, though many arguments suggest shell use for ceremonial purposes (Gregory and Vokes 2007; Gruner 2019; Smith 2002). Michael Merrill's (2014) dissertation examines the exchange networks between Southern California and the U.S. Southwest (Arizona, Nevada, Utah, Colorado, and New Mexico) via connections linking San Diego area groups to the Hohokam initially, who then redistributed goods to Northern Arizona. He examines how the Hohokam's transregional exchange with Southern California operated based on interactions between the two groups at Lake Cahuilla (of which only the modern Salton Sea remains), a body of water that rose and fell depending on the amount of water it received from rivers (Merrill 2014:1–5). Merrill (2014) studied shell artifacts from both regions and other evidence, to evaluate the probability of this exchange impacting Hohokam stability by increasing the potential for collapse. His inference is that the long-distance trade between the two regions increased the scale of the Hohokam system to support a growing population, possibly through importing fish from Lake Cahuilla, while also strengthening the Hohokam system's stability rather than causing its systemic collapse (Merrill 2014:Chapter 8). This assessment is based upon the combination of fish traps and bone middens along earlier Lake Cahuilla shorelines, historic evidence of the Yumans utilizing dried fish as a food source, prior Hohokam archaeological work indicating the presence the razorback chub (which appears at Lake Cahuilla archaeological sites too), and the Gila River acting as an efficient means of transporting the fish to the Hohokam (Merrill 2014:Chapter 4).

Indeed, recent literature (Gregory and Vokes 2007; Grimstead et al. 2013; Merrill 2014) examines the Hohokam's role in distributing goods from the Pacific Coast, but less discussion revolves around direct Northern Arizona connections to Southern California. William Smith's (2002) dissertation is one of a few studies that directly deals with the exchange between Southern California and Northern Arizona. However, he also discusses interaction with other parts of the Southwest to try and understand the sociocultural implications of exchange between the regions at large (Smith 2002:2). Smith studies the interaction by focusing analysis on molluscan artifacts (aka shell) under the assumption that shell was traded into the Southwest as a type of religiofauna (Smith 2002:2–4).

Smith's reason for shell as religiofauna is due to how far inland shell appears relative to its source area, in addition to the following ceremonial/symbolic reasons:

> Marine shells are seen to be socially important by their pervasive presence in archaeological deposits throughout the Southwest and southern California. The distinctive shapes, colors; and textures of certain molluskan shells provided markers of social or gender distinction, supporting social stratification. Religiofaunal objects may also reinforce common cultural perceptions and values, and may transmit symbolic or cosmologic knowledge by their codes of shape, color, texture, or place of origin. By exchanging religiofaunal items, such as shell products, members of social elite groups established ties beyond the individual kin group, reinforcing trade, technology exchange, and social alliances. In funerary contexts, Southwestern elites are generally associated with marine shells, polychrome ceramics, turquoise, and feathers. [Smith 2002:6].

Through Smith's study of all relevant archaeological data he could access from the Southwest, he concluded that the Chumash played a significant role in providing the shell that ultimately ended up in Northern Arizona via the Mojave Trail (Smith 2002:218, 223). This exchange was maintained and even increased despite competition with Hohokam shell sourced from the Gulf of California in the case of *Olivella* beads, while *Haliotis* shell declined in favor of *Glycimeris* shell for elite ceremonial and sociopolitical purposes (Smith 2002:Chapter V).

Other than William Smith's (2002) dissertation focusing heavily on shell exchange directly to Northern Arizona and Smith and Fauvelle's (2015) article on evidence of exchange, Jay Ruby's (1970) dissertation examines the exchange from California into the Southwest at large. Ruby attempts to provide evidence of culture contact between Southern California and the Southwest and then reconstruct how exchange between the two regions may have occurred (Ruby 1970:1). Ruby does this through an extensive literature, ethnographic and ethnohistorical, and archaeological site data review (Ruby 1970:Chapter I). He then applies a series of hypotheses to the data to evaluate the likelihood of directness and mechanisms of contact, in addition to the likely effects of exchange occurring from said contact (Ruby1970:v, Chapter I). Ruby's dissertation ultimately concludes that Southern California—Southwest exchange for the shell was not through direct means, unlike ceramics, and the two items (shell and ceramics) were not traded for each other and therefore not directly related (Ruby 1970:Chapter V). Prior to this dissertation, however, we must look at materials from the first half of the 20th century (Brand 1938; Colton 1941; Ezell 1937; Farmer 1935) for discussions about how Southern California marine shell may have been imported directly to Northern Arizona.

Thesis Outline

For this reason, I decided to examine direct connections between coastal Southern California and Northern Arizona. I accomplish this task by combining literature on the subject with the use of Geographic Information Systems. In Chapter 2 I discuss which shells traded into Northern Arizona are distinct to coastal Southern California and, therefore, indicate the connection between the two regions. I discuss the Indigenous groups that were likely involved in the shell exchange between California and Arizona in Chapter 3. Chapter 4 examines the literature surrounding California and Northern Arizona trails to show a direct connection between the two regions, independent of a Hohokam middleman. Chapters 5 and 6 introduce and use least cost path analysis in ESRI's ArcGIS Pro platform to model a potential route from source areas in the California areas traditionally inhabited by the Chumash and Gabrielino to a selection of sites (seven in Northern Arizona, one just across the border in Kanab, Utah) traditionally associated with Ancestral Pueblo peoples. Chapter 7 compares this model to the existing trail literature to delineate similarities or differences between the two. This effort is to bring a more modern analytical technique to our understanding of coastal Southern California Northern–Arizona exchange. Finally, Chapter 8 summarizes the information covered in chapters 1–7 discussed in the thesis and provides further refinement and further study avenues for archaeologists.

CHAPTER 2: SHELL

This chapter discusses the shells of coastal Southern California and their roles among Indigenous peoples of Arizona. I start by identifying the main shell species from Southern California that also appear in archaeological records in Arizona. I then touch upon the importance of these shells to various Arizona Indigenous groups, giving a reason for acquiring the materials despite the distance between source and use.

Coastal Southern California Shell

Two main shell genera appear in the archaeological record of the United States Southwest, which have their origins along the California coast. These are abalone from the genus *Haliotis* (Figure 1) and the sea snail of the genus *Olivella* (Smith and Fauvelle 2015:713–714; Tucker 1954:62, 76). Of these, the following species came from Southern California's coastal waters and appear at sites along proposed trade routes to the east:

- *Haliotis cracherodii,* or black abalone (Figure 2). The shell's exterior color ranges between bluish- and greenish-black, and the interior is a pearly white (Tucker 1954:92). It is ca. 15 cm long, oval and deep in shape, and its range extends from the Central Coast of Oregon to Baja California (Gruner 2020; Tucker 1954:92). However, according to the International Union for Conservation of Nature and Natural Resources (IUCN), the specific range is Point Arena in California to Bahia Tortugas in Mexico, though not very common in the areas north of San Francisco (Peters & Rogers-Bennett 2021a:3–4).
- *Haliotis fulgens*, or green abalone (Figure 4). The shell's exterior color is reddish-brown, while the interior is iridescent blues and greens (Tucker 1954:93). It measures ca. 18–20 cm long with a round and moderately deep shape (Tucker 1954:93).

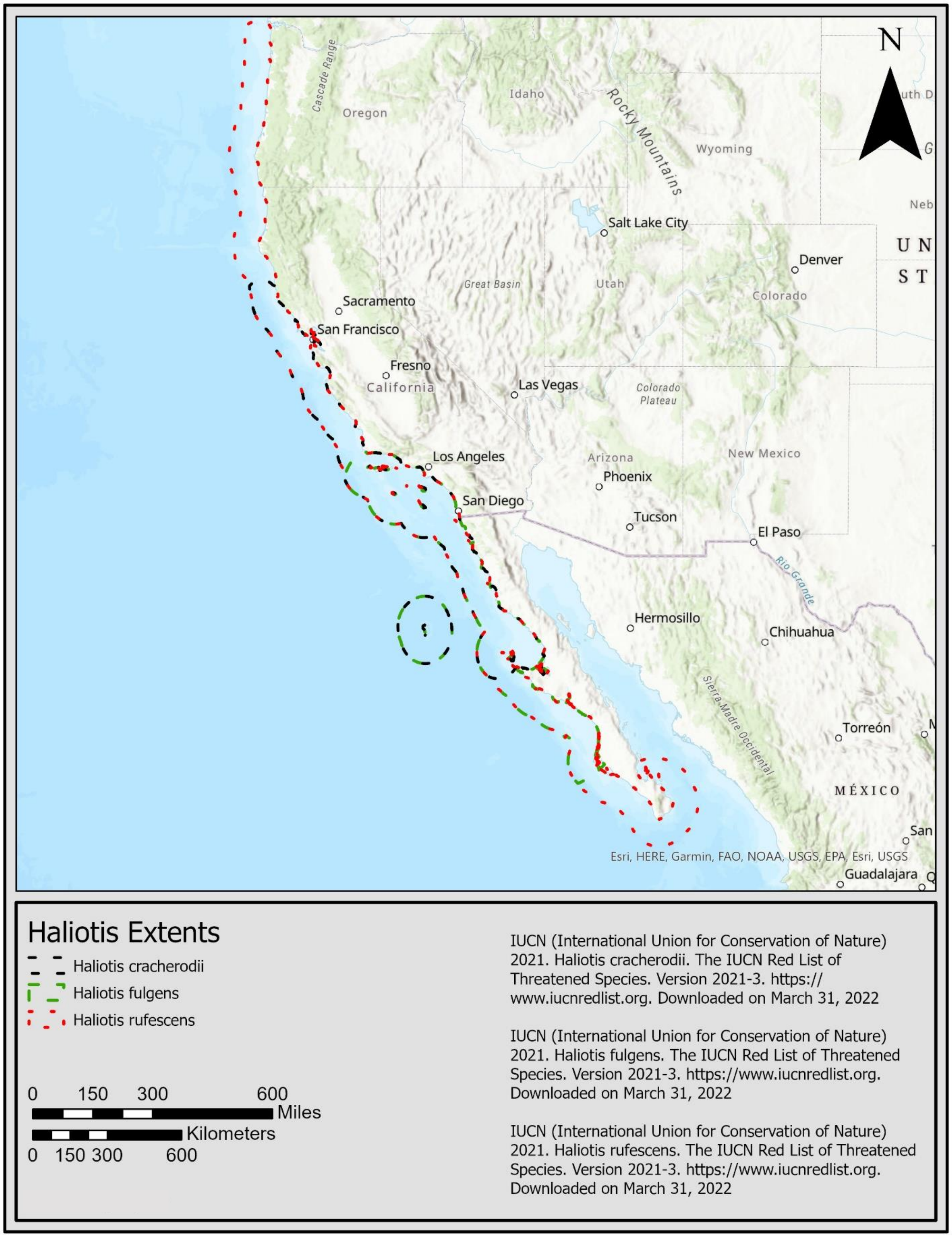

Figure 1. A Map of the *Haliotis* Geographic Range.

Figure 2. ***Haliotis cracherodii.***
Photographs courtesy of https://mexican-fish.com/black-abalone/,
photographed by Bob Hillis.

Figure 3. ***Haliotis rufescens.***
Photographs courtesy of https://mexican-fish.com/red-abalone/, photographed by Bob Hillis.

R. Abbott Tucker (1954) identifies the range as extending from the Farallon Islands (near San Francisco, California) to the Gulf of California; however, William Smith (2002:337) and Erina Gruner (2019:214, 2020) identify them as ranging from Point Conception (located roughly 13 miles south of Lompoc, California) to the Gulf of California. The ICUN describes the Green Abalone as two subspecies (*H. f. fulgens and H. f. guadalupensis)* encompassing a range between Point Conception, California, and Central Baja California Sur, Mexico, along with Guadalupe Island, Mexico (Peters and Rogers-Bennett 2021b:2–3).

- *Haliotis rufescens*, or red abalone (Figure 4). The shell's exterior color is described as a dull, brick red with a red border on the edge, while the interior is a mixture of iridescent blues and greens (Tucker 1954:92). It is ca. 25–31 cm long, oval and flattened in shape, and has a range extending from Northern California to Baja California (Gruner 2020; Tucker 1954:92). However, the ICUN places a more extensive range of Central Oregon to Central Baja California (Peters et al. 2021:2–3)
- *Olivella biplicata*, or Purple Dwarf Olive (Figure 5). This taxonomic designation is still common amongst archaeologists (and is used throughout this paper), but the modern designation is *Callianax biplicata* (Powell et al. 2020). The color of the shell is highly variable, though it is typically bluish-gray or whitish-brown with violet stains (Powell et al. 2020:7; Tucker 1954:248). The shells measure ca. 2.5–3 cm long and vary in shape; they inhabit a range between The Gulf of Alaska and Baja California, though more common in ranges south of Vancouver Island (Powell et al. 2020:8; Tucker 1954:248).

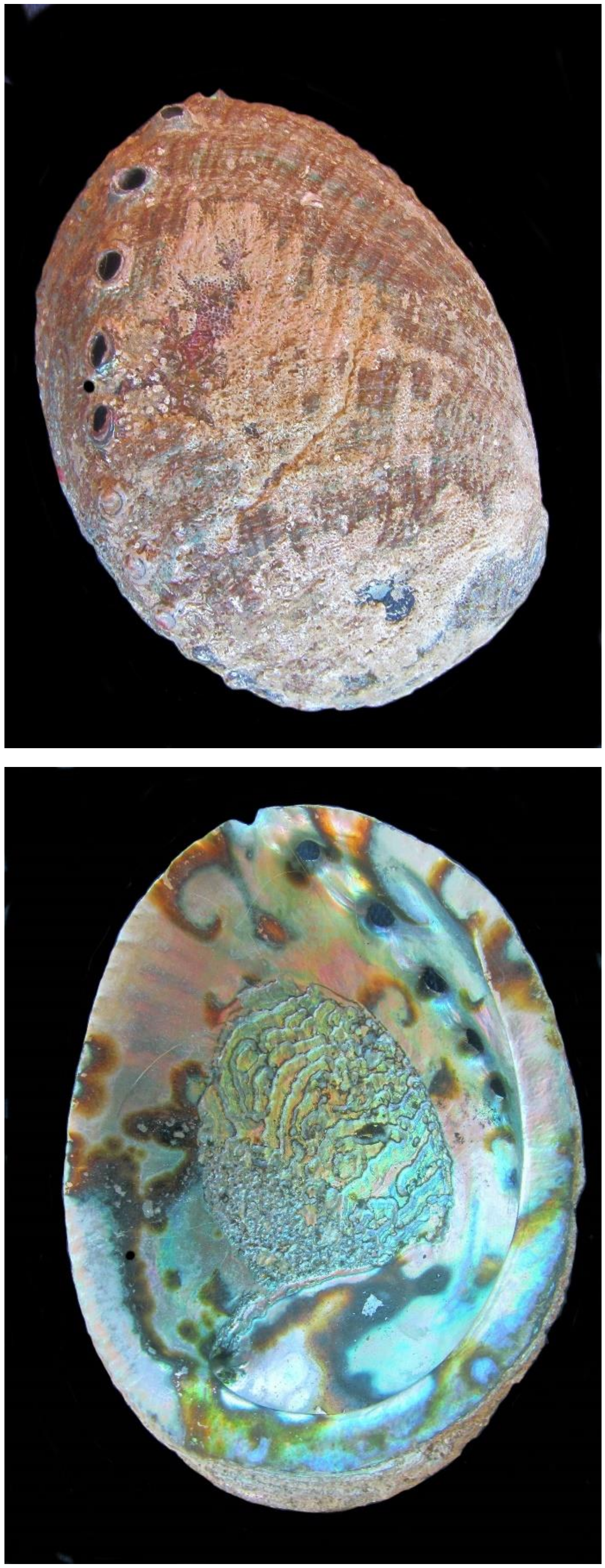

Figure 4. ***Haliotis fulgens.***
Photographs courtesy of https://mexican-fish.com/green-abalone/, photographed by Bob Hillis.

Figure 5. ***Olivella (Callianax) biplicata.***
Photographs courtesy of https://mexican-fish.com/purple-dwarf-olive/,
photographed by Bob Hillis.

Evidence of Shell Connection between Southern California and Arizona

Coastal Southern California has long been acknowledged as a source for many of the shells that ended up as worked products in the archaeological record of the U.S. Southwest. Erin Smith and Mikael Fauvelle (2015) note work undertaken in the late 19th century by Edwin Barber and Jesse Walter Fewkes as some of the earliest linking shell ornaments traded from California (in worked and unworked format) into the U.S. Southwest. Paul Ezell (1937) counts *Olivella* and *Haliotis* (no specific species) amongst the various shell types found throughout the whole U.S. Southwest, along with the forms of ornaments they were worked into or their utilization. More recent additions to the link between coastal Southern California and the U.S. Southwest include dissertations by Jay Ruby (1970), William Smith (2002), Michael Merrill (2014), and Erina Gruner (2019). Michael Merrill's dissertation discusses the connections of California to the Hohokam group. This interregional connection was linked via travel that passed through the region around the former Lake Cahuilla, crossed the Lower Colorado River and the Indigenous groups living along the river, and up the Salt and Gila Rivers into the Central and Southern Arizona regions (where the Hohokam were most prominent) (Merrill 2014:16–19).

Furthermore, Merrill contends that the Chumash of Southern California (encompassing the modern-day Santa Barbara and Ventura Counties) were the primary shell trade source into the Hohokam region. This sourcing came by way of Chumash trade to the Gabrielino/Tongva and groups farther south in Southern California before traversing eastwards (Merrill 2014:33, 58–59). Merrill also notes a direct connection between the Hopi peoples and California through the Gabrielino/Tongva (Merrill 2014:56).

Smith (2002) and Gruner (2019) instead focus more on direct links between coastal Southern California and the Puebloan people of the U.S. Southwest. Smith notes an exchange between the two areas based on the premise of Pacific coast shells being exchanged (among other things) into the Southwest and appearing at archaeological sites (Smith 2002:126–155). These California goods were exchanged for items such as textiles, split twig figurines, pottery, shell artifacts sourced from the Gulf of California (e.g., *Glycymeris)*, and stone axes (Smith 2002:126–155). What is interesting, however, is that most artifacts coming from the Southwest did not make it much farther than the Mojave Desert; only historical evidence of Southwest-style textiles, and a few archaeological finds containing Southwest pottery sherds and *Glycymeris* bracelets are noted in coastal Southern California (Davis 1961:2; Smith 2002:139–141, 145–153). Gruner similarly notes Pacific Coast shell appearing further into the Pueblo heartland over time; Canyon del Muerto was the farthest eastern extent of shell exchange prior to late Basketmaker III/ Pueblo I times; later Chaco Canyon was the easternmost terminus (Gruner 2019:213; Gruner 2020).

Work by Hannah Mattson (2015) attests to the likelihood of a Chaco Canyon terminus. Various *Haliotis* species (no specific identification) appear in refuse middens, kivas, burials at Pueblo Bonito, and some burials at Aztec West Ruin (Mattson 2015:Table 2; Mattson 2016b:Tables 1 &2). *Olivella* is also present at Pueblo Bonito and at Aztec Ruin West. However, Mattson doesn't provide an exact species, so it is not clear whether the dwarf olive snail shells are *Olivella biplicata* only, a combination of *O. biplicata* and *Olivella* species endemic to the Gulf of California, or the Gulf of California alone. Her dissertation identifies these shells as ornamentation for the human body (specifically pendants), particularly between AD 1150–1300 in Pueblo III contexts within the Ancestral Pueblo area (Mattson 2015:39). Later work suggests Ancestral Puebloans primarily utilized *Haliotis cracherodii* for pendants, but no specific species are mentioned in the assemblage summaries (Mattson 2016a:177). There is also a question of whether *Haliotis* shell appearing in Pueblo III is more likely tied to exchange through the Hohokam versus direct from California; Mattson does not elaborate on this point.

Work by Ruby (1970) further supports shell exchange between the two regions. His analysis shows that *Haliotis*, specific to the Pacific Coast and thus indicating a Southern California origin, is present at sites throughout the Puebloan region ranging from Basketmaker II to the Pueblo IV period (Ruby 1970:238–241). Ruby's work indicates that routine shell trade occurred between A.D. 1–A.D. 1300 and was likely made through reciprocal and indirect means, i.e., trade through Indigenous middlemen located between the shell's origin source in Southern California and the U.S. Southwest (Ruby 1970:69; 123–125). Smith's *Haliotis* research supports this continuous shell flow from California to the U.S. Southwest Ruby initially identified the region. Smith's data shows a near-even split between sites before and after AD 900 for 100 *Haliotis* artifacts inventoried in the Puebloan area (Smith 2002:48–49).

It is clear that shell was prized throughout the Southwest by various Indigenous groups. The question then becomes, why was it so prized? The answer appears to be twofold. The first answer, which I shall briefly discuss, is potentially currency. While not unanimously agreed upon, *Olivella biplicata* beads are documented in the 19th century as a potential form of shell bead currency utilized in the Southwest and shared many similarities with Chumash shell bead currency use (Smith and Fauvelle 2015:714). Donald Brand discounted this possibility in the mid-20th century due to a lack of archaeological evidence of Southwest currency; yet he notes consistent records of shells as currency through much of the coastal United States, including in California, where the southwestern shell was sourced (Brand 1938:7). For example, the Pomo of Central California are documented turning clam shells into beads exchangeable for various items and services as an explicit form of wealth (Safer and Gill 1982: 58–60). If such actions were occurring as late as the 19th century, then it is certainly possible that this form of exchange extended to interactions long preceding Spanish contact within either region. Alternatively, the discussion of *O. biplicata* as a currency may find better description as a value representing status. For example, items made of shells have been used in various cultures to mark rites of passage or indicate political or social rank (Safer and Gill 1982:85–120). This could potentially bridge the gap between Smith and Fauvelle's currency description and Donald Brand's argument.

The second possibility is as containers for ceremonial materials or ceremonial use itself. Smith and Fauvelle point towards Donald Brand and Donald Tower as early examples of exploring ritual connections for marine shells in the first half of the 20th century (Smith and Fauvelle 2015:714). However, one can make a stronger case when specifically targeting abalone shells for their use in potential religious contexts. For example, Donald Brand describes the shells in the Southwest deriving their values from aesthetic or ceremonial reasons, particularly in the form of ornaments and pendants (Brand 1938:7). This idea is supported by Davis, who points to work by Gifford (1947) showing the presence of shells at multiple Pueblo sites throughout history that can only be sourced to the Pacific coast (Davis 1961:2).

To that end, William Smith (2002) posits the idea of marine shell in the Southwest as a type of religiofauna linked to cosmology and political aggrandizement. He suggests the following:

> One possible motivation for intense marine shell ritualization in the far west and Southwest may be because many aboriginal peoples of the coast had been marine oriented from earliest times and were highly conversant with impressive, potentially iconic forms, such as spirals and shell shapes. The universal shamanic cosmology may also have influenced the manifestation of marine shell ritualization. Marine shell was important to the shamanic process because of the iconographic importance of spiral morphology, colors, and the symbology of the oceanic non-terrestrial realm, which was the source of shells [Smith 2002:209].

Smith, in essence, is putting forward an economic exchange theory revolving around elite political control as the reason for interregional exchange between coastal Southern California and the Puebloan peoples. The shell played into Puebloan cosmology; therefore, a constant exchange or supply was necessary to fuel and facilitate connections to the cosmology, thereby perpetuating power (Smith 2002:207–216). This is unsurprising; colors found in *Haliotis* shell would associate with symbolic colors found in Pueblo cosmology. For example, red, which red abalone could represent, is associated with warfare, blood, and the southern direction (Munson and Hays-Gilpin 2020:Table 1.1, 19). The green abalone could be associated with blue-green, representing vegetation, males, and the western direction (Munson and Hays-Gilpin 2020:Table 1.1, 24). On the other hand, black has many meanings in Puebloan cosmology depending on the specific group; black abalone could fill this role (Munson and Hays-Gilpin 2020:20– 21). These examples only cover the exterior colors of *Haliotis*; the iridescent interior colors of *Haliotis* could easily fit into other Puebloan cosmological color representations. Erina Gruner (2019) provides concurring evidence that shell (specifically *Haliotis*) appears in quite a few different contexts:

> The restricted distribution of finished mosaic ornaments at Chaco Canyon suggests that *Haliotis* backings for mosaic inlay were likely prepared within Pueblo Bonito. Catalog records for shell blanks from Wupatki confirm that *Haliotis* ornaments were produced at the site (see WUPA 5168, WUPA 509, Appendix B). The life histories for whole versus processed *Haliotis* shells differed dramatically at all four sites reviewed. Whole shells concentrate nearly exclusively in burial contexts at Pueblo Bonito, Ridge Ruin, and Wupatki. Whole *Haliotis* shells are entirely absent from the Aztec West assemblage. Depositional context and functional attributes suggest that these artifacts were, in and of themselves, ritual paraphernalia. Abalone shell "medicine dippers" were used by several historic Pueblo groups to consume various sacred preparations, and such artifacts were often curated within sodalities or matrilines (Parsons 1939:331, 414, 689). Shells H/ 03652 (Figure 31) and NA1785.B16.8—from Pueblo Bonito and Ridge Ruin, respectively— were waterproofed with asphaltum suggesting use as a dipper… Pendants are the most common artifact type at all four sites within the dataset, followed by mosaic inlay tesserae, which, as previously discussed, are associated with elite and ritual contexts in multiple areas of the Southwest. [Gruner 2019:216–217].

When taken together, Smith and Gruner's assessments of ritual demand appear to be the greatest impetus for a strong and steady flow of shell from coastal California to the U.S. Southwest. Even if ritual is not the only reason, it provides a strong justification for trying to discern the movement of these shells. This, however, requires an understanding of the trails that the shell most likely moved through and whose land these trails crossed.

CHAPTER 3: ETHNOGRAPHIC CONTEXT

This chapter focuses on the ethnographic context of Indigenous groups involved, directly or indirectly, in the exchange of shell between the regions of coastal Southern California and Northern Arizona. The trade of shell from coastal Southern California to Arizona lands previously inhabited by Ancestral Puebloan peoples requires exchange through the traditional lands of multiple Indigenous groups, including the Chumash, Gabrielino, Chemehuevi, Mojave, Hualapai, Havasupai, and the Hopi (who are Ancestral Pueblo descendants). It is not a stretch to assume that each group played some role in facilitating the shell movement between the regions. As such, it is important to provide a brief overview of the groups involved in the exchange. A map of the Indigenous groups is supplements the overview (Figure 6).

Coastal California

Gabrielino

Gabrielino (Tongva) territory spanned from the Pacific coast eastward to the San Gabriel Mountain range and from Topanga Canyon south to Aliso Creek. The Gabrielino-Tongva occupied and exploited resources from Santa Catalina, Santa Barbara, San Clemente, and San Nicolas Islands. The term Gabrielino (aka Gabrieleño) is derived from the Spanish Mission San Gabriel to describe its administered neophytes. The pre-contact name for Los Angeles Basin people is Tongva (Bean and Smith 1978a). The pre-contact Tongva population estimate was between 5,000 and 10,000 inhabitants, including the Tongva residing on the Channel Islands. All Tongva subgroups spoke a Takic branch of the Uzo-Aztecan language (Singleton 2004). The Tongva lived in large, permanent lowland villages and subsisted on a hunting and gathering procurement strategy that included freshwater and marine fish and shellfish, mammals, insects, birds, and

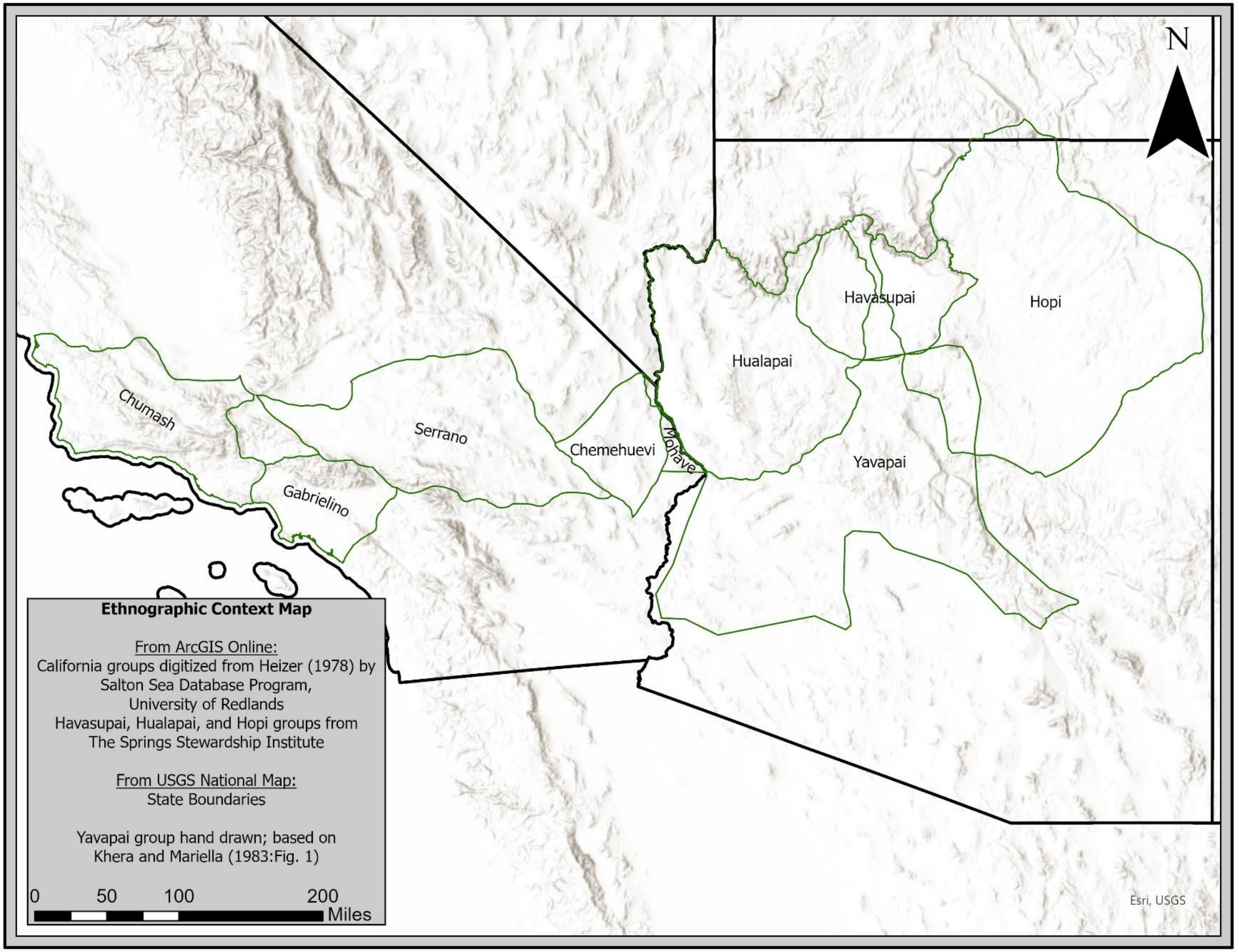

Figure 6. A Map of the Ethnographic Groups Described in the Chapter.

reptiles (Bean and Smith 1978a; Singleton 2004). They established a complex trade network with other tribes from California and Arizona, with a diversity of goods that included local chert, fish and otter pelts, and marine shell, beads, and ornaments offered in exchange for acorns, obsidian, and nonlocal seeds (Bean and Smith 1978a; Kroeber 1925).

European contact occurred around 1542, although colonization did not begin until at least 1769. In 1797 the San Fernando Mission was founded, and the Tongva were forced to live under the direction of the mission priest who required them to farm, raise cattle, tend vineyards, and conduct trades like carpenters and tailors—a mission style life. The introduction of mission-style living also introduced European diseases that decimated many Tongva communities (Bean and Smith 1978a; Singleton 2004). The presence of glass beads and metal tools in the archaeological record indicates European influence in the area (Sutton 2011).

Chumash

Chumash refers to the Indigenous peoples who traditionally resided within the modern-day Ventura County, Santa Barbara County, and the southern half of San Luis Obispo County. They are divided into six language groups (at minimum): The Ventureño (Ventura County), Barbareño (Coastal Santa Barbara County), Ynezeño (Inland Santa Barbara County), Purisimeños (around Point Conception, CA), Obispeño (San Luis Obispo County), and the Northern Santa Barbara Islands (Grant 1978a:505).

Woven baskets were the primary method of food collection, storage, and cooking for the Chumash (Gamble 2015). The Chumash also utilized canoes to facilitate trade between the islands, where steatite (utilized in trade or for food preparation) could be obtained in exchange for mainland artifacts or items such as sandstone storage bowls (Grant 1978b:514). Based on midden contexts, both the island and mainland Chumash groups obtained a variety of shells (Gamble 2015; Grant 1978b:517, Grant 1978c:524–525; Greenwood 1978). Interestingly, however, abalone shell does not appear prolifically in their middens despite being a significant resource for creating shell ornaments and utilitarian items (Grant 1978b:516). Chester King (1981) notes the creation of disk beads collars and bracelets of *Haliotis* shell as a form of dowry when a woman is married to a chief, along with only being used for ceremonial display in the form of ornaments (King 1981:103, 108). Items like these, when found, are expected in burial contexts (King 1981:158, 187, 194–195, 273–279, 303–306). In the case of utilitarian items made of shell, notably fishing related equipment, such resources would not make it into middens due to loss during resource gathering (King 1981:79–81). This lack of abalone in middens is significant because these shells and other items were associated with other native groups that regularly traded with the Chumash, such as the Tongva, Salinans, and Yokuts (Gamble 2015; Grant 1978b:517). King also recognizes the importance of shell beads as part of a critical trade. Outside of abalone shells, other shell beads were used for various purposes, such as inlays on stone vessels, baskets, and bone whistles. Purple *Olivella* shell beads appeared first, and later, clam and mussel disk beads were also used (Greenwood 1978). In particular, the shell beads acted as a currency to procure steatite vessels such as ollas and comals (Gamble 2015).

The Chumash were the first noted California Indigenous group during Juan Rodriguez Cabrillo’s exploration along the coast in October of 1542; four missions were established within Chumash lands between 1772 and 1804 (Grant 1978a:508). The setup of missions was followed by rapid missionization of the Chumash peoples during roughly the same period. The mission period ended in 1834, following Mexico's secularization of the churches that previously caused a decimation of the Chumash population during missionization (Grant 1978a:506).

Mojave Desert

The Mojave Desert area between the Gabrielino and the Colorado River is where there is an intersection of three groups. All three Indigenous groups appear to be associated with the path of potential trade between California and Arizona: the Serrano, the Chemehuevi, and the Mohave.

Serrano

Serrano is a collection of Indigenous groups encompassing the San Bernardino Mountains and a portion of the western Mojave Desert (Bean and Smith 1978b: 570, Figure 1). This collection is very loosely based on a multitude of languages rather than any substantial evidence of group organization or affiliation (Bean and Smith 1978b:570). A case in point is that the Vanyumé, or Desert Serrano, are classified with the Serrano of the San Bernardino mountains, but it is unclear whether they are linguistically similar or separate (Bean and Smith 1978b:570; Sutton and Earle 2017:2). The Vanyumé resided along a potential trade path between coastal Southern California and the United States Southwest, yet very little literature exists discussing them. Ethnographic work by Kroeber, along with historical documents from the Spanish and early American settlers, indicate that neighboring groups recognized the Vanyumé as a separate group from the mountain Serrano (Earle 2005:4; Sutton and Earle 2017:9–12). Overall, both groups are highly understudied in their sociopolitical organization beyond mission records from the late 18th to early 19th centuries. The current inference is that they were primarily organized into exogamous clans affiliated with two moieties (Bean and Smith 1978b:572; Sutton and Earle 2017:34–36).

Following Spanish contact, the mountain Serrano were moved to missions in 1834 (Bean and Smith 1978b:573). The history of the Vanyumé, on the other hand, is less specific. Interviews with people considered to be the last survivors of the Vanyumé give answers that include massacre by Mexicans, a revenge killing by the Mojave for an incident that led to Mojave deaths at the hands of Mexican settlers, to potential relocation to the missions just like the mountain Serrano (Earle 2005:24–26; Sutton and Earle 2017:49)

Chemehuevi

The Chemehuevi is an Indigenous group living within the California section of the Mojave Desert, with an eastern boundary roughly consistent with the Colorado River (Earle 2005:11–12; Kelly and Fowler 1986:Figure 1; Stewart 1968). While not the same as the peoples generally comprising the Southern Paiute, apparently, they are closely related enough that discussions of the Chemehuevi traditionally group them in with the larger Southern Paiute (Earle 2005:5; Kelly and Fowler 1986:368; Stewart 1968:9). In addition, documents describe them as actively interacting with other Southern Paiutes, the Shoshone, Kawaiisu, Serrano, Vanyumé, Cahuilla, and Diegueño (Kelly and Fowler 1986:370). Spanish arrival did not affect the Chemehuevi until roughly the late 18th century, introducing disease and enslavement by the Spaniards (Kelly and Fowler 1986:386). This period was followed by hostile interactions between American settlers moving west during the mid and late 19th century, typically involving the raiding of settlers (Earle 2005:26–27; Kelly and Fowler 1986:387).

Mohave

The Mohave (or Mojave) is a Yuman-speaking Indigenous group described as living along the Colorado River from 15 miles north of the current Davis Dam in Nevada to “The Needles” just south of Topock, Arizona (Stewart 1983:55). Evidence suggests the Mohave, or at least a branch related to the current day Fort Mojave and Colorado River Reservation groups (referred to hereafter as Desert Mojave), inhabited the same Mojave Desert lands traditionally associated with the Chemehuevi (Earle 2005:6). What happened is not fully clear. The current Mohave suggest that the Chemehuevi were allowed to settle or co-inhabit in the Desert Mojave lands; the Chemehuevi claim they invaded and exterminated the Desert Mojave as retaliation for raids with the remaining peoples adapting culturally to mirror the Chemehuevi (Earle 2005:7). However, what is undeniably clear is that over the intervening years, a blending or transference of cultural elements between the Mohave and the Chemehuevi occurred, with each group adopting elements of the other (Earle 2005:5-7; Kelly and Fowler 1986:370–371). This similarity also continues into the post-contact era; while the Mohave maintained their independence from the Spanish and were minimally affected by their presence (atypical for most Indigenous groups), they did clash with American settlers (sometimes with Chemehuevi allies, despite the two groups having fought a war between 1865-1871) and eventually lost to the American Army in the late 19th century (Earle 2005:7; Kelly and Fowler 1986:387; Stewart 1983:57).

Arizona

Hualapai

The Hualapai (or Walapai) is another Yuman-speaking Indigenous group located in northwestern Arizona. Specifically, the group's traditional boundaries were the Mohave to the west, the Colorado River to the north, and the Bill Williams and Santa Maria Rivers to the south (McGuire 1983:26; Shepherd 2010:20). The eastern boundary is slightly more challenging to define because the Hualapai range overlaps with the Havasupai, a closely related group they actively traded with; however, it appears to extend to the Little Colorado River (McGuire 1983:25, Figure 1, 32). There is potential evidence that their maximum range may have crossed the Little Colorado River and bordered on the Hopi and Navajo (Shepherd 2010:20). Archaeological evidence of Puebloan vessels, or ceramics imitating them, and Chemehuevi tools and objects appear in Hualapai excavations, providing a solid indicator that the group engaged with the trade from coastal Southern California to Hopi (Shepherd 2010:22). Trade items included shell neck pendants as adornment for individuals (McGuire 1983:34).

The Hualapai first appeared in European texts via Spanish visitations during the 16th to 17th centuries, but apparently, they never fell under the influence of Spanish missionization (McGuire 1983:27; Shepherd 2010:25–27). After initial Spanish contact, the next significant Euromerican contact came in exploratory incursions by the United States Army in the middle of the 19th century (McGuire 1983:27; Shepherd 2010:29). Hostilities broke out between the Hualapai and United States in the late 1850s, leading to a forced relocation on foot to La Paz located on the Little Colorado Reservation, an action that killed many individuals and ultimately failed when they fled back to their traditional lands in 1875 (McGuire 1983:27; Shepherd 2010:29–44). After that trauma, their lands were reduced to the current reservation in 1883 (McGuire 1983:27).

Havasupai

Havasupai (a Yuman-speaking group) lands traditionally centered upon the Coconino Plateau (Schwartz 1983:13, Figure 1). The Havasupai are considered distinct from the Hualapai In the modern-day, but this was not the case in the past. Instead, the Hualapai and Havasupai are apparently closely related and potentially better represented collectively as 13 regional bands known as "the Pai" (Braatz 1998:19; Schwartz 1983:14; Shepherd 2010:19–20; Weber and Seaman 1985:4). The split between Havasupai and Hualapai, in particular, appears to be one forced upon them during clashes with the U.S. Army and American settlers. This division was highlighted with the creation of separate reservations intentionally splitting the two groups, which may be why they are now considered separate and distinct (Braatz 1998:19; Schwartz 1983:14). Despite this, the Hualapai and Havasupai are still on friendly terms, in some cases involving intermarriage (McGuire 1983:14; Weber and Seaman 1985:4).

Havasupai's contact with Europeans and Americans followed a similar path as the Hualapai. Spaniards visited the Havasupai between 1600 and 1820, with no missionization apparently occurring (Weber and Seaman 1985:11–12). American contact was initially through trappers, but by 1863 settlers and miners flooded into the area, which had slowly been shrinking as Hualapai and Navajo appropriated their western and eastern lands independent of American contact (Weber and Seaman 1985:12). This influx of settlers accelerated the limitation of the Havasupai range, requiring a presidential proclamation to create a reservation for their minimal area (Weber and Seaman 1985:12).

Yavapai

Southwest Yavapai territory historically locates itself in Central Western Arizona, particularly in the Verde River Valley and the central Western Desert (Crandall 2020:498; Khera and Mariella 1983:39). More specifically, the rough boundaries include the San Francisco Peaks to the north, the Gila River to the south (with a finger to the Superstition and Pinal mountains), the Gila Basin to the east, the Colorado River to the west, and the Bill Williams and Santa Maria Rivers to the northwest (Khera and Mariella 1983:38). Four regional bands are recognized ethnographically and by the Yavapai themselves: the Kwevkepayas, the Tolkepayas, the Wipukepas, and the Yavapés (Crandall 2020:489–490; Khera and Mariella 1983:39, Figure 1). They are a Yuman-speaking people like the Havasupai and Hualapai; however, the Yavapai consider themselves distinct historical enemies of the groups previously mentioned (Crandall 2020:489; Khera and Mariella 1983:38, 40; McGuire 1983:25; Schwartz 1983:14). The Yavapai traded with the Hopi and Navajo and were considered peaceful with the Mohave (Khera and Mariella 1983:40). The relations with the Hopi and Mohave, in particular, are noteworthy, as it potentially places them in a position to be part of an extended trade between Southern California and the United States Southwest.

The Yavapai first appeared in Spanish accounts of exploration in the late 16th and early 17th centuries; however, their descriptions portray them as having minimal contact with anyone of European or Euromerican descent until miners entered the region in 1860 following the discovery of gold (Khera and Mariella 1983:40). At this time, most settlers referred to the Yavapai as Apache in an effort to paint them as hostile Indians needing removal from the area (Crandall 2020:506). This portrayal led the U.S. military to attempt to push the Yavapai onto reservations, sparking conflict and leading to a series of massacres directly tied to reservation relocation (Crandall 2020:507; Khera and Mariella 1983:41). The five current reservations are the Fort McDowell Reservation, the Camp Verde reservation, the Middle Verde Reservation, the Clarkdale Reservation, and the Prescott Reservation.

Hopi

The Hopi are an Indigenous group directly descended from the Ancestral Puebloans, formerly (and incorrectly/problematically) referred to as the Anasazi (Plog 1979:108). Their historical territory is roughly analogous with northeastern Arizona; more specifically, it revolves around a series of Mesas: First Mesa, Second Mesa, and Third Mesa, collectively located on the southern portion of Black Mesa (Adams et al. 2004:401; Bernardini and Adams 2017:Fig.21.2; Brew 1979:Fig.1, 515). The Hopi are grouped along with the Zuni, Acoma, and Laguna peoples into the "Western Pueblos" due to a social and religious similarities (Sutton 2016:208). It is possible that the Hopi's ancestral people inhabited the area in roughly 2,000 BCE (likely from Central America), but there is definite habitation evidence from 500 BCE (Bernardini and Adams 2017:433; Plog 1979:119). Consolidation from clusters of pit houses into larger communities with masonry structures occurred following AD 900, with the villages we more readily tie to the current Hopi arising in the early 1200s through population aggregation (Adams et al. 2004:405; Bernardini and Adams 2017:434: Plog 1979:120).

Spanish contact came to the Hopi villages starting with Coronado's first military expedition in 1540 (Brew 1979:519–520; Bernardini and Adams 2017:435; Brew 1979:519; Knaut 1995:18, 23; Sheridan et al. 2015:44; Wilcox 2009:107). Extensive Spanish missionization efforts to convert the Hopi starting in 1629 followed the expeditions and led to a history of brutal oppression (Brew 1979:519–520; Cordell and McBrinn 2016:31; Knaut 1995; Sheridan et al. 2015; Sheridan et al. 2020; Wilcox 2009). Spanish actions led to the Pueblo Revolt of 1680 and 12 years of no outside influence in the short term; the long-term implications were that the Spanish gave up on aggressive missionization and control by the end of the 18^{th} century (Brew 1979:521–522). This success left the Hopi with a return to self-governance over their lives in practice (albeit changed through extensive Spanish contact), though not peace. Fending off Mexican and Native attacks characterized the first half of the 19^{th} century, so governmental control was less important to the Hopi (Dockstader 1979:524; Sutton 2016:205–206). The Hopi (and the Southwest at large) fell under the jurisdiction of the United States with the conclusion of the Mexican-American War (Cordell and McBrinn 2016:33; Dockstader 1979:524; Sutton 2016:206). Settlers began to enter the Hopi region; however, the U.S. military would not provide a significant and active presence in the region until the cessation of the American Civil War (Dockstader 1979:525). The purpose of this presence was more due to the pressing issue of Apache and Navajo raids; however, it opened the gates for increased control of the Hopi by the United States government at the hands of Euroamerican expansion, which undoubtedly led to the official creation of the Hopi Reservation in 1882 (Cordell and McBrinn 2016:300; Dockstader 1979:526).

Summary

The long-distance between Coastal Southern California and the Ancestral Puebloan lands of northeastern Arizona contained a variety of Indigenous groups. Each group has its rich history, and each undoubtedly influenced the travel of abalone shells from west to east. Whether directly involved in the exchange or claiming lands that others traveled through (with or without permission), such a long trek begs a new question: is there knowledge of how people moved across the land that supports this? The answer is yes, and it lies explicitly with the studies of trails.

CHAPTER 4: TRAILS

This chapter discusses the role of trails between coastal Southern California and Northern Arizona. I start with a brief discussion of how trails are archaeologically significant, along with different ways of viewing them. Next, I focus on previous documentation of the trails between coastal Southern California and Northern Arizona to link California Indigenous groups and the lands inhabited by the Ancestral Puebloans.

The Significance of Trails

Trails between California and Arizona are well documented in the archaeological record (e.g., Colton 1941; Davis 1961; Earle 2005; Farmer 1935; Ford 1983:Figure 8). This is unsurprising because trails are implicit indicators of connection and trade between locations. However, despite their importance, determining the location of trails is not easy. Traditional methods involve reconnaissance or intensive surveys of the land; however, this is contingent on the skill of the surveyors and the visibility of features for identifying paths themselves (Snead et al. 2009:10). Scale also plays a significant role in successfully mapping trails; regional connections are more often than not mapped in the context of local projects, which then need aggregation as collective data rather than being looked at in narrow scope (Snead et al. 2009:2–3).

To determine how people made their way from point A to point B is to gain information on how and why groups interacted, whether simply for trade or for more complex reasons. Snead et al. (2009) describe them as "landscapes of movement," or ways of structuring human life (Snead et al. 2009: 1–2). However, it is not always easy to track pathways connecting different groups and regions across the country. Snead mentions that T.T. Waterman (1920) would not commit trails to a physical medium because he had not personally travelled along them (Snead et al. 2009:2). Simultaneously, he also points to a series of ethnographies that discuss how trails fit into societies; however, this often does not translate into being directly linked to the physical trails, paths, routes, etc. (Snead et al. 2009:2).

Ferguson et al. (2009) elaborate upon attempts to determine Hopi trails that are associated with their migration to their current homeland. While the impact of the United States expansion and federal taking of lands cannot be understated, efforts have only recently occurred to document disappearing evidence of physical trails through collaboration between the Hopi Tribe and trail researchers (Ferguson et al. 2009:21). Where the Hopi orally can describe the paths, a lack of use coupled with construction activities provided the impetus to commit these trails to physical records; however, many of these studies are not (and rightly so) available for access due to cultural concerns for sites and locations of importance (Ferguson et al. 2009:32–33). This limitation of information is entirely understandable; however, it does make the task of identifying routes, particularly in the northern portions of Arizona, tricky to accomplish without formal negotiations and consultation.

Historical Documentation of Trails

Malcolm F. Farmer (1935) provides evidence of trails between coastal Southern California around Los Angeles and the Southwest, but only as far as the Colorado River (Figure 7). He notes a primary trail connecting the Mojave to the Indigenous groups located within the modern-day Ventura, Los Angeles, Orange, and Santa Barbara Counties. Historically, these were the Gabrielinos, Fernandeños, Serranos, Ventureños, and Barbarbeños; these groups would later be aggregated by Heizer (1978) underneath the broader umbrellas of Gabrielino (Gabrielinos and

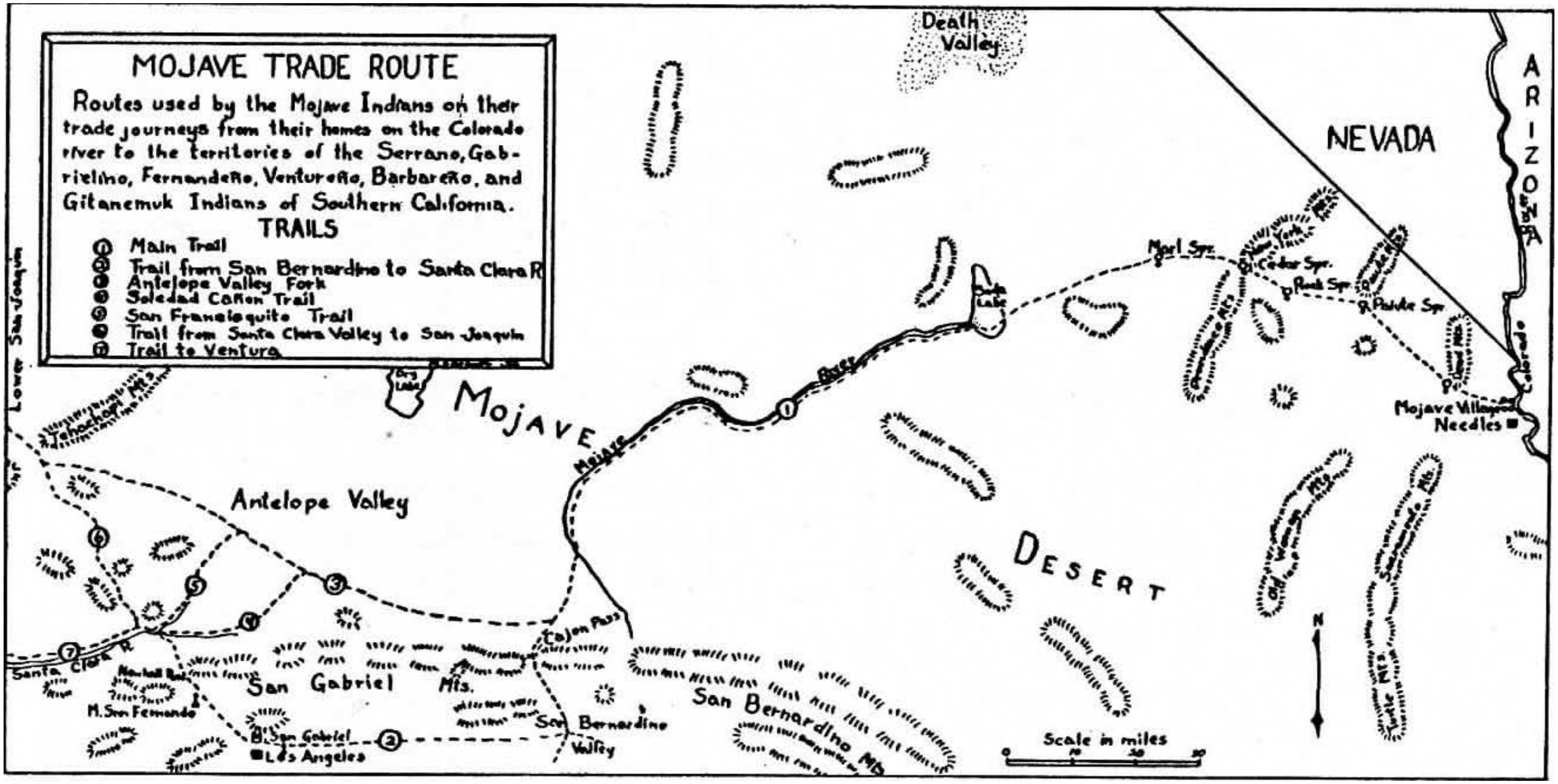

Figure 7. The Farmer Map (1935:154).

Fernandeños), Chumash (Ventureños and Barbarbeños) and Serrano. As Farmer (1935) describes it, the Mojave acted as the facilitators of exchange between Arizonan and coastal Southern Californian Indigenous groups, traveling through the Mojave towards the Cajon Pass before branching to different groups to acquire goods. However, these trails cross many lands and various Indigenous groups; it could be the case that successive exchange between neighboring groups was also a method of moving shells eastward. Harold Sellers Colton (1941) elaborates further on Farmer's (1935) assessment of trails by providing an insight into the trail as it "ran from the Pacific Coast in the Los Angeles area to the Rio Grande" (Colton 1941:308). He states that the trail followed the Santa Fe Railroad and Route 66, heading north of the two locations after passing the Cajon Pass, which mirrors the trail as previously documented by Farmer (Colton 1941:308; Farmer 1935). Although the documentation becomes murky after crossing into Arizona, overall, it still follows Route 66. Colton then claims that it passed through Walapai and Havasupai lands on its way towards the Hopi, then heading southeast to Zuni before heading eastward to the Rio Grande near Isleta (Colton 1941:308; Figure 8). A map by Davis (1961:Map 1), reaffirms Farmer's and Colton's understanding regarding the general path way of the Mojave Trail from the San Bernardino Mountains to the Colorado River (Figure 9).

What is interesting is the persistence of the Mojave route from Coastal California. Even as late as 1776, there is Spanish documentation of active eastwards shell trade for Californian Indigenous groups (Colton 1941; Earle 2005:12–15). Father Garcés notes in his travels of Mojave people visiting or traveling in the Tehachapi Mountains, Santa Clarita Valley, and Mission San Gabriel, all areas located on the westernmost extension of previously discussed trails (Earle 2005:12). A later trip in 1819 by Father Nuez documents springs described by the Chemhuevi

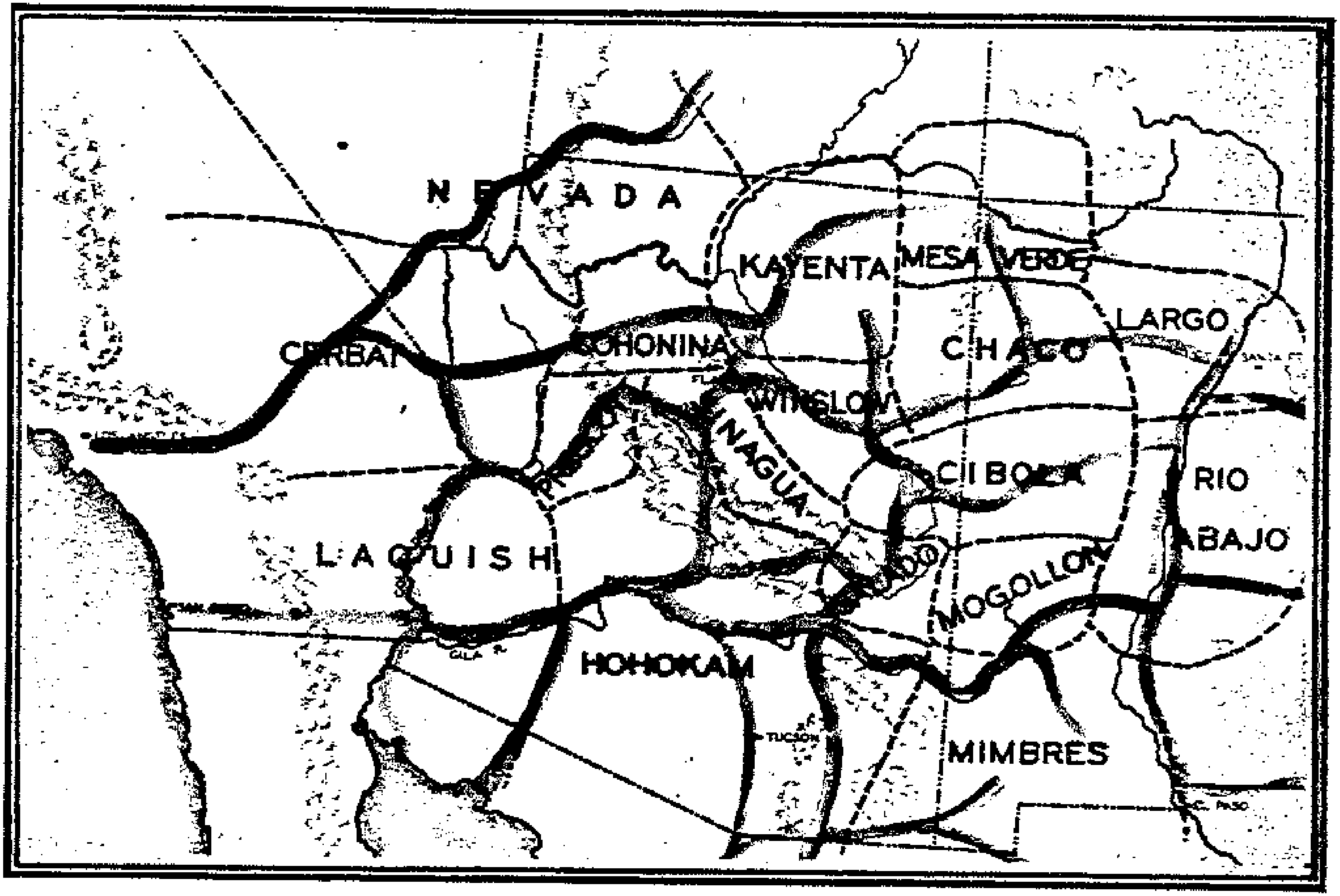

Figure 8. The Colton Map (1941:311).

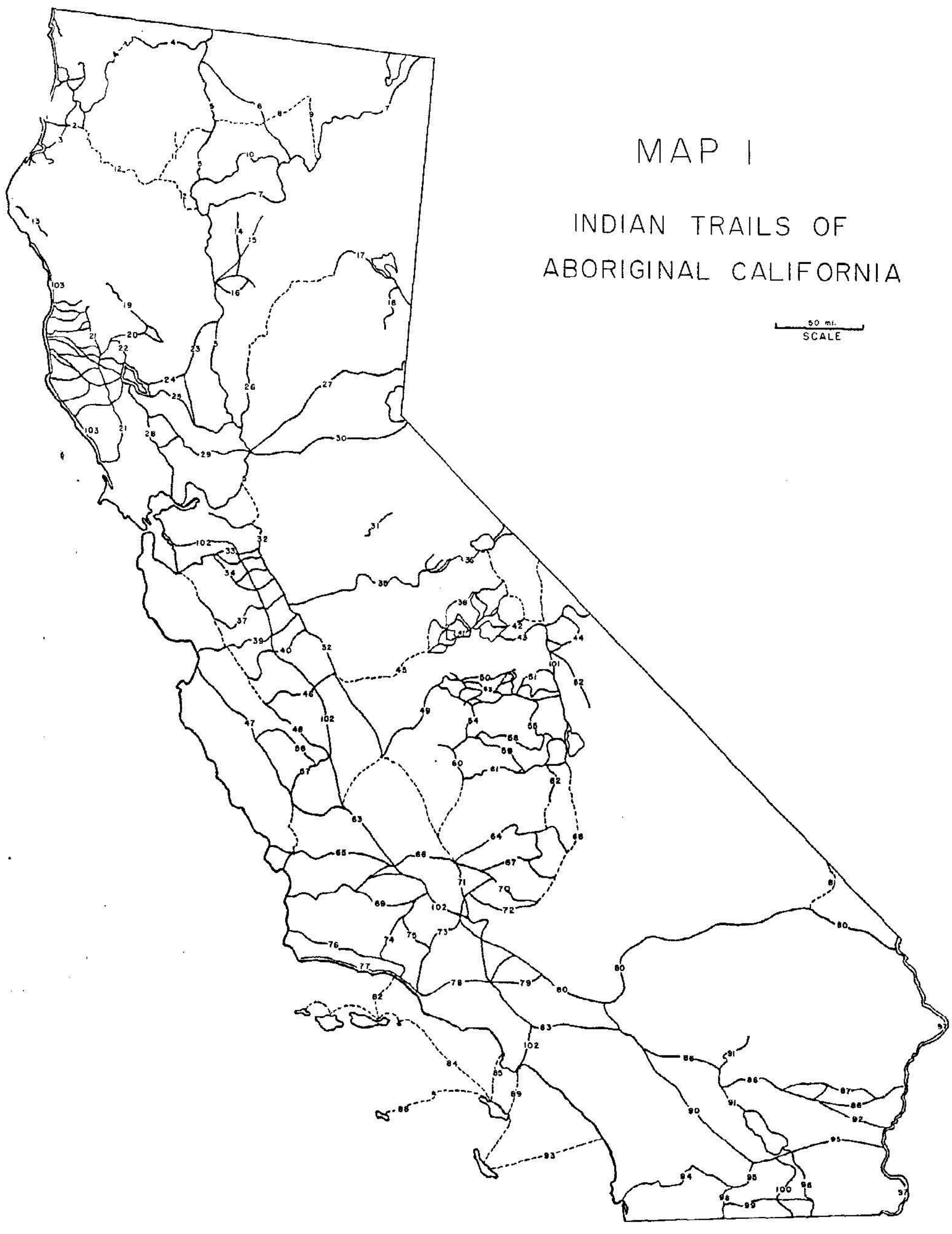

Figure 9. The Davis Map (1961:Map 1).

along the trail that align with Farmer's (1935) identifications: *Guanichique* for the area associated with the modern-day Soda Lake and *Patsoboauet* for Paiute (Piute) Spring (Earle 2005:11).

These are further supported by Laird's (1976) work identifying *Paasa* as another name for Paiute Spring and *Tooyagah* for Rock Spring, while evidence for *Chinchinipobeat* and *Uchique* potentially associates them with Marl Springs and Rock Spring (Earle 2005:11–12). All four of these locations appear in Farmer (1935) and lend credence to the relative accuracy of maps depicting the trails running from the coast to the Colorado River. Colton (1941), Earle was unable to find descriptions of the trails and paths followed from the Colorado River through Arizona beyond a general mention of traveling through the Hualapai (Walapai) and Havasupai to get to the Hopi village of Oraibi, a process that required roughly two weeks (Earle 2005:14).

Vokes and Gregory (2007) also provide evidence of trails coming into Arizona based on the archaeological resources found along the routes (Figure 10). Two of these routes, labeled PC 1 and PC 2, are identified as primarily used for moving shell and turquoise eastwards to the Puebloan groups (Vokes and Gregory 2007:Figure 17.1). PC 2, in particular, is cross identified as being the Mojave Trail. Their map shows a strong match when compared to maps from Colton (1941) and Davis (1961) (Figure 8 Figure 9). One concern, however, is that Colton and Earle's descriptions of trade routes suggest networks including the Hualapai and Havasupai; Vokes and Gregory (2007) suggested routes that skirt just south of these two groups along the fringes of their traditional ranges.

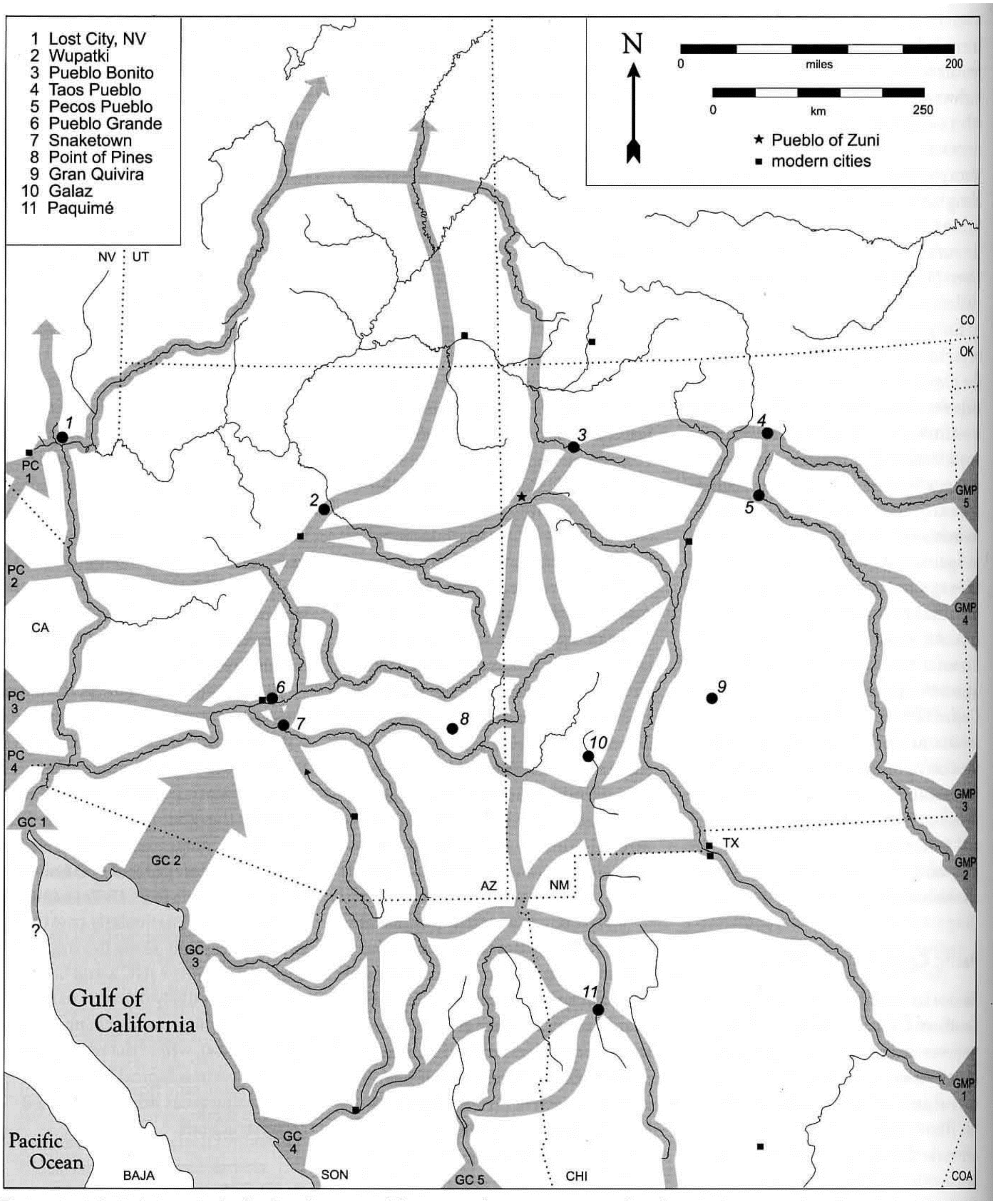

Figure 10. The Vokes and Gregory Map (2007:Figure 17.1).

A map in the *Handbook of North American Indians, Vol. 10* provides a potential answer while rectifying the difference between the various routes proposed (Ford 1983:Figure 8) (Figure 11). The map depicts the Mojave Trail coming out of California to the Arizona border around Needles. From there, it splits into two different routes heading to lands inhabited by the Ancestral Puebloans in Arizona. One is a northern route that cuts directly through Hualapai and Havasupai lands as it heads northeast towards the San Juan River, eventually bending southeast towards the Pueblos along the Rio Grande in New Mexico. This is similar to the descriptions provided by Colton and Earle (Ford 1983:Figure 8). However, the southern route fits better when compared against Gregory and Vokes' (2007) map of the Pacific to Arizona route (Vokes and Gregory 2007:Figure 17.1). From Needles, the route dips south along the Colorado River to the Bill Williams River, before heading northeast through Flagstaff (Ford 1983:Figure 8). From there, the southern route either reconnects to the northern one or heads due east towards the Hopi and Zuni Pueblos before ultimately reaching the New Mexico Pueblos (Ford 1983:Figure 8).

One concern needing consideration for the maps previously provided is their scale. These maps are on a very small scale and have no associated spatial data. This means that they require georeferencing when imported into a GIS system, potentially leading to errors. For example, a millimeter of discrepancy between Arizona’s northwest corner in Ford’s map and its position in ArcGIS Pro, at a scale of 1:6,000,000, results in an error of 6 kilometers for the Ford map. This means that Ford’s map is accurate but not very precise (i.e., accurate to 6 km per millimeter). Still, the general path of these trails makes such errors acceptable in the study between regions.

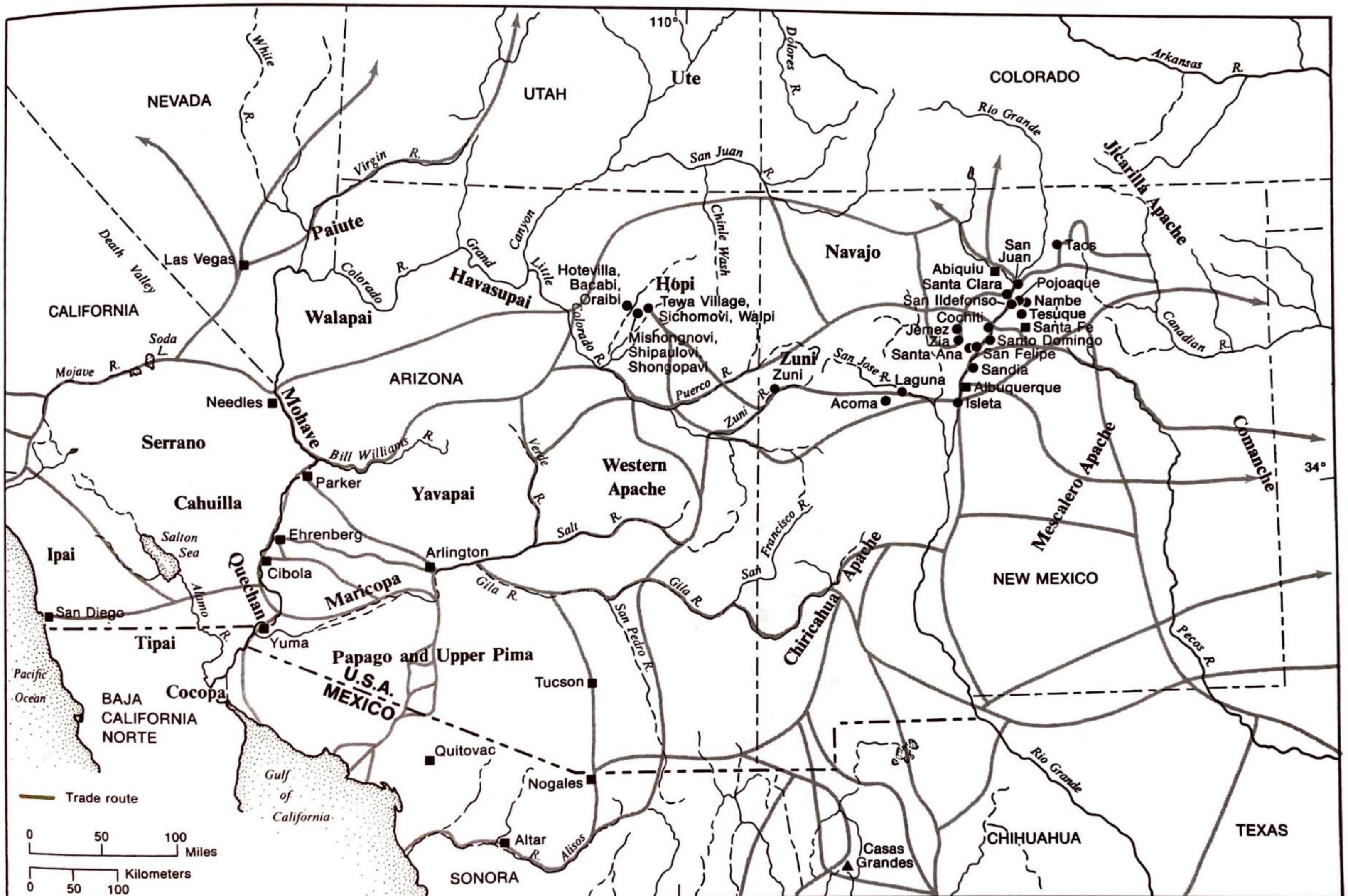

Fig. 8. Traditional trade routes in the Southwest.

Figure 11. The Ford Map (1983:Figure 8).

Summary

The literature overwhelmingly indicates that the Mojave Trail corridors were the primary route for exchange leading from the Chumash and Gabrielino groups of coastal Southern California to the Colorado River, providing access to the Northern Arizona region, and later the Puebloan groups. The California trails are unquestionable in their accuracy. Repeated documentation of the route, particularly repeated identifications of the various springs necessary to survive the trek through the Mojave Desert, supports the route's habitual and continuous use. The Arizona half of the trails, on the other hand, are more difficult to ascertain due to less information regarding waypoints of major significance along the routes. However, there appears to be general consistency between Colton’s (1941), Earle’s (2005), and Vokes and Gregory’s (2007) assessments of the path leading into the Ancestral Puebloan areas of Arizona. This consensus also matches the map of traditional trade routes through the Southwest published by the Smithsonian Institution (Ford 1983:Figure 8).

However, sole reliance on the literature is not the only tool available to archaeology in the modern era. There are ways to model potential trail routes to confirm what we already know. These modeling techniques, commonly done through Geographic Information Systems programs, illuminate potential paths and corridors that literature has not yet considered. One modeling technique used in archaeology is least cost path analysis.

CHAPTER 5: LEAST COST PATH ANALYSIS

This chapter discusses least cost path analysis and its utility for exploring exchange routes. I start by providing a brief description of least cost path analysis and the possible results through its use. Next, I provide previous case examples of this modeling technique in archaeological projects. Finally, I discuss some of the potential snags and appropriate applications needing consideration for archaeological examination using this modeling technique.

What is Least Cost Path Analysis?

Geographic Information Systems (GIS) provides a valuable window on spatial relationships between archaeological data across a landscape. For example, in the case of shell exchange between coastal Southern California and the Ancestral Pueblos in Arizona, it is possible to recreate routes in which *Haliotis* and *Olivella* shells could have traversed many hundreds of miles and transitioned through the hands of numerous Indigenous groups. A key to producing this information is to utilize least cost path analysis.

Least cost paths (LCP; or least cost analysis [LCA]) evaluate the feasibility of moving between two points. Newhard et al. (2008) defines LCP as follows:

> Least-cost pathway analysis is a means of evaluating the easiest method (least-cost) of moving from a given point to another. By combining numerical values tied to spatial data (such as elevation and slope angle) in a weighted fashion, the surface of an area of interest can be represented with values indicating the expected effort required to traverse the area. [Newhard et al. 2008:91].

Alternatively, LCP depicts the most energy efficient path across the earth's surface between an origin and a destination or destinations. This path factors the cumulative effort invested in moving between the locations, combining a variety of factors such as the distance, difficulty of slope traversed, energy expenditure, or time involved in travel (Caseldine 2021:9). To create an LCP, an archaeologist must first complete a path distance analysis.

Path distance analysis enables archaeologists to calculate accumulating effort for traveling from an origin to a destination, or to destinations, incorporating four elements: points representing origins, a surface representing the distance a person travels (both horizontally and vertically), factors helping or hindering movement along the surface, and elevation factors that slow or speed people during their travel. These factors typically are primarily based on a digital elevation model (DEM). DEMs are raster datasets, or images comprised of a tessellation of cells. Each cell in the DEM represents area and elevation (typically in meters) across the earth's surface. The DEM is the foundation for calculating true distance of travel. DEMs are readily accessible in the present day from online services. The most well-known ones for the public to obtain are from the Shuttle Radar Topography Mission (SRTM), the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and ones created by the United States Geological Survey (USGS) from their 7.5' topographic quadrangle sheets.

In addition to true distance, the vertical and horizontal data in a DEM can be used to derive a cost surface based on slope. The cost surface usually represents the time or energy expended to travel across a given cell in the raster and the uphill and downhill movement from cell to cell. The cost surface typically appears in the form of an image depicting the changing slope of the earth's surface. The idea is that an increasing slope is increasingly challenging for someone to traverse and, therefore, an undesirable path. Meanwhile, a low or negative slope is far more desirable for a person to travel through due to less energy required. The slope can also be modified. For example, Tobler's hiking function (1993) attaches a cost of time to the slope to better represent the difficulty of traveling through ranges of steepness on the earth's surface. The slope is typically input as a cost raster during path distance analysis. The factors representing variations in traveling across the earth or varying elevations then modify the slope map's initial expected difficulty of travel. These are referred to as horizontal and vertical factors during path distance analysis.

Path distance is calculated using origin feature/s – the point/s from which the least cost path will be calculated, surface depiction – cost of traveling across the said surface, and modifying factors for the cost are combined to create two images. The first image, the path distance raster, shows the accumulating difficulty of travel from the origin point outwards along the raster's surface. The other image is called a backlink raster. The backlink raster is an image where each cell is assigned a value based on an associated cardinal (north, south, east, west) or intercardinal (northeast, southeast, southwest, northwest). These numbers and their associated directions ca be seen as a turn-by-turn instructions leading back to the origin point, or points, along the most energy efficient path.

In its simplest form, LCP analysis consists of a combination of starting and ending points coupled with a continuous surface of elevations, such as those found in DEMs. LCP results give us models of potential travel routes across a landscape. These models are created using GIS software applications, such as ArcGIS Pro and Grass GIS. More sophisticated models can also be created by incorporating other spatial data such as geographic barriers (rivers and lakes), or necessary waypoints between starting and finishing points, such as a continuously flowing spring in an arid environment. However, the end goal remains the same. The LCP modeling process provides archaeologists with ideas about where to look on the ground to confirm the presence or absence of ancient trails that may have played a role in travel or exchange.

Case Studies of Least Cost Path Analysis

LCP has been successfully used in previous archaeological projects involved in plotting routes. For example, Thomas Whitley and Lacey Hicks (2003) utilized LCP modeling to speculate on potential travel routes along Georgia's Northern Arc corridor. They were able to do so by comparing DEMs, hydrologic data for lakes and streams in the corridor, and a temporally diverse set of archaeological sites from the area. These data were utilized to create a friction surface, the most simplistic of which is a slope model (Whitley and Hicks 2003:80). By running the model, Whitley and Hicks (2003) generated primary and secondary pathways throughout the Northern Arc corridor, which were then compared against other forms of evidence such as known historic trails.

Similarly, James Newhard, Norm Levine, and Allen Rutherford (2008) applied LCP to the Göksu Valley in Turkey to answer questions regarding its potential for inter-regional interactions between the Anatolian Plateau and the Mediterranean Ocean. Like Whitley and Hicks, their examination required creating a slope model, which resulted in a potential route supporting the Göksu Valley as an important trade corridor due to constraints of extreme slope (Newhard et al. 2008:99). This analysis supports the prevailing thought that trade between Central Anatolia and Syria required access to the Mediterranean through Lower Cilicia (Newhard et al. 2008:99). However, what is more significant is that their work required DEMs far larger than previous mappings, such as ones from ASTER, SRTM, and those based on USGS 7.5' quadrangles, all of which have a cell size around 30 meters. Instead, the analysis relied on DEMs from the National Geospatial-Intelligence Agency with cell sizes of nearly 200m, citing a need to keep the dataset small enough for quick and efficient processing over a large area, accepting the loss in resolution because the goal was to obtain a rough idea of potential paths for future studies (Newhard et al. 2008:92–93,99).

While LCP is habitually used to model routes that help support hypotheses based on previously uncovered data, it can also force the consideration of atypical answers based on its modeling. An LCP analysis by Matthew Purtill (2021) of Paleoindian travel in the upper Ohio Valley is a perfect case in point of this situation. His modeling of travel showed that travel through the lower Scioto Valley (LSV) would have been optimal for Paleoindians traveling from Sandy Springs to chert deposits north of the previously mentioned site based on the lack of extreme slopes and terrain that needed traversing (Purtill 2021:134). However, the location of Paleoindian archaeological sites indicates the preferred route was through the Ohio Brush Creek—Baker's Fork (OBC-BF) drainage, despite being more challenging terrain and 54 hours of extra traveling time compared to the LSV (Purtill 2021:143). This model leads to further questions and hypotheses regarding risk aversion by Paleoindian peoples, such as whether the LSV's geomorphology suggests it was an unstable and natural disaster hazard compared to the OBC-BF or if the relative "familiar" look of the OBC-BF's environment led to instinctive selection bias (Purtill 2021:144–146).

LCP has also seen application in the U.S. Southwest. Most recently, Christopher Caseldine (2021) applied LCP within Central Arizona's Tonto Basin to reconnect the Lower Tonto Cliff

Dwellings to the archaeological history of the Tonto Basin. Caseldine built LCP models based on simple slope calculation, energy expenditure, and time expenditure while also factoring in elements such as different environments traversed (Caseldine 2021:7–10). The result is that despite the variance in the calculation of the LCP, there is significant overlap between modeling parameters, in addition to portions of historical travel routes, culminating in three major and two minor travel routes identified between the Tonto Cliff Dwellings and other Tonto Basin settlements (Caseldine 2021:16, 19–20). In addition, Caseldine makes a note of a disconnect between the model emphasizing the Salt River for traveling between areas versus the reality of a lack of settlements along that route, not too dissimilar to the model vs. the empirical distribution of Paleoindian sites seen in Purtill's (2021) Ohio Valley work (Caseldine 2021:22). He also points out that these LCPs should be compared against verified trails to confirm hypotheses posited by the modeling and return to update the models as more information is discovered that can be incorporated into the modeling process (Purtill 2021:23–24).

Field et al. (2019) provide another instance of applying LCP in the U.S. Southwest. Their case study applied LCP modeling to evaluate whether Chaco roads, amongst other uses, were built to aid timber importation to the Chaco region (Field et al. 2019:136). The timbers were imported by multiple people carrying them based on a lack of drag scars; therefore, the roads had gentle enough slopes to navigate as a concerted group, even though potentially costly (Field 2019:140–141). Interestingly, Field et al. also incorporate a horizontal travel variable, specifically terrain difficulty, to adjust the costs of people traveling through different types of landscapes (Field et al. 2019:140). Ultimately, the authors indicate a strong correlation between the Chaco roads and their correlative LCP analysis, meaning that Chaco roads could have been created for optimal resource importation alongside proposed reasons for their creation proposed by other archaeologists.

Considerations for Least Cost Path Analysis

Two critical considerations need addressing when utilizing LCP. The first consideration is the resolution of the rasters used in the analysis. As previously mentioned, most elevation models that are publicly available are created in either 1 arc-second — approximately 30-meter resolution at the latitude of the study area, or based on USGS 7.5’ quadrangle maps — also 30-meter resolution. While this resolution provides incredible surface detail for analysis, it can come at the cost of file size. For example, a 7.5’ quadrangle adapted DEM map ranges from 25–60 megabytes in size depending on where the data was downloaded from. Using 1 arc-second DEMs from the SRTM, my project came out to just under 3 gigabytes (or 1,088,018,470 cells) for 118 stitched together 1 arc-second maps. These high-resolution surfaces did not pose a problem for projects such as Whitley and Hicks in the Northern Arc corridor, which required a mere 16 30-meter DEMs (adapted from 7.5’ quadrangle maps) to model their potential routes (Whitley and Hicks 2003:79). But suppose you are working on a larger scale project, such as interregional trade between the Mediterranean and the Central Anatolia region like Newhard et al. (2008). In that case, the analysis might require a supercomputer to process at such a high resolution. Newhard’s solution was to use coarser raster DEMs from the National Geospatial Intelligence Agency to reduce processing time (Newhard et al. 2008:93). Unfortunately, this relies on gaining access to data from a government source that isn’t readily available to the public, which can be tough to achieve without proper planning and requests. As such, one needs to strike a balance between the demands of data acquisition, the data itself, and the processing time for programs such as ArcGIS Pro.

The second consideration in LCP is that these analyses cannot provide a definitive answer with the information they create. As Caseldine (2021) states:

> An important aspect of individual LCPs is that they suggest paths, but cannot refute or discount proposed routes without further lines of evidence, which may include further LCP generation. Moving the start and end points and changing the calculated costs can and will alter the paths created. [Caseldine 2021:23–24].

Newhard et al. (2008) provide a similar assessment:

> It should be noted that LCPA is a form of computer modelling, and as such is only as effective and accurate as the data it uses. It should also be noted that, as a model, it selects the route of least effort, not necessarily the actual route taken by people (De Silva, Pizziolo 2001: 282). Furthermore, the end result cannot (in most cases) be used to prove or disprove an established position, but rather is best used in concert with other data or at the beginning of the hypothesis-forming stage of research, thus providing the researcher with questions based on basic assumptions of topography. [Newhard et al. 2008:9].

The analysis itself is predictive and variable based on the data used, the method employed, and the particular software used to do the analysis. The better the data used in the analysis, the more precise the possible route generated between two locations. However, the routes LCP provides are not indisputable or evidence that anybody ever used them for travel. Instead, these provide a plausible expectation that can be tested by conducting fieldwork that identifies the archaeological indicators along a route, be it some minor feature or the trail itself imprinted on the land from countless retreading. LCP is a means to an end; it can never be the end result itself. However, this does not mean the analysis is less useful in applying to a particular research question. It merely requires additional supporting evidence to create a comprehensive answer.

Summary

LCP is an excellent tool for exploring potential avenues of archaeological study or proposed hypotheses. The modeling technique gives us insight into the most probable route outcomes based on how much (or little) data we input into the system. These models are then comparable against previously documented and accepted data, such as the case of the Northern Arc corridor (Whitley and Hicks 2003). In many cases, such as Newhard et al. (2008) and Caseldine (2021), the model aligns with the previous studies. In other cases, such as Purtill (2021), the model provides a wholly different path, and archaeologists need to ask further questions to explain the reason or look at new alternatives. The question for this thesis is, where does a model stand for *Haliotis* from Southern California traveling into Northern Arizona?

CHAPTER 6: MODELING PROCESS

This chapter discusses the process involved in applying least cost path analysis (LCP) to *Haliotis* shell exchange from coastal Southern California (centered around the Gabrielino and Chumash groups) to Northern Arizona. First, I detail the modeling process step by step. This progression includes data acquisition, the types of spatial data created to support the modeling process, and the process itself. I finish by providing the results of the LCP in map format, along with a brief description of what they show.

To recapitulate, LCP involves calculating the path of lowest energy across the earth's surface between two locations. This calculation is accomplished by evaluating the true distance and the difficulty of moving across the earth's surface based on rasters containing elevation and slope data, assigning different values of difficulty based on said data to move between the two points, and incorporating functions modifying the challenges in traveling up and down slopes. These factors create a raster showing the cumulative distance and difficulty of traveling to each cell of the study area from the origin location. It also creates a raster showing the directions a person would take from any point in the study area across the earth's surface in order to return to the origin location. Finally, calculations applied to the resulting data determine the least demanding path between the two locations and represent it as a connecting line.

Data Acquisition

Three main elements were identified for use in the modeling process to properly model a potential trade route between coastal Southern California and Northern Arizona. These were 1) an origin point or origin points for the shell in Southern California; 2) destination sites in

Northern Arizona where previous archaeological evidence of *Haliotis* was recorded; and 3) a raster digital elevation model (DEM) of the area encompassing the start and endpoints.

This model's coastal Southern California origin locations were the historic territorial extents of the Chumash and Gabrielino Indigenous groups. While these two groups were not the only ones in coastal Southern California trading shell into Arizona, they were the only two that have been mentioned in the literature to use trails that led to Pueblo areas without passing through the Hohokam region first (Colton 1941; Earle 2005; Farmer 1935; Ford 1983; Vokes and Gregory 2007). Next, a digital map of Indigenous language groups found in Heizer (1978:ix) was georeferenced. Polygons for these two indigenous areas were then digitized from the Heizer map, creating a feature class in the spatial database (Figure 12).

I selected a site from each Indigenous area for use in the model. The Chumash village, *Syuxtun*, was georeferenced from a map of Chumash villages (King 1976:288). Its location is the modern city of Santa Barbara; with an approximate population of 450–800, it is highly likely to have been involved in abalone acquisition. *Syuxtun* excavations revealed extensive evidence of shell bead creation, while other documentation notes the village as a capitol, or at least an important village (Brandhoff and Reeves 2014:48; Gamble 2001:186; Perry 2012:232). The Gabrielino village selected was three sites (CA-LAN-663, CA-LAN-64, CA-LAN-206A) studied collectively as a part of data recovery and analysis undertaken by Statistical Research, Inc. for the West Bluffs Project in Los Angeles, California. The project is close to the Pacific Ocean (located next to the Ballona Wetlands), and abalone shells appear in its features (Douglass et al. 2005). I compared a map of the project location against a topographic map accessible in ArcGIS Pro to create a suitable feature point for the West Bluffs project area (Douglass et al. 2005: Figure 1.1).

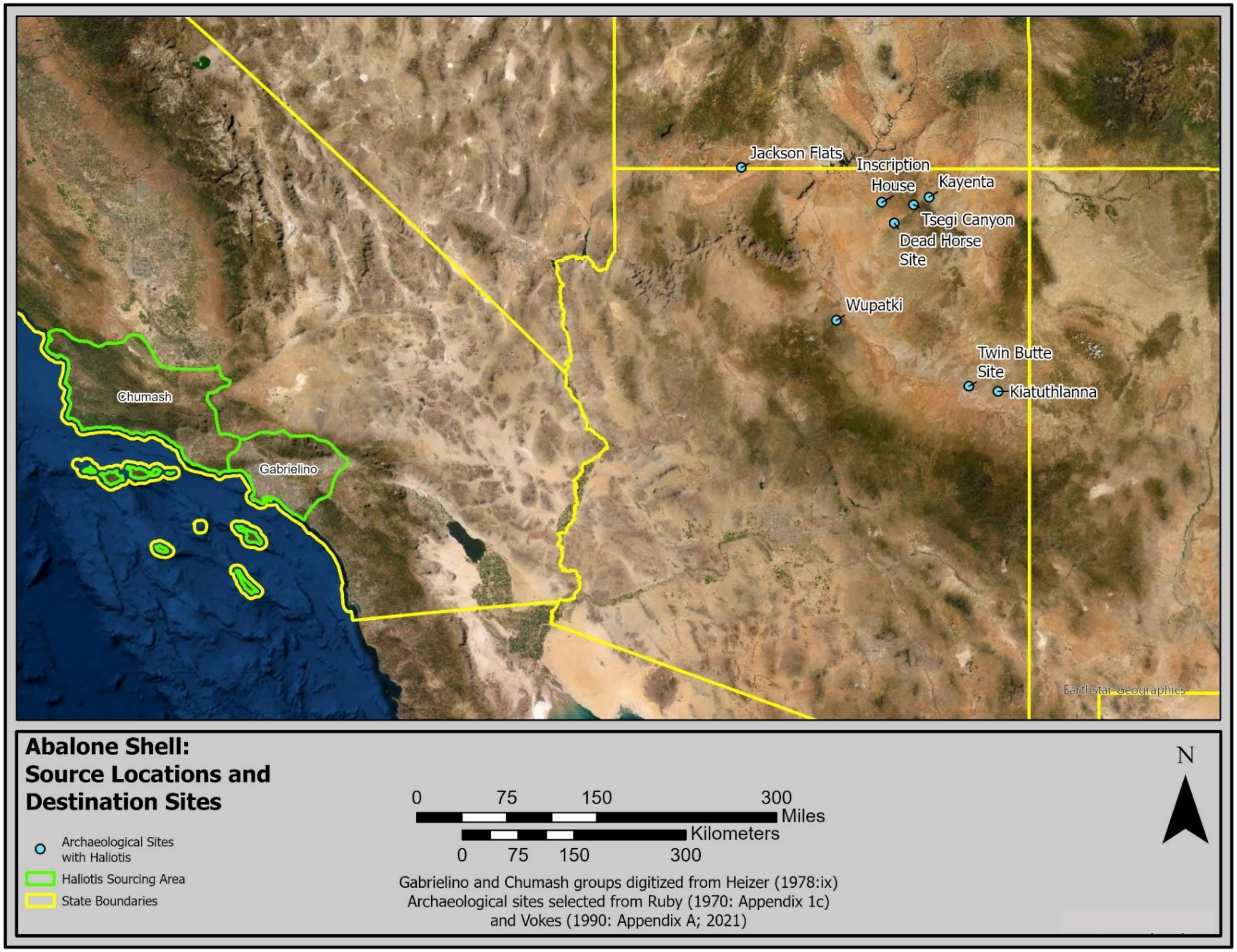

Figure 12. ***A*** **Map of** ***Haliotis*** **Sourcing Areas and Archaeological Sites Where it is Present.**

Destination sites were easier to capture. Eight archaeological sites were selected from Ruby (1970:Appendix 1c) and Vokes (1990:Appendix A; 2021) based on whether they had evidence of *Haliotis* shell or not. These included Tsegi Canyon (referred to in Ruby [1970:Appendix 1c] as Segi Canyon), Kayenta (Ruby 1970:Appendix 1c), Jackson Flats (Vokes 2022), Inscription House (Vokes 1990:Appendix A), Dead Horse Site (Vokes 1990:Appendix A), Twin Butte Site (Vokes 1990:Appendix A), Kiatuthlanna (Vokes 1990:Appendix A), and Wupatki (Vokes 1990:Appendix A). I used cyberSW's exploratory map (https://cybersw.org/) to determine approximate coordinate values for the eight destination sites, then created a feature class in the spatial database containing the corresponding points for the LCP analysis (Figure 12).

The DEM data came from the publicly accessible Shuttle Radar Topography Mission (SRTM). The SRTM DEMs were each at a data resolution of 1 arc-second, or roughly 30 meters, and were downloaded from https://earthexplorer.usgs.gov. The 118 individual DEMs were then stitched together into a GeoTIFF file using ArcGIS Pro's "Mosaic to Raster Dataset" tool (Figure 13). SRTM data was chosen over other sources, such as DEMs created by the USGS from their 7.5' topographic quadrangle sheets, because of a lack of overlap between DEMs. Stitching overlapping DEMs causes errors in the elevation values within the overlap as the program tries to calculate an approximately correct value. Since the SRTM DEMs do not overlap, stitching them together leads to a seamless transition between each map without elevation errors. One concern for the SRTM data is gaps within the DEMs due to cloud cover during the process of gathering elevation values. NASA, however, corrected the voids found in the SRTM data using interpolation algorithms that calculated the correct elevation (Earth Resources Observation And Science [EROS] Center 2017).

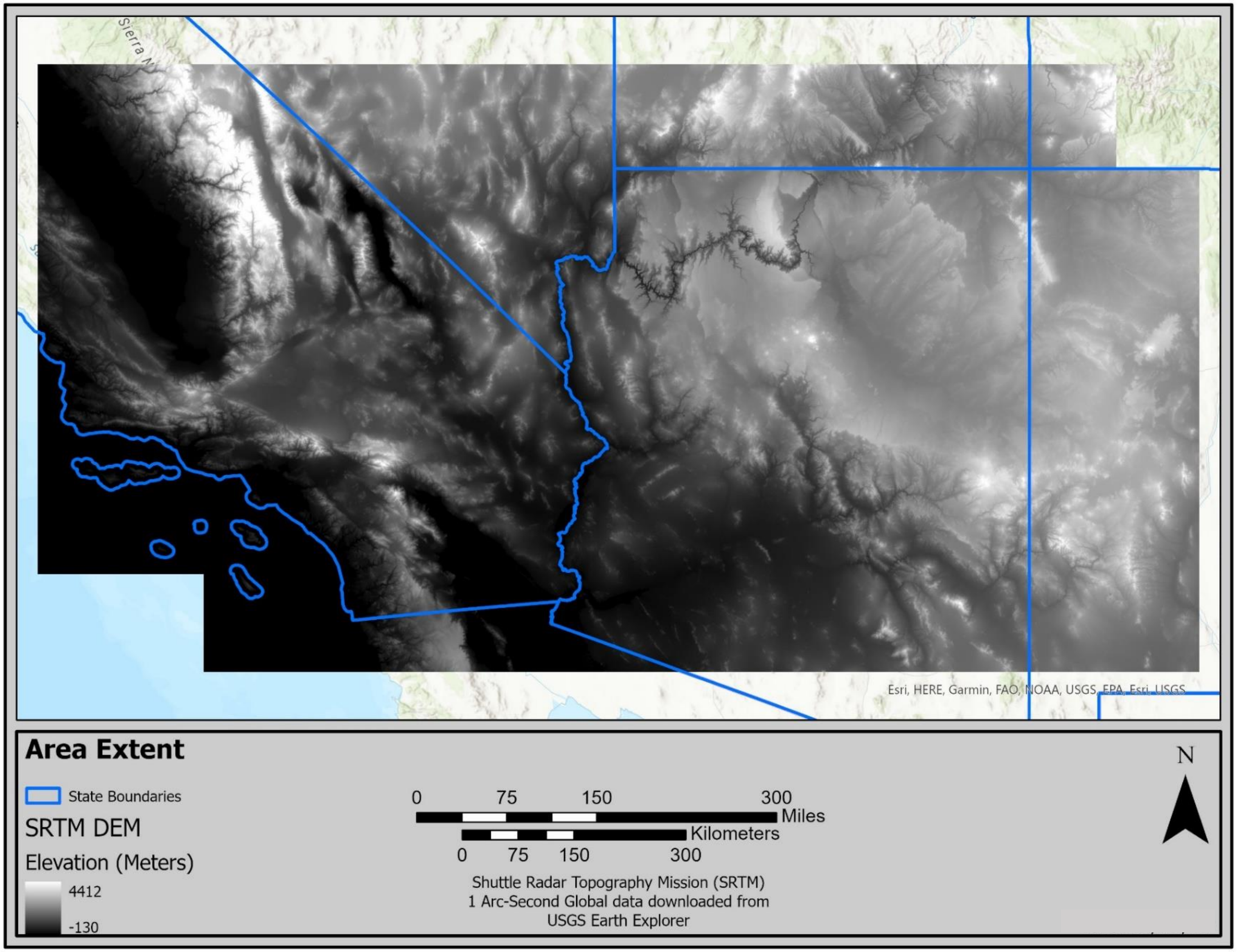

Figure 13. A Digital Elevation Model of the Study Area.

Modeling Process

With the data prepared, the next step was to complete the LCP, starting with a path distance analysis. First, the origin feature points were put into the analysis as starting locations in Southern California for travel to the U.S. Southwest. Next, the stitched-together SRTM DEM was put into the analysis to represent the earth's surface the model traveled across from the origin points. At the same time, surface elevation values from the DEM were also used to calculate a raster of slope values (Figure 14). When put into the analysis, these slope values acted as impedances of varying difficulty to traveling across the earth's surface between Southern California and the U.S. Southwest. The LCP analysis also incorporated a hiking function created by Waldo Tobler (1993) to modify the travel cost of slope degrees (-90 and 90). Modifying the initial slope values makes it more challenging to travel on very steep positive and negative slopes while causing low slope to moderately negative slopes values to be more favorably represented in the analysis.

The path distance analysis creates two raster images with the previously mentioned data. The first raster image is a path distance surface raster. This raster image represents the accumulative cost difficulty, cell by cell, of traveling from the starting locations in Southern California across the earth's surface into the U.S. Southwest (Figure 15 Figure 16). The other raster image is a backlink surface raster. Each cell in the backlink raster displays a unique color associated with a cardinal (north, south, east, west) or intercardinal (northwest, northeast, southeast, southwest) direction. The backlink raster shows the most efficient way back to the origin points in Southern California from anywhere else in the image, simply by traveling in the direction of each passed-through cell on the earth's surface (Figure 17 Figure 18).

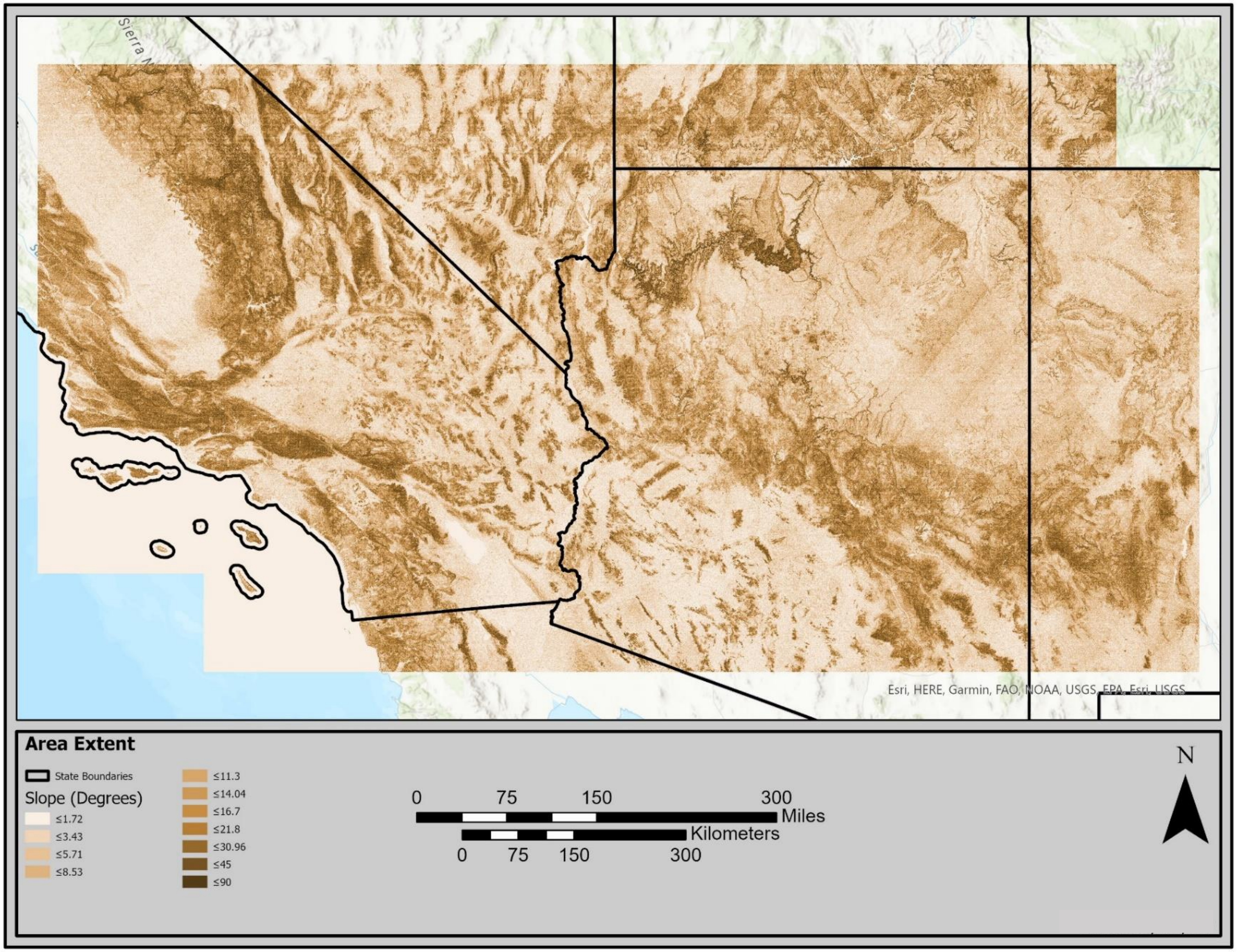

Figure 14. A Slope Map of the Study Area.

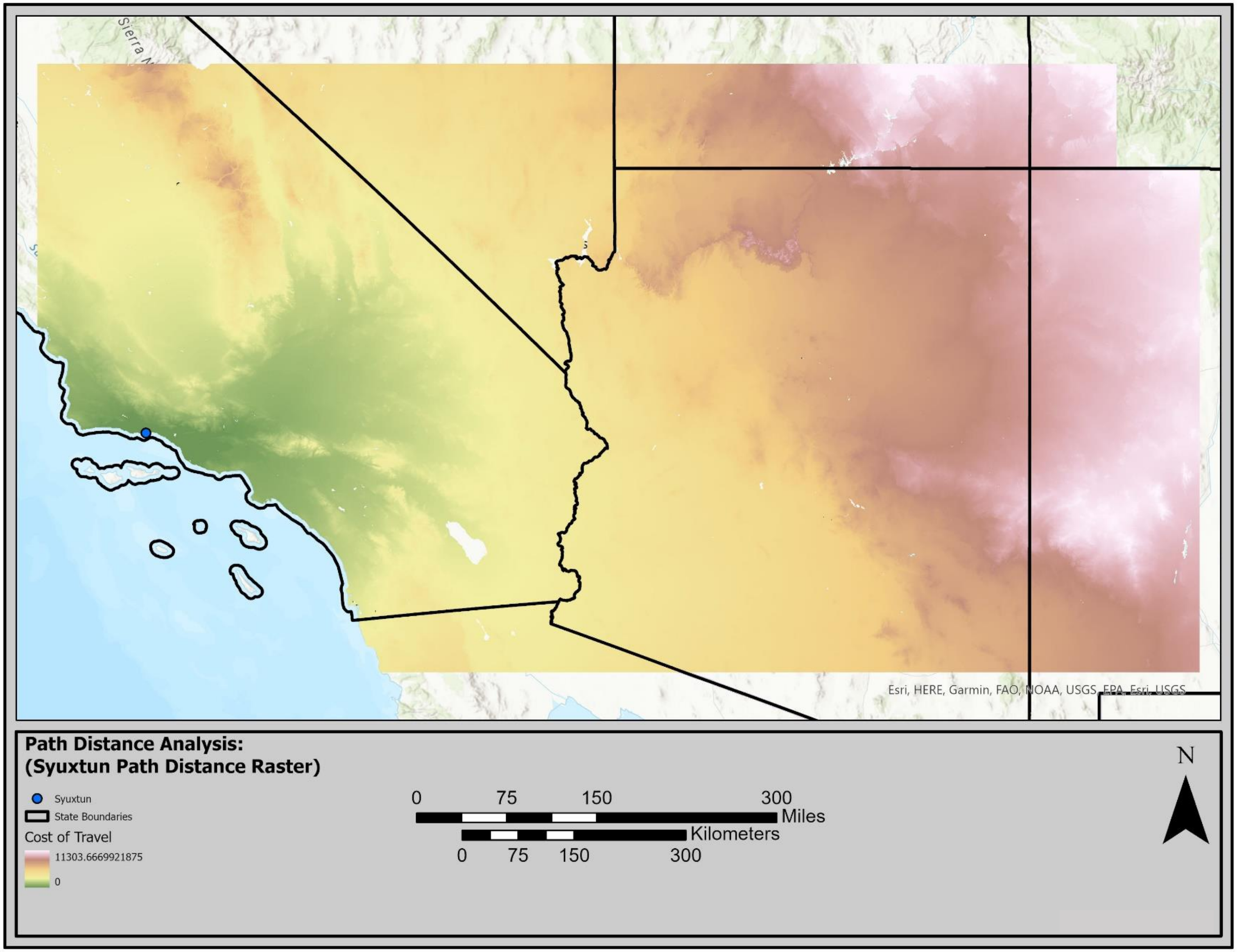

Figure 15. A Path Distance Raster Map for the Chumash Village *Syuxtun*.

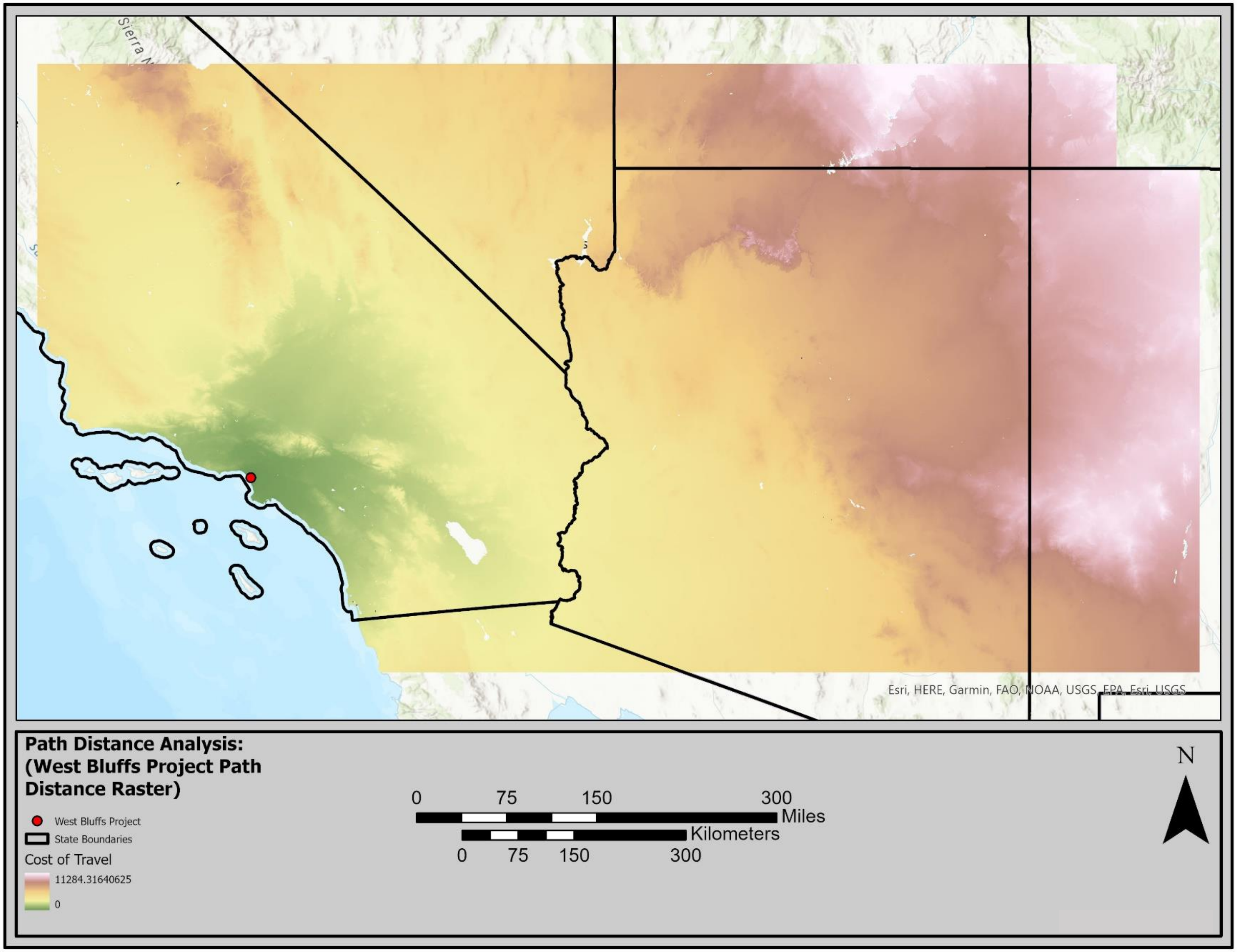

Figure 16. A Path Distance Raster Map for the West Bluffs Project.

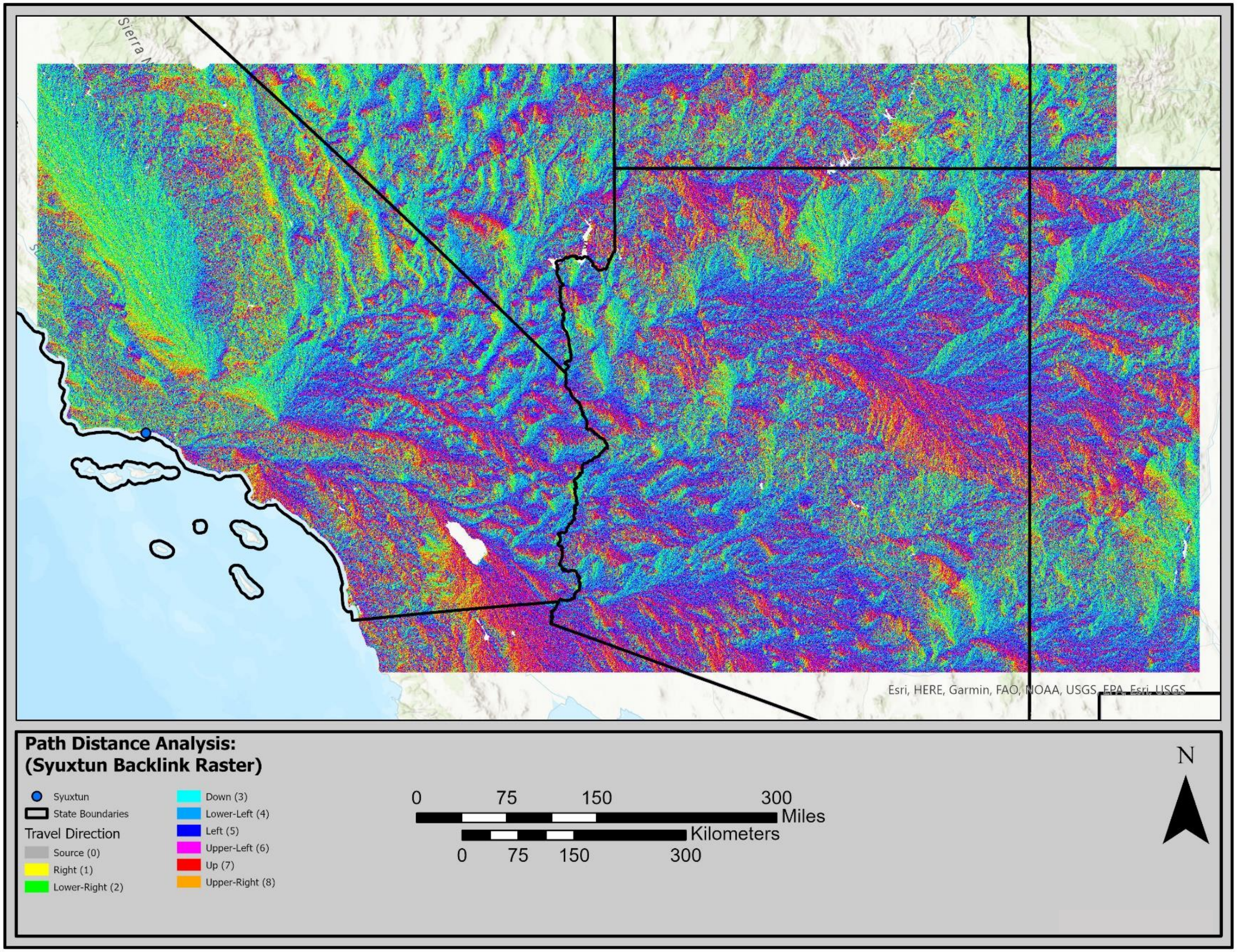

Figure 17. A Backlink Raster Map for the Chumash Village *Syuxtun*.

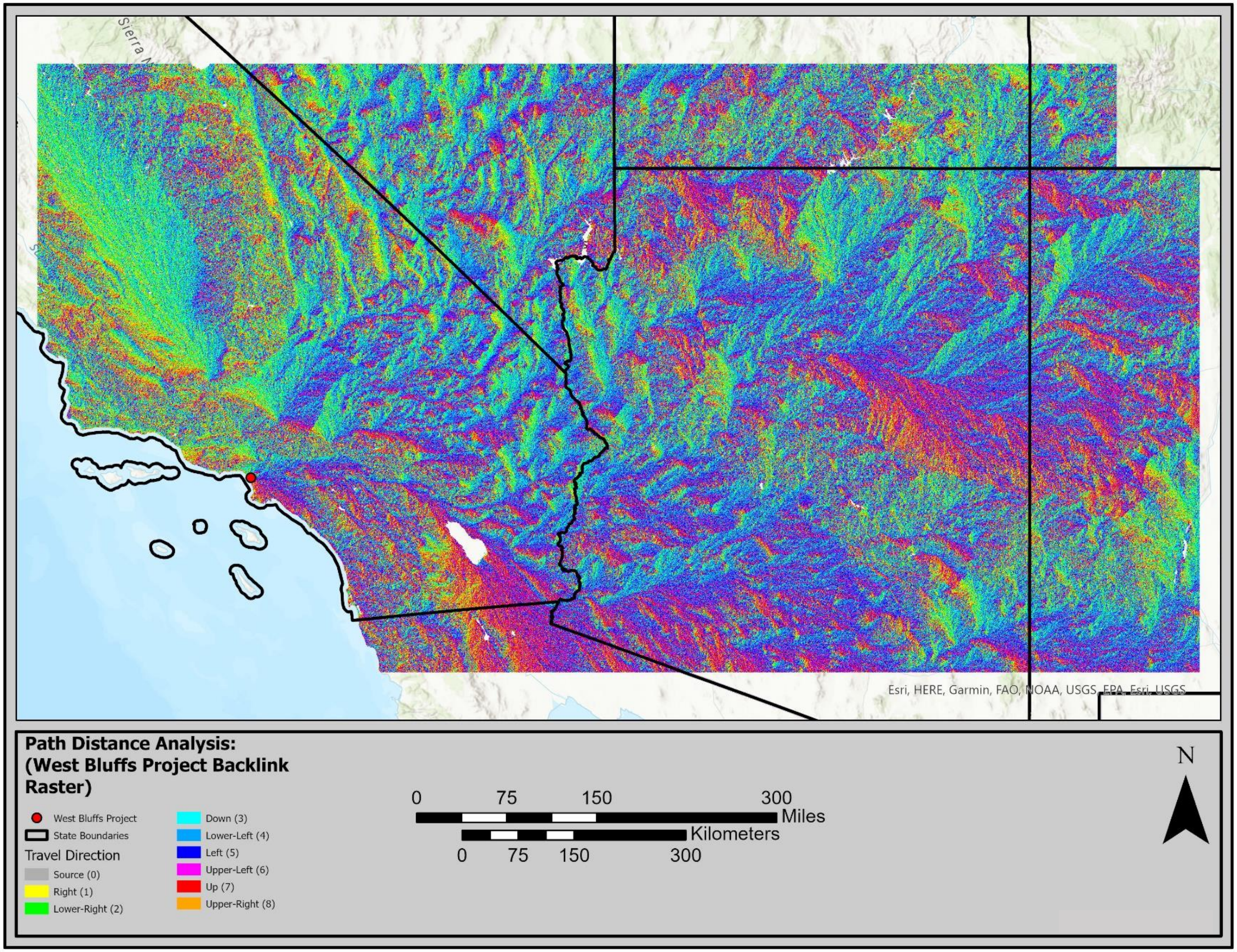

Figure 18. A Backlink Raster Map for the West Bluffs Project.

Imagine standing in a cell in a backlink raster. Looking down, you would see an arrow pointing southwest (the least cost direction from this cell). You would obey the arrow and take a step into the cell to the southwest. Once there, you could look down and see another arrow pointing south. You would then follow this arrow to the cell to the south. Each of those arrows point in the direction of least cost. If you continue doing this, cell by cell, you eventually reach the origin point along a path of least cost.

By combining the true distance and impedance from the path distance raster, the direction of traveling through each cell displayed by the backlink raster, and our feature class containing the destination archaeological sites, I was then able to create line feature classes. These lines visually represent the most cost-effective path (aka LCP) from our *Haliotis* source origin areas in Southern California to our selected archaeological sites in the U.S. Southwest, where *Haliotis* was present (Figure 19 Figure 20). Next, I ran an LCP for each origin point to link them to all the destination sites. Finally, the two LCPs, one from the West Bluffs Project origin point and the other from the *Syuxtun* origin point, were combined on a map to show where the paths merged and diverged (Figure 21).

Results

With the LCPs from each sourcing area to the Arizonan (and Jackson Flats) sites completed, I looked at them against a topographic base map from ArcGIS Online. After leaving the origin point, the West Bluffs Project route splits around San Bernardino, California (Figure 22). The northern path goes to the Jackson Flats site, first traveling through the San Gabriel Mountains towards the Mojave River. It follows the Mojave to its origin, then goes east, following the Kelso Wash to Cima, California, in the Mojave National Preserve. The path then heads

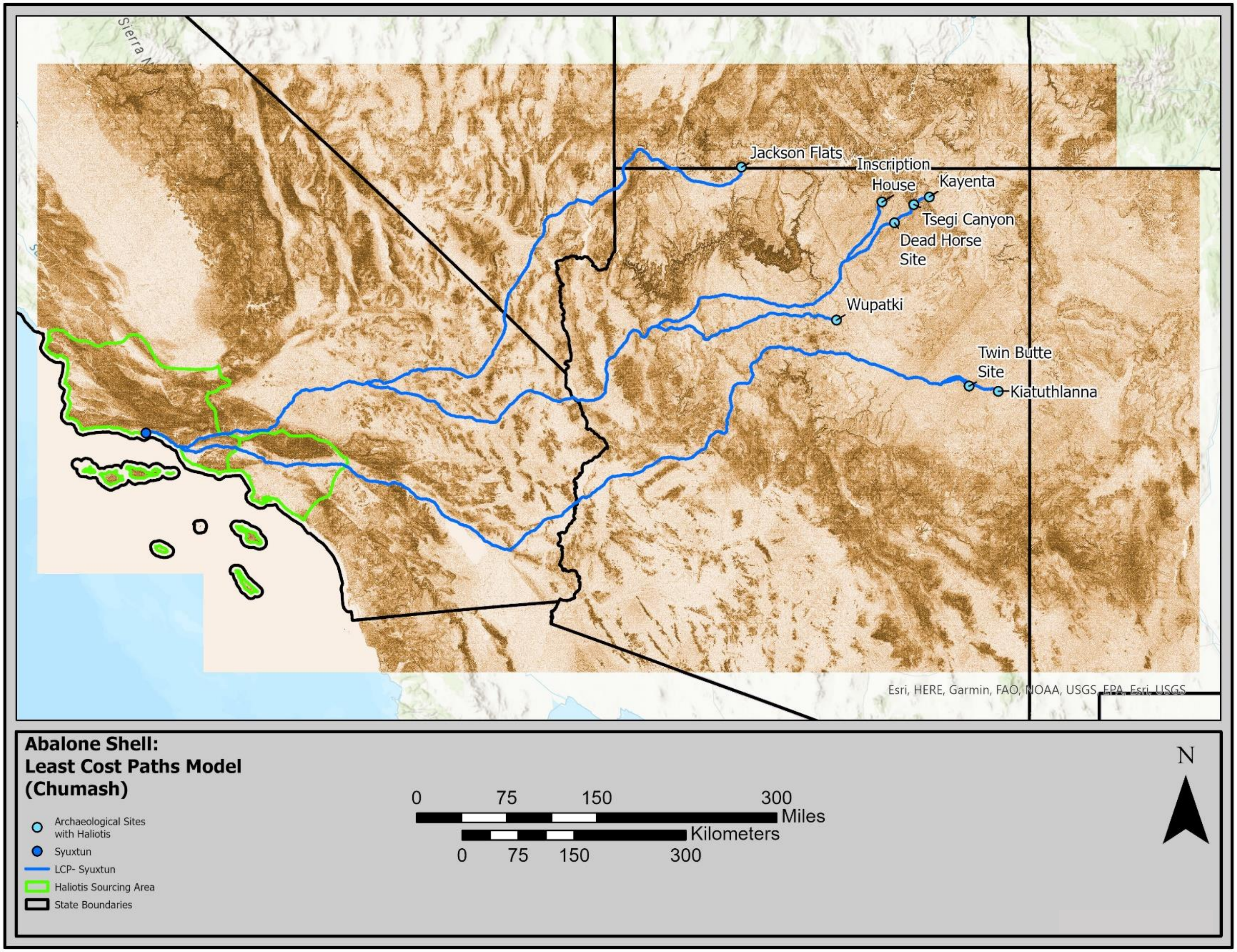

Figure 19. The *Syuxtun* LCP Map, Overlaid on the Slope Raster.

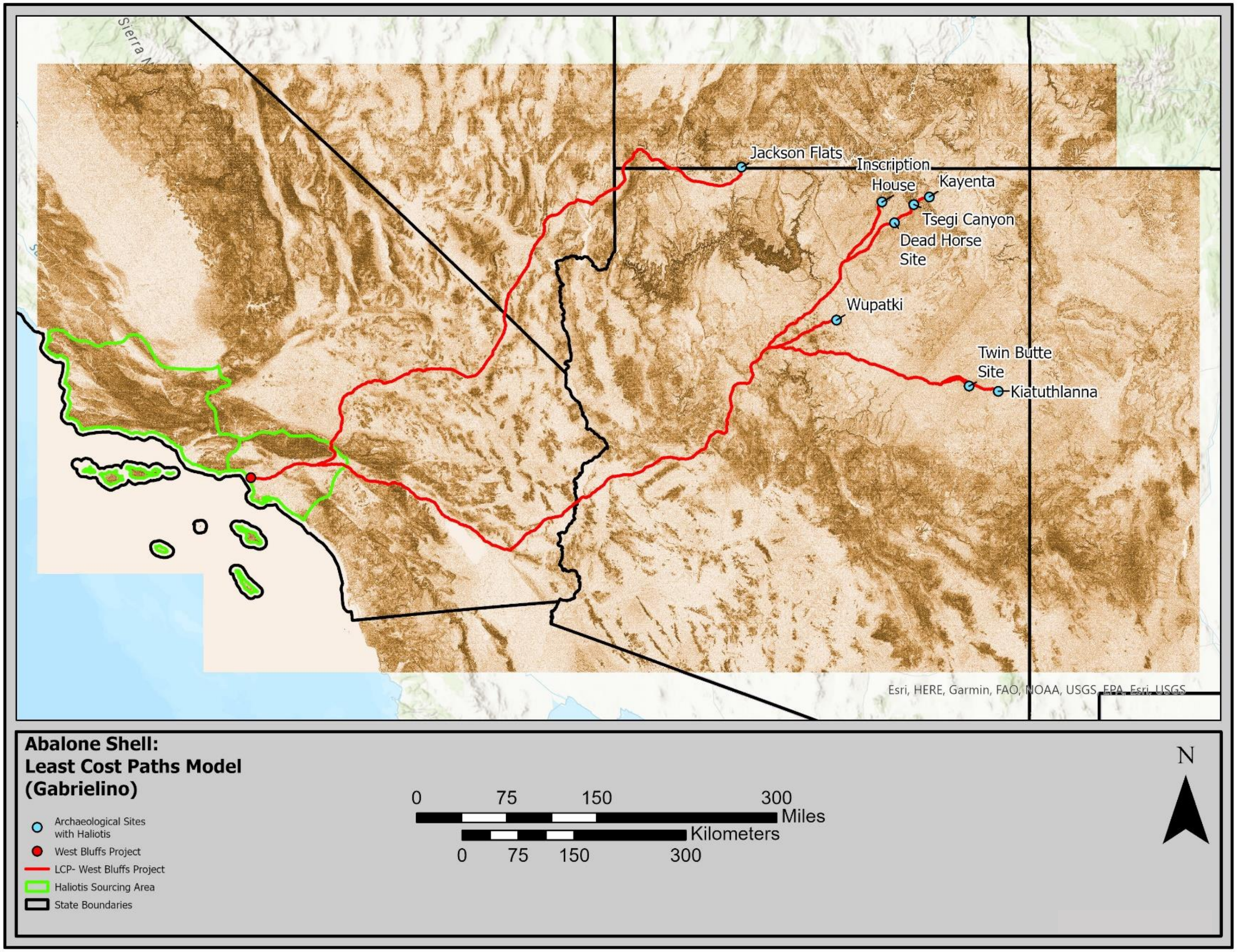

Figure 20. The West Bluffs Project LCP Map, Overlaid on the Slope Raster.

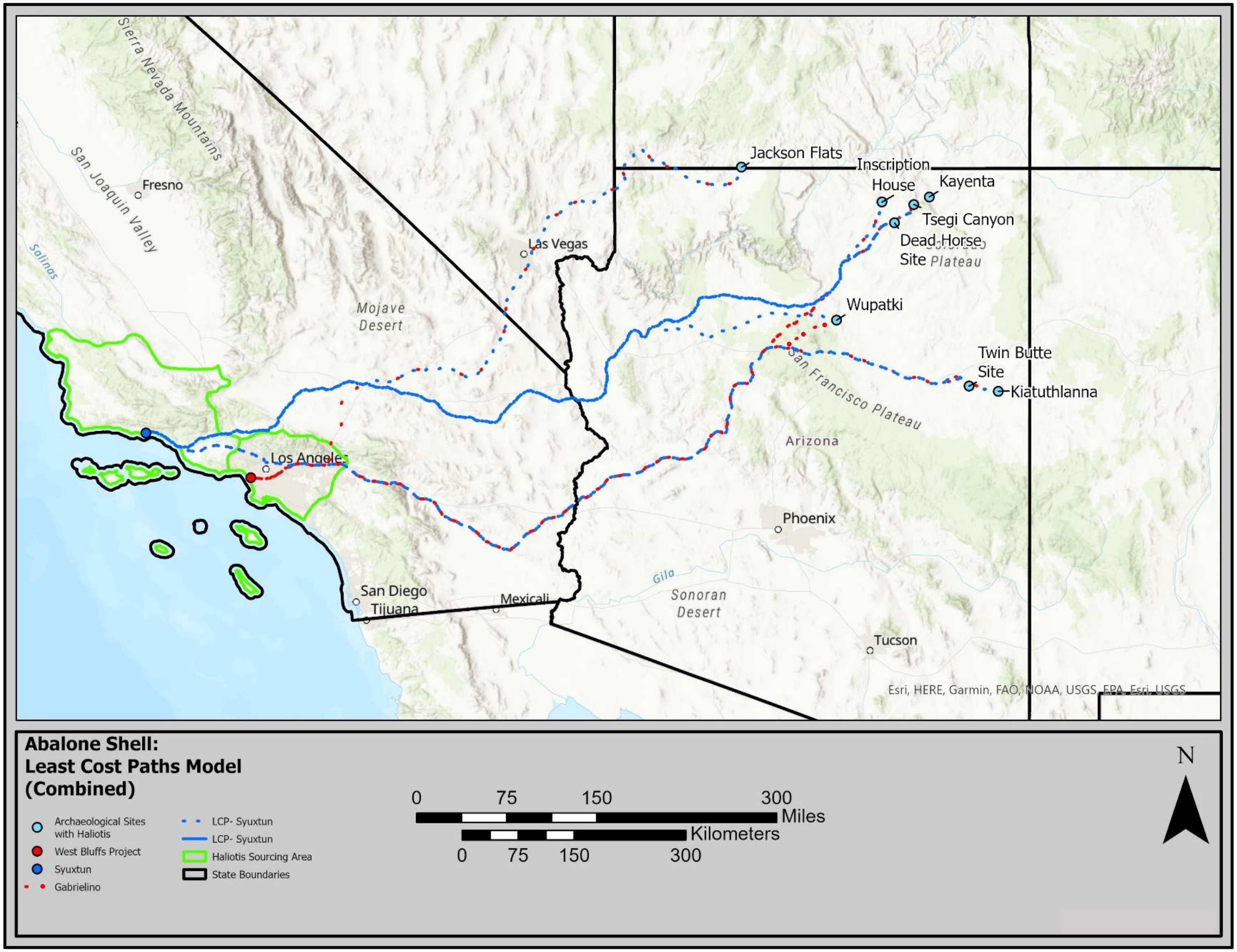

Figure 21. The Combined Results Map.

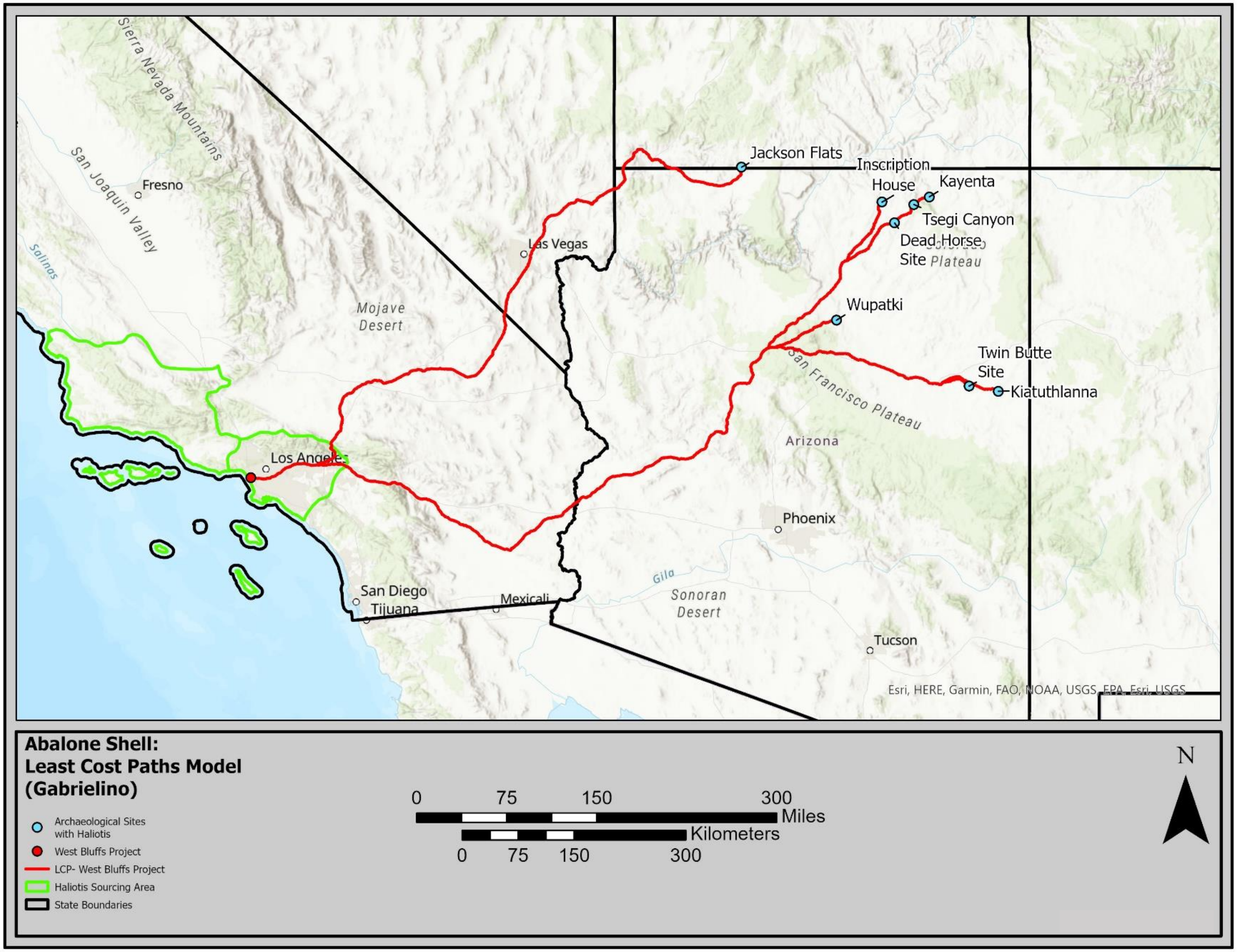

Figure 22. The West Bluffs Project LCP Map.

northward through the Ivanpah Valley and Moapa valleys, following the modern Interstate 15 corridor and Old U.S. Highway 91 through Arizona towards St. George, Utah. From St. George, it follows a series of washes east-southeast to the Jackson Flats site near Kanab, Utah.

The southern portion of the West Bluff Project LCP follows the Interstate 10 corridor into the Coachella Valley to Indio. It then goes southeast along the eastern side of the modern Salton Sea into the Chocolate Mountains, then abruptly heads northeast towards Blythe, California. The path then crosses the Colorado River north of Blythe, just east of where the modern U.S. Route 95 is closest to the Colorado River. After crossing the river, the path continues northeast towards Cunningham Wash, following it to Date Creek. The path then follows Date Creek to Hawkins, Arizona, where it heads north-northeast through Sunflower Flat and across Black Canyon to the Lower Kirkland Valley and Kirkland, Arizona. The next leg of the model path follows the Atchinson Topeka and Santa Fe (ATSF) rail line north through Skull Valley, up Woolsey Wash and Tonto Wash, eastwards along the Williamson Valley Wash towards Hell Canyon (near Paulden, Arizona). Upon reaching Hell Canyon, the model path follows the canyon before diverging to come around the Western side of Bill Williams Mountain to where the modern town of Williams, Arizona, is situated.

The southern path then splits into three branches. The central path heads northeast through the San Francisco Peaks to Wupatki. The southern path parallels the modern Interstate 40 to Holbrook, AZ, splitting and following the Puerco River and a series of washes to the Twin Butte Site and Kiatuthlanna. The northern path also heads northeast through the San Francisco Peaks, albeit on a path slightly north of the central one leading to Wupatki, until it reaches Cedar Wash. It very roughly follows Cedar Wash to Cameron, Arizona, where it then splits away to cross the Little Colorado River and make its way towards Fivemile Wash. Fivemile Wash is the model path's route until reaching Tuba City, Arizona. Finally, the northern branch splits, with one fork heading to the Dead Horse, Tsegi Canyon, and Kayenta Sites along a path roughly paralleling U.S. Route 160, while the other fork runs across the Red Lake Valley and up the Shonto Plateau to the Inscription House site.

The *Syuxtun* LCP is a little more straightforward (Figure 23). From its start point near Santa Barbara, California, it heads along the California coast towards Ventura, California. It then splits into two paths. The southern path travels eastwards through the modern cities of Camarillo, Moorpark, and Simi Valley to the San Fernando Valley. The path goes southeast across the valley to Glendale, California, before heading east towards Pasadena, California. It meets and merges with the West Bluffs Project LCP around West Covina, California, and then follows the southern West Bluffs LCP to Kiatuthlanna and the Twin Butte Site.

The northern path travels along the Santa Clara River towards Acton, California, and into the Antelope Valley around Palmdale, California. The path continues northeast to the southern end of Rogers Dry Lake, then eastward to Barstow, California, and the Mojave River, where it meets the Northern LCP from the Gabrielino mean center and splits in two. The northern split of the *Syuxtun* LCP is straightforward: it merges with the northern Gabrielino LCP path and takes the previously described route to the Jackson Flats site.

From Barstow, the southern *Syuxtun* LCP split follows the modern Interstate 40 corridor to cross the Colorado River at Needles, California, only briefly diverging from I-40 to go through the Fenner Valley. Upon crossing the river, the model continues along I-40 to Kingman, Arizona,

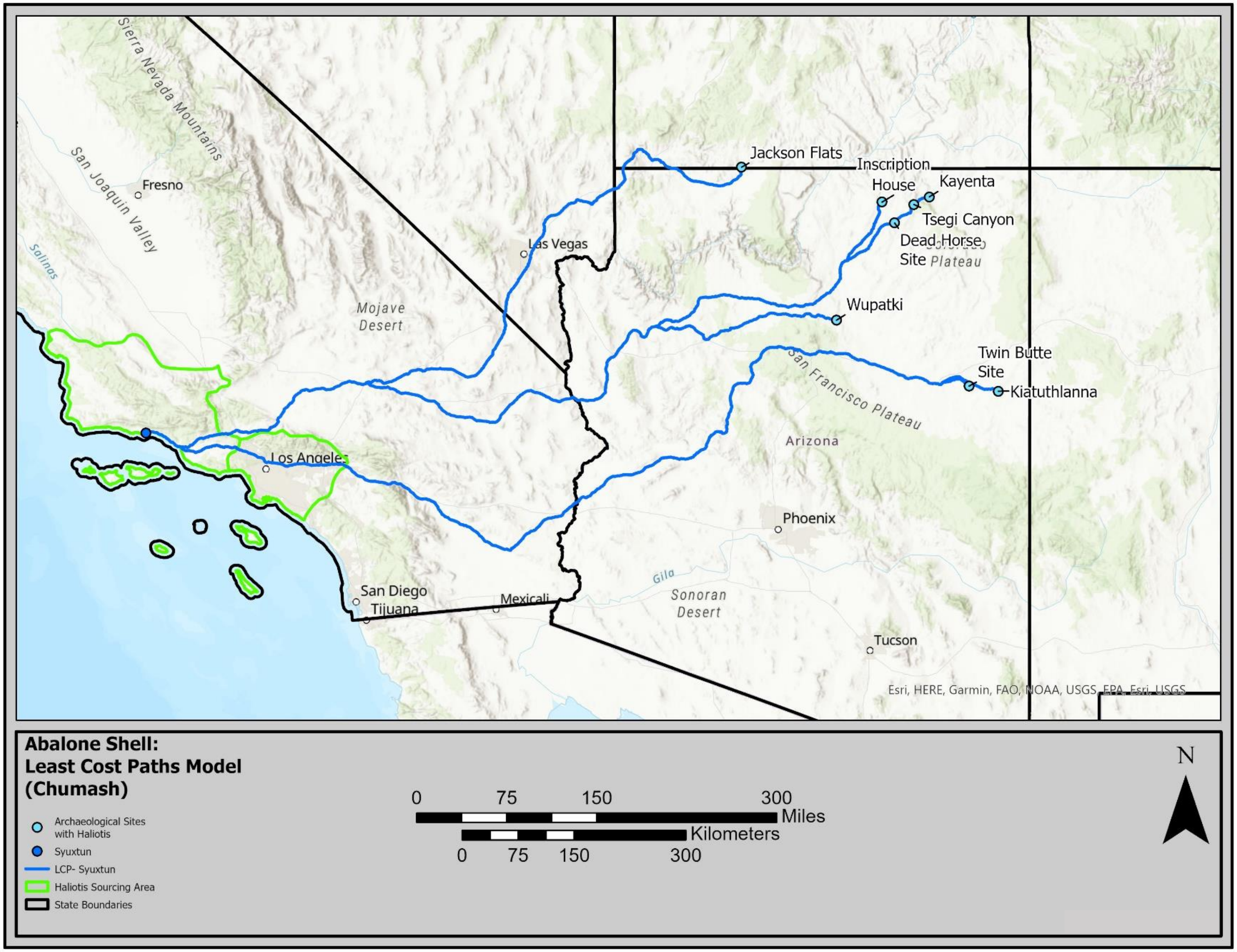

Figure 23. The Syuxtun LCP Map.

and then begins to follow Historic U.S. Route 66, diverging to follow the Burlington Northern Santa Fe rail line near Crozier, Arizona. The southern LCP split continues until a point just south of Truxton, Arizona, where it splits again. The northern branch of this split continues to follow the Burlington Northern Santa Fe rail line to the eastern side of Yampai Canyon, where it diverges to head through the Aubrey Valley and east along the Coconino Plateau. This northern branch of the southern *Syuxtun* LCP split eventually meets with the northern branch of the southern West Bluffs Project LCP path and mirrors its routes to the Inscription House, Kayenta, Tsegi Canyon, and Dead Horse sites.

The southern branch of the southern *Syuxtun* LCP path, following the split, then heads along a wash and through Rock Canyon east back towards the Burlington Northern Santa Fe rail line and historic U.S. Route 66 near Pica, Arizona. The branch follows these two features towards Seligman, Arizona. It then heads east-northeast across Partridge Creek and Monument Wash to where Red Lake Wash and Cataract Creek meet in Cataract Canyon. From this junction, the model path travels eastward across Spring Valley Wash and Miller Wash towards a point just west of Cedar Wash. Finally, the branch goes eastwards to Wupatki.

Summary

The GIS modeling process for abalone shell exchange from the Chumash and Gabrielino areas to the eight sites where it appears required the use of a Digital Elevation Model and custom feature classes created through a combination of georeferencing and geoprocessing operations. The Indigenous area centroids were run twice through the LCP process to determine the most efficient paths between origins and the destination points. The West Bluff Project paths either went north through the Mojave Desert and Southern Nevada before turning east to the Arizona–

Utah border or east along the modern Interstate 10 before heading northeast towards Flagstaff and the sites located in northeastern Arizona. The *Syuxtun* paths went along the California coast to Ventura, then split east to the Antelope Valley along the Santa Clara River or south-southeast to meet the West Bluffs path. The northern *Syuxtun* path mirrored the northern West Bluffs Project path, while the central *Syutxun* path continued eastwards along the modern Interstate 40 to access destination sites in northeastern Arizona. The southern *Syuxtun* path merges with the southern West Bluffs Project path to reach northeastern Arizona's two southernmost destination sites.

Interestingly, the LCP modeled paths intentionally avoid passing through destination sites on the way to ones farther away. For example, the model traveling to the Twin Buttes Site and Kiatuthlanna pass has a fork that diverges and heads to Wupatki. Suppose Wupatki is potentially a waypoint of trade before heading to Kiatuthlanna or the Twin Buttes Site. In that case, it is unlikely that Indigenous peoples would double back along the fork to return to the main modeling path. Similar comments can be made for going from Wupatki to the four sites in northeast Arizona or from the Inscription House to its three closest neighbors. This is a flaw in using the LCP process: It only considers a single origin and destination point at a time, independent of all destination sites within proximity. This is potentially resolvable by running the LCP model between destination points to create a comprehensive web of paths.

As mentioned in Chapter 4, these models do not tell the whole story. They only show us what is theoretically most effective and efficient for people traversing the landscape with *Haliotis* shell. It is up to archaeologists to determine their merit by either surveying along the proposed route or comparing it against literature documenting previous paths. This latter option is utilized for the results detailed in the next chapter.

CHAPTER 7: COMPARISON OF THE LCPA AND HISTORIC TRAIL INFORMATION

This chapter discusses the similarities and differences between the paths modeled through least cost paths (LCP) analysis from Chapter 5 and the historically documented trails discussed in Chapter 4. I start by briefly recapping what Chapter 4 suggests about trails which abalone shell traveled along. Next, I present copies of the historical trail maps with overlaid GIS results. I then discuss how they do or do not match each other. It should be noted that the historic maps likely contain a significant error comparison given the scale of the map, the way the trail lines were created (often hand drawn) and the nature of the georeferencing process.

Recap: Historic Trail Documentation

Historical documentation of trails discussed in Chapter 4 is broken down into two main areas: California and Arizona. Farmer (1935), Davis (1961), and Earle (2005) form a consensus on the California portion of the transregional exchange. The consensus is that the Mojave Trail, running from the Cajon Pass through the Mojave Desert to the California-Arizona border roughly around Needles, California, was the main link for Northern Arizona to coastal Southern California. This trail corresponds to Farmer's map (1935:154) and Trails 83 and 80 (via a connector route around San Bernardino) on Davis's map (1961:Map 1). For the United States Southwest, Colton's map (1941:4), Ford's map (1983:Figure 8), and Vokes and Gregory's map (2007:Figure 17.1) point to a trail heading through Nevada and into Utah and a trail cutting eastward along the southern extents of Havasupai and Hualapai territory towards Ancestral Puebloan lands in northeastern Arizona. The question is, how do the LCP models compare to the maps discussed in Chapter 4?

Comparison: LCP Model and California Trails

Davis Map

Given how complete the trails are for California on the Davis (1961) map, I started my comparison with it (Figure 24). The *Syuxtun* model route starts by following a documented trail along the coast to Ventura, California, where it splits. The southern split eschews trails documented by Davis and cuts across the San Fernando Valley to meet with other trails towards the Coachella Valley and the Salton Sea before shifting northeast towards Blythe, California. The northern split follows another trail to the Antelope Valley and Western Mojave desert. After reaching this point, it heads directly through the Mojave desert rather than heading southeast along the northern part of the San Gabriel Mountains towards the Cajon Pass. The route meets back with the Mojave Trail around Barstow, California. However, only the northern path roughly follows the Mojave Trail. The southern path splits away from the Mojave Trail as it makes its way towards the California-Arizona border, meeting up just a bit south of the Mojave Trail's terminus around Needles, California.

The West Bluffs Project model route is far more interesting. While its northern path mirrors the Mojave Trail almost perfectly until heading north towards Nevada, the southern path takes a radically different approach. First, it travels through the gap in the San Bernardino and the San Jacinto Mountains, roughly along Trail 86, then diverting southeast along Trail 91 (which goes along the Salton Sea). Then, after taking Trail 91 to Trail 93, it cuts across multiple trails to cross the California-Arizona border roughly where the eastern terminus of Trail 86 lies.

The model fits the Davis map for California relatively well. Spanish missionaries did note Indigenous groups traveling through the mountains to arrive at the Chumash, which a portion of

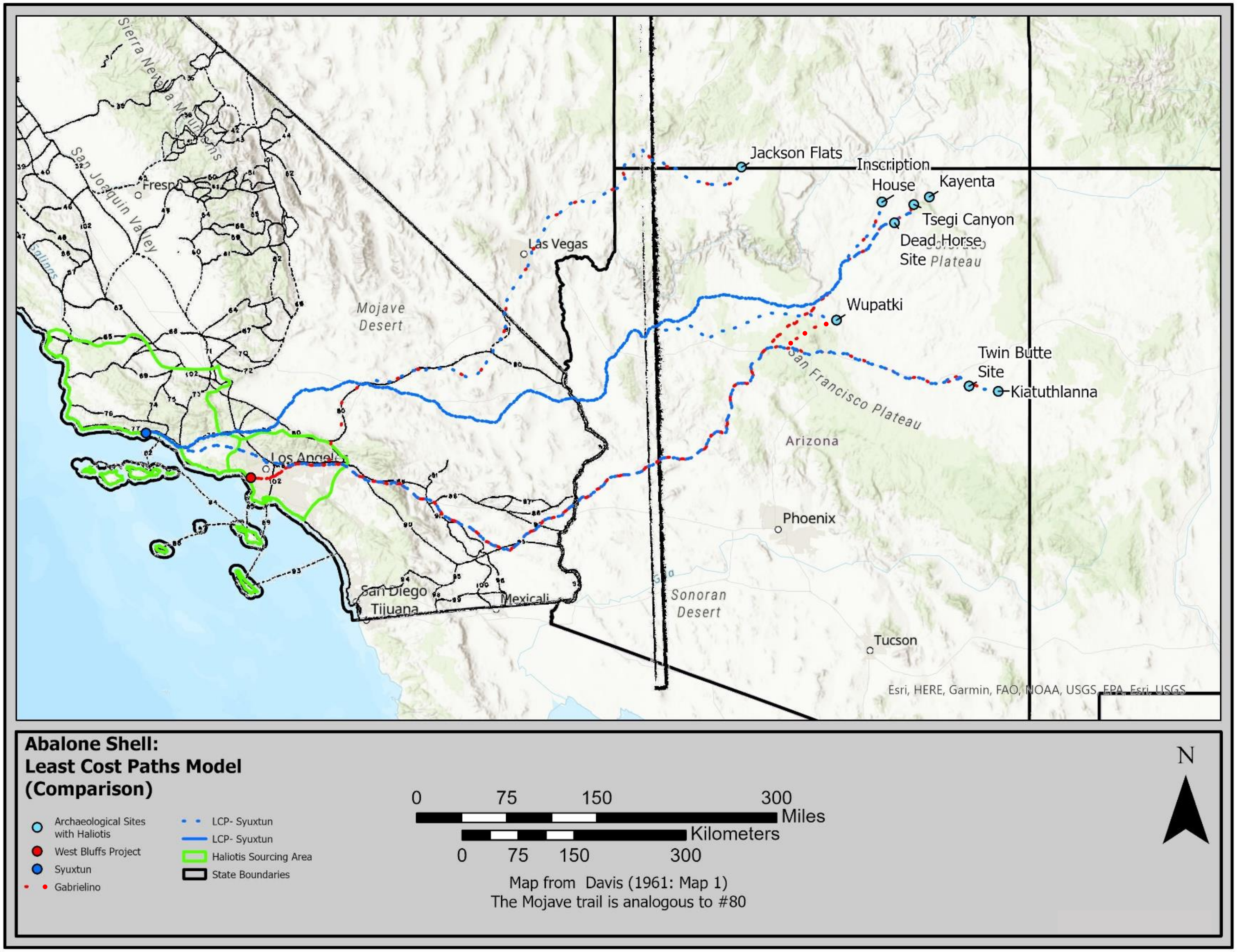

Figure 24. A Model Comparison against the Davis Map.

the model does (Earle 2005:12). There are some exceptions. One is the *Syuxtun* LCP taking the most direct route across the Antelope Valley to arrive at the Mojave Trail around Barstow, California, rather than following a documented trail along the San Gabriel Mountains to the Mojave Trail's start point before heading into the desert. The model is plausible, though it does not entirely fit with depictions of trails coming through the Antelope Valley to meet the Mojave Trail.

The other reason, which involves the southern West Bluffs Project and the southern *Syuxtun* LCP paths, is solely an attempt to follow the path of least resistance. It isn't that the model doesn't follow any documented path; the Davis map shows that it does travel close to or directly along a few. However, the model is heading towards trails more indicative of trading with the Hohokam region. Smith (2002), Merrill (2014), and Smith and Fauvelle (2015) all note an exchange between the Hohokam and Indigenous Groups with presence in San Diego and Imperial Counties revolving around Lake Cahuilla, which encompassed the Salton Sea that the model path skirts along. The route doesn't match the historical sources revolving around the Mojave Trail referenced in previous chapters.

Farmer Map

The *Syuxtun* and West Bluffs Project models do not differ from the Farmer map (1935:154) (Figure 25). Unlike the Davis map (1961:Map 1), the Farmer map shows the location of potential springs and other water sources that make travel through the Mojave Desert possible. It is this information that is worth discussing. While not following trails along the southern Antelope Valley, the *Syuxtun* route heads towards a lake bed before turning east. The modern-day name of the dry lake on the map is Roger's Dry lake, located within the confines of

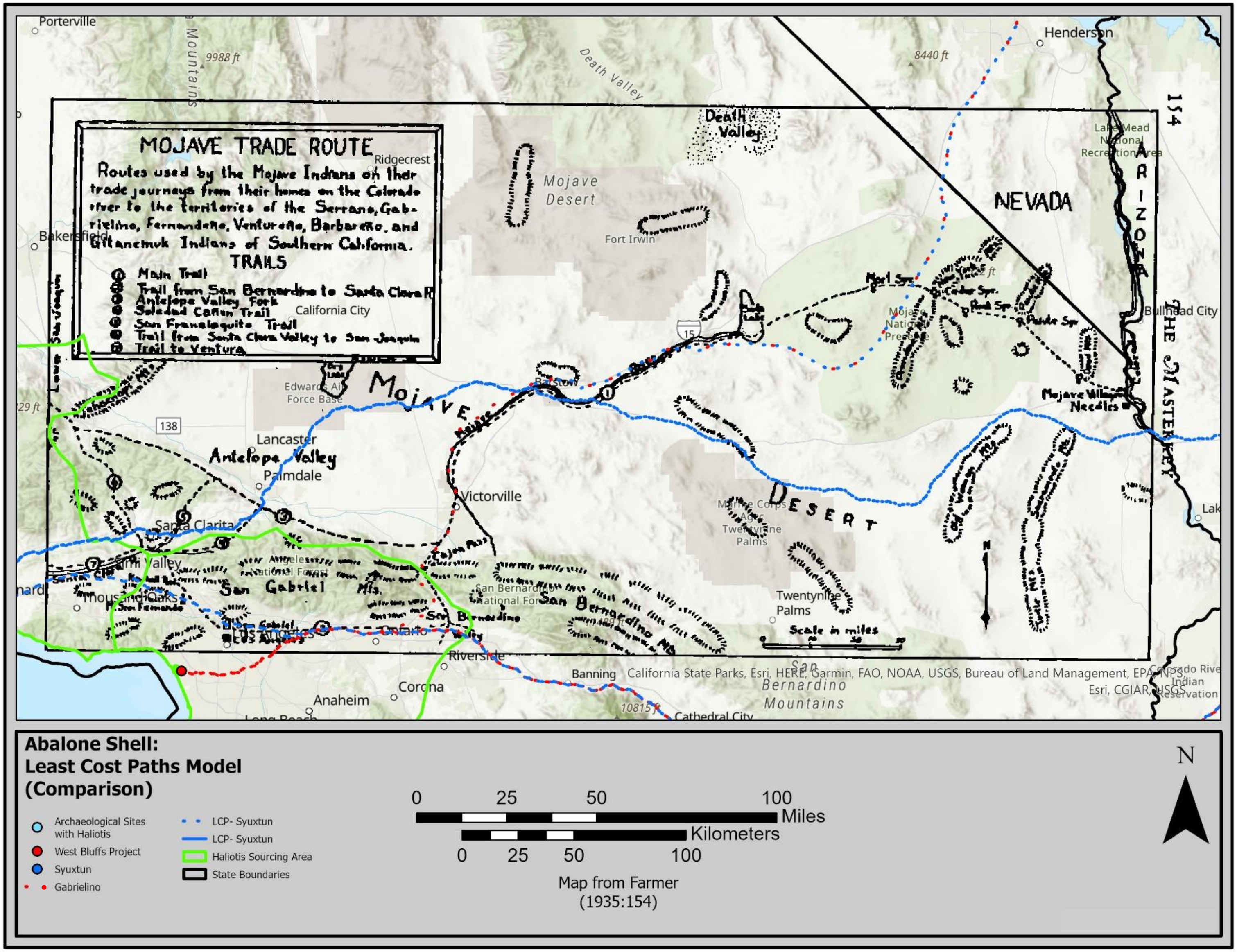

Figure 25. A Model Comparison against the Farmer Map.

Edwards Air Force Base.

Interestingly, this lake has archaeological sites that date to roughly AD 996–1492, some of which have been excavated (Sutton 1996:237, 239). According to the USGS National Map of the area, these sites are not a clear indicator of an unrealized water source; this lake is wholly dependent on rainfall rather than any regularly flowing water sources (United States Geological Survey:N.D.). If it did hold water of some amount, an unmentioned path could run through the area to connect to the Mojave Trail rather than taking the indirect route towards the Cajon Pass. As soon as the *Syuxtun* route meets the Mojave Trail, it just as quickly splits away. The *Syuxtun* path leaves the Mojave Trail and instead follows rail lines towards the Mojave's eastern terminus. It begs whether any springs or perennial water sources exist within proximity to the route that a portion of the northern path takes.

However, the northern *Syuxtun* and West Bluffs Project paths (both of which eventually lead to the Jackson Flats site by way of Nevada) are strongly supported by historical documentation, with one slight exception. After following the Mojave Trail to Soda Lake, they divert southwards and come back to the trail roughly halfway between Marl and Cedar Springs. It is unclear whether Farmer's map (1935:154) is wholly accurate of the exact path traveled, given that it is a hand-drawn map, so it may be that the model paths are correct. However, it may be that Farmer's map is accurate but imprecise, while the LCP is precise but potentially inaccurate. However, as mentioned in Chapter 4, they are following Kelso Wash and a modern rail line during this (so-called) diversion. The rail line was likely laid along similar criteria that Indigenous groups might have wanted to traverse the landscape: through a route with ease of travel, which Colton (1941:308) noted in his work. However, rail lines cannot travel up slopes as steep as those humans can on foot. This discrepancy might be a potential flaw for the LCP model if people traveling across the land decided not to prioritize the gentlest elevations.

Conclusion-California

The model is moderately reliable at accurately predicting the use of the Mojave Trail to source shell from coastal Southern California. Some of the model paths leading into northeastern Arizona wholly and completely ignore the Mojave Trail, which multiple sources identified as the path leading to most of the shell moving into the Ancestral Puebloan areas. On the other hand, the two paths heading towards the Jackson Flats site and the central *Syuxtun* path somewhat follow the Mojave Trail. Unfortunately, only the Gabrielino path replicates most of it. The suspected reason for this lack of adherence to the expected route for the southern paths is the elevation profile of the Mojave Trail being rougher than areas further south. However, it is unclear from the literature examined in previous chapters whether there are suitable resources (notably reliable water) to enable travel through the deserts compared to the documented springs along the Mojave Trail. There is also the question of whether the southern West Bluffs Project and southern *Syuxtun* paths are feasible. As Merrill (2014) discussed, Lake Cahuilla was a lake centered on the Salton Sea but far larger at periods before Spanish contact. The two paths may run through an area that would have been submerged, therefore inaccessible and unpredictable by the LCPs.

Comparison: LCP Model and the U.S. Southwest Trails

Colton Map

Compared to the Colton (1941) map of the U.S. Southwest, the models show a high degree of similarity, unlike California (Figure 26). This similarity is partly due to the Colton map

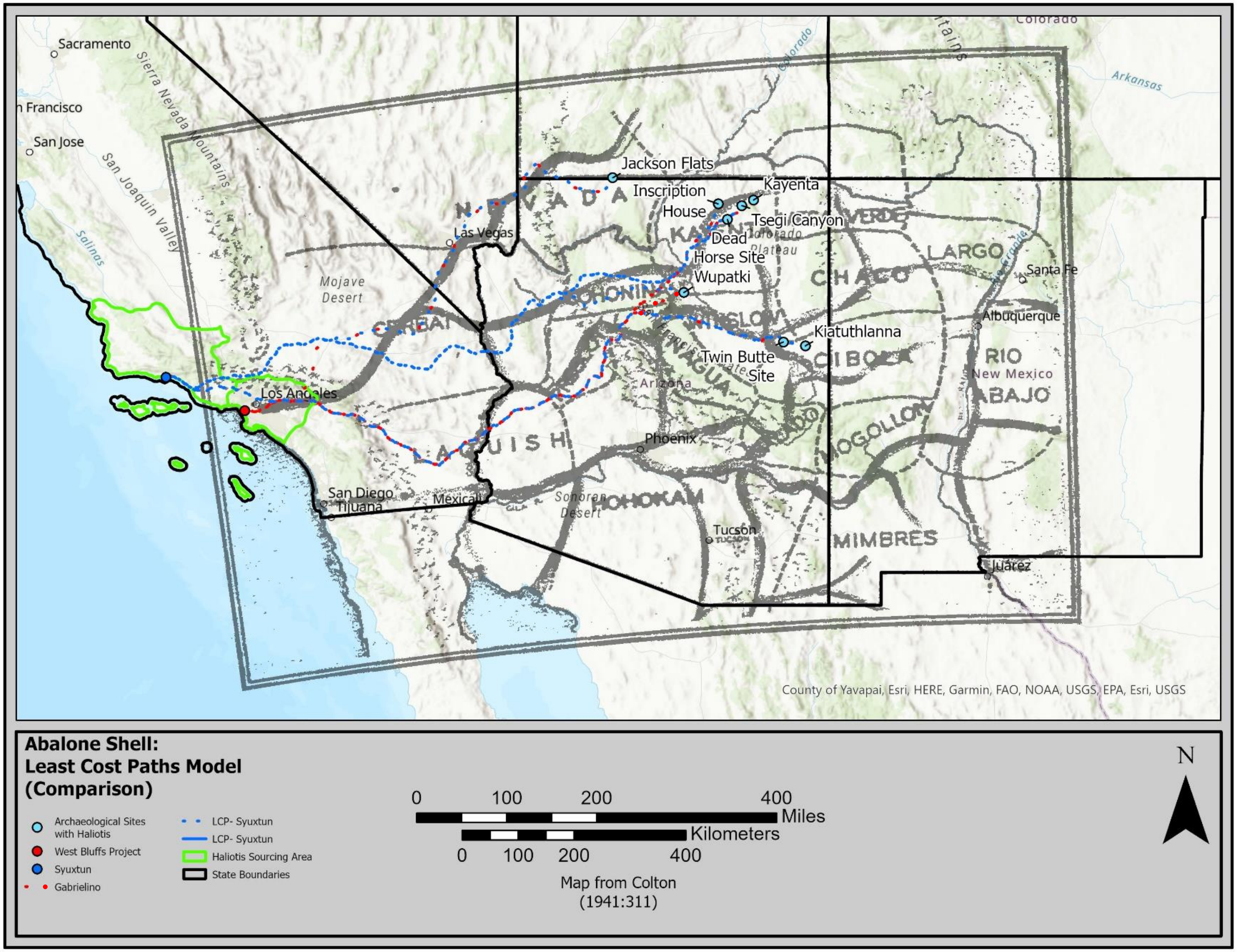

Figure 26. A Model Comparison against the Colton Map.

being hand drawn as broad strokes rather than being associated with specific features. However, we see the northern *Syuxtun* and northern West Bluffs Project LCP paths heading towards the Jackson Flats site mirror a route Colton described passing "North of Boulder Dam to the Virgin Valley sites and other Utah points" of the Great Basin (Colton 1941:318). Meanwhile, the central *Syuxtun* path relatively closely aligns with a path coming from Needles "onto the plateau following the Little Colorado tributaries" on its way towards the San Juan River (Colton 1941:318). The plateau Colton refers to isn't explicitly identified. However, based on the path description, he likely refers to the Colorado Plateau, less likely the Coconino Plateau (though the model goes across both).

The southern West Bluffs Project and southern *Syuxtun* paths, on the other hand, are a bit less clear. They are roughly analogous to a path on Colton's map crossing south of Needles, then slowly working northeast towards the San Francisco Plateau and later the Colorado Plateau. There is no mention of this path among the other ones Colton identifies coming out of the Pacific Coast region beyond this map; however, the rough parity between the map and the LCPs indicates that the area should receive consideration in further studies.

Ford Map

The Ford (1983) map helps clear up some of the confusion encountered in the Colton Map, at least in the case of the central *Syuxtun* LCP path (Figure 27). The undescribed path from Colton (1941) appears to be a path that starts following the Bill Williams River before traveling up towards Flagstaff before splitting into various routes to the destination sites used in this model. According to the Ford map, the southern West Bluffs Project and Syuxtun paths cross into Arizona around Ehrenberg (where the modern Interstate 10 does as well). There they make their

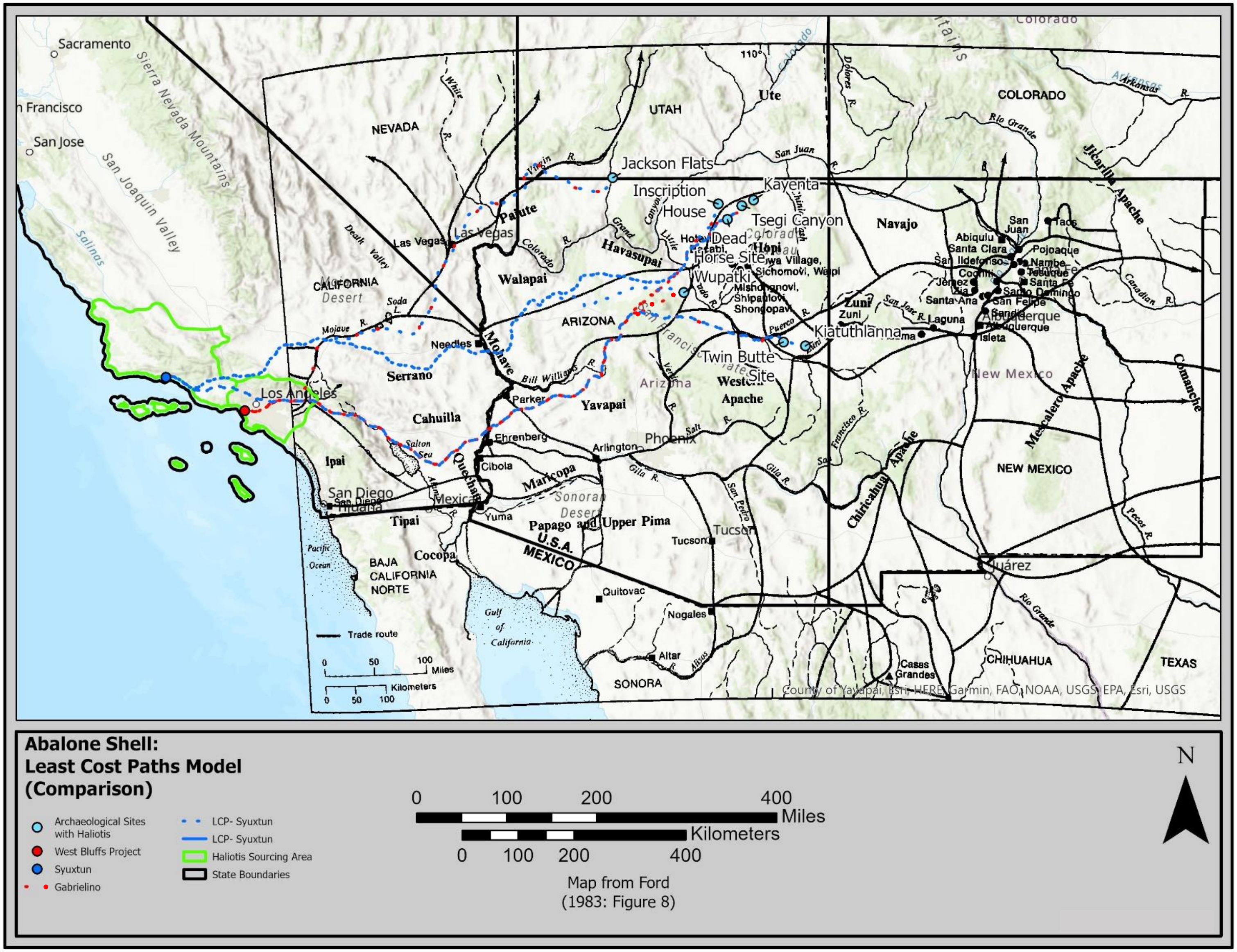

Figure 27. A Model Comparison against the Ford Map.

way towards the trail running along the Bill Williams River, though staying south of it until crossing it and staying north of the drawn route. The central *Syuxtun*, northern West Bluffs Project, and northern *Syuxtun* LCP paths are all relatively close matches to the routes shown by Ford (which are likely hand drawn rather than cartographic representations), with minor variations based on the most accessible paths of travel identified by the model.

Vokes and Gregory Map

Unlike the previous two maps, the Vokes and Gregory (2007) map (Figure 28) does not indicate a trail running along the Bill Williams River (though it does show the river in its layout), which makes comparing the southern West Bluffs Project and southern *Syuxtun* models to this map difficult. On the other hand, it does line up very well with the northern LCPs. The PC 1 route, which Vokes and Gregory identify as the Old Spanish Trail, heads into Utah along roughly the same path as the model (Vokes and Gregory 2007:Figure 17.1, Table 17.1). Aside from the model leaving it to dip back into Arizona before arriving at the Jackson Flats site, PC 1 comes very close to Jackson Flats on its own, lending some credence to the overall strength of the northern model paths.

The central *Syuxtun* path does not fit well into the PC 2 route displayed in Vokes and Gregory's map, which they identify as the Mojave Trail terminus (Vokes and Gregory 2007:Figure 17.1, Table 17.1). Unlike the previous two maps, which indicate travel closer to the modern Interstate 40, this map suggests shell coming off the Mojave Trail took a route south of I-40 to get to Flagstaff, Arizona, and the sites located beyond it. Wilcox et al. (1991:122) describe a trail traveling from the Mohave Valley through the Chino and Verde Valleys towards Flagstaff. The primary question, in this case, becomes whether the paths on this map are general indicators of

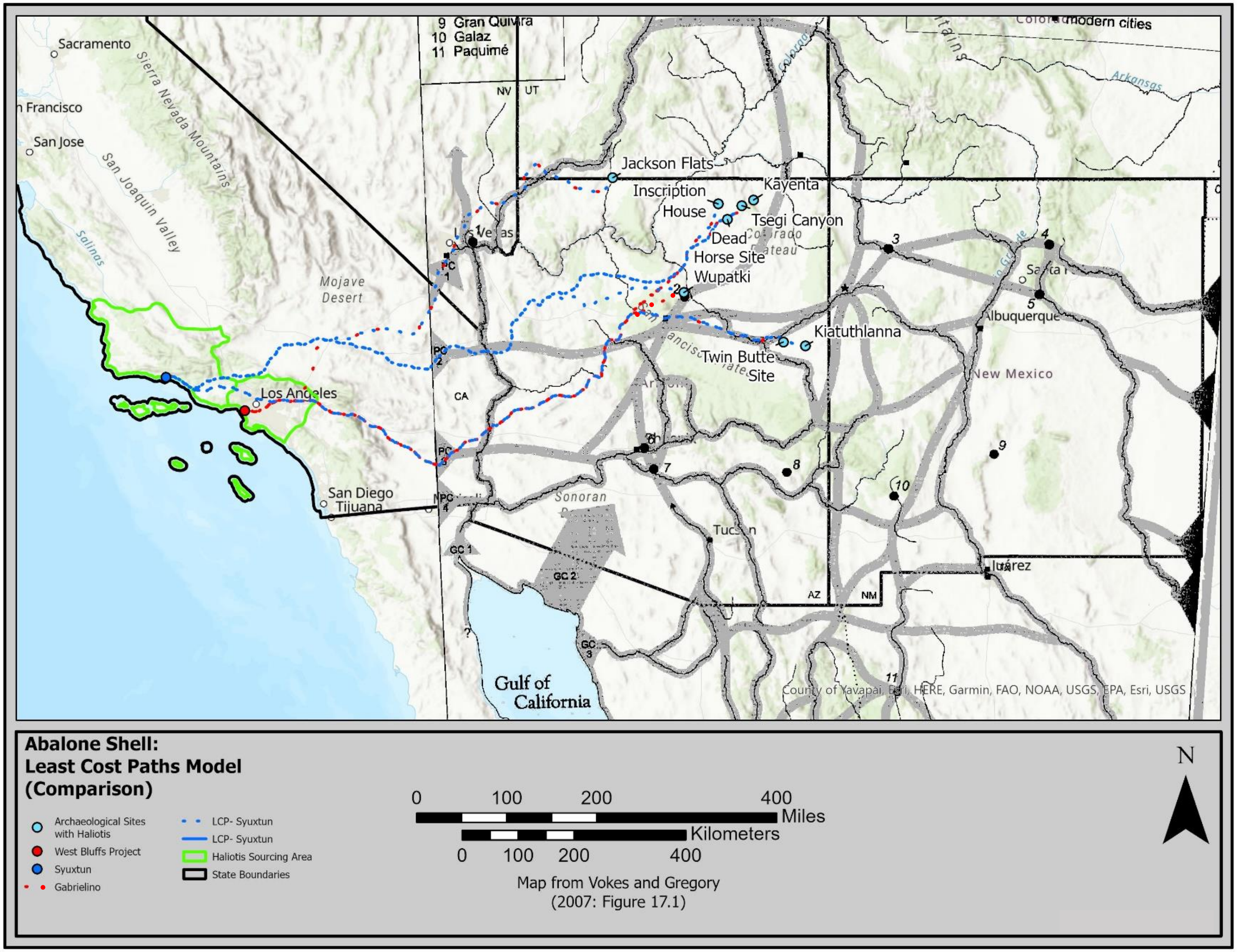

Figure 28. A Model Comparison against the Vokes and Gregory Map.

direction or accurate depictions of the historically documented trail traversing Northern Arizona. My inclination is toward the first option, especially considering two of the three maps provided fit the LCP models generated in ArcGIS Pro.

Conclusion-U.S. Southwest

Unlike California, I find that the routes displayed in the three previously mentioned maps support the Southwest portions of the LCP modeling. There are some variations in how closely the model paths align with the map paths, unlike in California where easier elevation favors travel around the Salton Sea at the expense of the Mojave Trail. For the U.S. Southwest, I would argue that the variations are less significant. It would prove worthwhile to further study areas along the model route for evidence of trails or sites that continue to support the California-U.S. Southwest exchange. Even the southern West Bluffs Project and southern *Syuxtun* paths, the models least fitting any of the historic trails expected for direct exchange between Southern California and Northern Arizona., still quickly reconnect to paths detailed by Colton (1941) and Ford (1983) and roughly follow them to the destination sites.

Another concern (initially voiced in Chapter 6) is that destination points, such as Inscription House or Wupatki, are located on modeling forks off main paths. It is highly improbable that the people traveling to these two sites before the other ones would actively choose to backtrack along the fork to take the main path to further away sites. Instead, they would likely take a more efficient path between the two destination sites. This decision is something the LCP model cannot account for due to its limitation in considering one origin and destination point independent of all other data. In this sense, the model does not necessarily accurately reflect the decisions of people traveling between the sites for the exchange of, amongst other things, *Haliotis*. The project could only represent this by running LCPs for each destination site to every other destination.

Summary

Visual comparison of the LCP model paths against five maps (two for California and three for the U.S. Southwest) resulted in similarities and differences throughout the study area. The California half of the study matches moderately well; the most notable deviation is a distinct lack of use of the Mojave Trail to lead to the northeastern Arizona destination sites where abalone shell is present. This lack of use directly contrasts with the information discussed in Chapter 4, which overwhelmingly supports the Mojave Trail's use. The U.S. Southwest portion of the study, on the other hand, appears to have a far more consistent alignment between models and maps.

The result is that more information needs to be worked into the model to help explain or compensate for some extreme differences seen during the comparison. This information includes potentially adjusting the model to examine a wider variety of Gabrielino or Chumash sites or incorporating impassible bodies of water, sources of drinking water, or other intentionally chosen waypoints. At the same time, other portions should be surveyed for sites or features within proximity of the model path to see if it is genuinely accurate. The model also does not account for paths unconsidered between sites in proximity of each other, so this is another avenue of improvement.

CHAPTER 8: SUMMARY AND CONCLUSIONS

Summary of Thesis

This study aimed to see whether least cost path analysis modeling in GIS can reproduce paths documented by previous studies of exchange between coastal Southern California and Ancestral Puebloan lands of Northern Arizona. The idea behind the study was that if models and documentation matched, areas along the modeling path could be surveyed or studied in the future for evidence of their use during exchange between the two groups. Suppose the models and the documentation did not match, however. In that case, both could be examined to determine whether the modeling process did not take some element into account (assuming a significant degree of variance) or if the model might indicate a path not previously considered or known (assuming a small degree of variance).

Information about coastal Southern California shells, specifically abalone shell, was presented in Chapter 2. Abalone shell acts as a unique proxy for shell exchange between the two regions because the genus *Haliotis* is unique to the Pacific coast. This contrasts with Dwarf olive snail shells, *Olivella*, which are found on both the Pacific coast and the Gulf of California and are more difficult to distinguish between due to physical similarities. Both types of shell, however, are considered to be important for the Southwest at large due to ceremonial and cosmological significance (Gruner 2019; Smith 2002) and hence show up at archaeological sites such as the eight selected for this project (see Chapter 6) based upon documented abalone shell presence in previous excavations.

Chapter 3 discussed the various Indigenous groups across the study area, the historic trails, and the expected model paths crossed during the exchange between coastal Southern

California and Northern Arizona. It is doubtful that the Chumash and Gabrielino were solely trading directly with people within Northern Arizona, meaning that shell (and other resources) likely exchanged multiple sets of hands and groups to move eastwards. The expected groups included the Gabrielino, Chumash, Serrano, Chemehuevi, Mojave, Hualapai, Havasupai, Yavapai, and Hopi.

Chapter 4 covered the topic of trails and their roles in facilitating exchange between coastal Southern California and Northern Arizona. Trails play more than just a role of simple exchange; they also can provide a connection to a group's history and overall identity, structuring elements of life that are not immediately tangible upon finding a prior trail on the landscape (Ferguson et al. 2009; Snead et al. 2009). Some of these intangible elements have been documented by archaeologists or the groups they directly pertain to but are not always accessible by outside groups or have physical documentation linked to said intangibles (Ferguson et al. 2009; Snead et al. 2009). Thankfully, several maps (discussed in Chapter 4) provide an idea of the routes used. In California, the Mojave Trail is the most strongly supported for direct exchange with the Ancestral Puebloan areas of the U.S. Southwest, being used before Spanish contact and even well past Spanish contact (Colton 1941; Earle 2005; Farmer 1935; Ford 1983). This trail was either accessed by the Gabrielino through the Cajon Pass or the Chumash by trading with the Gabrielino or a trail running through the mountains and along the southern Antelope Valley to meet the Mojave Trail (Davis 1961:Map 1; Farmer 1935:154). In the U.S. Southwest trails run up through the Las Vegas area and into the Utah region around the Utah-Arizona border, or instead, run from the Mojave Trail through or along the edges of the Hualapai and Havasupai to access Northern Arizona (Colton 1941:311; Ford 1983:Figure 8; Vokes and Gregory 2007:Figure 17.1).

Chapters 5, 6, and 7 are all dedicated to modeling least cost path analysis. Chapter 5 detailed what the analysis can do for archaeology, which shows the fastest route across the terrain regardless of physical or culturally significant features a person may wish to include in their travel. Such analyses have been used on multiple scales of exchange in various regions (Caseldine 2021; Newhard et al. 2008; Purtill 2021; Whitley and Hicks 2003). It was also stressed that such models cannot be accepted unquestioningly. Their purpose is to provide data that can then be compared against other lines of archaeological evidence. If it represents the other lines of evidence well, then it strengthens the prevailing theory. If it doesn't match, it either shows alternatives that should be tested by fieldwork or a need to refine the model by including other data, such as physical impedances or cultural restrictions.

Chapter 6 details the modeling process undertaken for this thesis, from start to finish. This includes the data initially expected to be incorporated into the model, refinements of the modeling steps based on unforeseen difficulties with data elements, and the results of the data creation. Chapter 7 compares the model results against five maps discussed in Chapter 4. The comparison shows a mixture of matches and mismatches between the model and the historical trail evidence. Some California portions of the model were significantly different from the historical evidence, while others matched relatively well. The U.S. Southwest portions of the model were more in line with documentation. This suggests that elements missing in California need incorporation into the model, such as significant impedances or different origin points based on sites of interest. Meanwhile, in the U.S. Southwest, the minor variations from the path should potentially be evaluated through a survey for evidence of trails or archaeological evidence associated with coastal Southern California.

Conclusions

This thesis attempts to provide a proof of concept for the least cost path analysis between coastal Southern California and the U.S. Southwest. Some might question whether applying LCP modeling to archaeological exchange is appropriate. The modeling process, after all, is better suited to answer problems regarding the creation of interstates and railroad routes. These types of infrastructure require relatively gentle rising and falling slopes, while people are able to traverse far more challenging terrain. Along with previous archaeologists utilizing LCP modeling, I think it is still helpful for archaeologists. The movement of heavy or cumbersome loads of resources, such as the large timbers destined for the Chaco region, would not be able to traverse more difficult slopes that a single, lightly encumbered person could (Field et al. 2019). Furthermore, proper incorporation of human characteristics such as the ones used by Field et al. (2019:140) or the costs of elevation using hiking functions (such as ones created by Tobler [1993] and White[2015]) as Purtill (2021) does, can provide more precise predictions of how humans decide to move across, along with up and down, the landscape. In addition, just because humans can traverse more difficult slopes does not mean they will. That can only be answered by finding or incorporating other data sources to refine the path. As stated in Chapter 4, LCP modeling is a tool to test hypotheses and suggest initial study areas; it is not an irrefutable answer. I would rather utilize all potential ways of evaluating potential exchange routes rather than leave a source of investigation unturned, merely because the modeling process's initial use was for something other than archaeology.

There is also a question of whether we can, or should, compare hand-drawn historical maps to ones produced by GIS programs. Hand-drawn maps of trails are accurate for the scale they are produced at. However, the trail accuracy remains similar when they are scaled up or down (such as during georeferencing in a GIS program) while the precision degrades. The LCP trails I modeled in ArcGIS Pro, on the other hand, are very precise based on the cell size (30 meters) of the raster datasets used in the process. However, this precision does not always mean accuracy; there may be elements on the landscape humans wish to travel to or along, even if it creates a less efficient route than the model. Even when models and hand-drawn maps align to a point where we say they agree with each other, there is still some measure of error that we have to account for. As stated previously, one millimeter of error between paths mutually supporting each other at a 1:6,000,000 scale means an error of 6 kilometers (3.75 miles) between the two map types. My opinion, however, is that comparing the two types of maps still holds value. Most of the trails yielded by both sources of evidence support relatively similar routes, suggesting that the model's precision is also accurate. At worst, the similarity of the two sources of evidence, when taken together, help refine a much smaller range for field study compared to using either source individually. Where the model strays away from the historical documentation, it opens new avenues of investigation to determine whether there are locations along the LCP that may indicate previously unidentified past movements.

Undoubtedly, the analysis presented here requires further refinement based on the evidence provided due to slight inconsistencies between the model and the existing evidence utilized. However, there are four methods of refinement, touched upon briefly in Chapters 6 and 7, that I believe would significantly improve the model and bring it closer in line with previous studies.

The first is the incorporation of hydrological data. The method this thesis initially attempted to use, creating stream orders, was unsuccessful despite following traditional GIS steps for creating the required streams in a raster dataset. The United States Geological Survey has publicly accessible vector line shapefiles for water features within the study area. These can be rasterized and assigned a slope value of about 15 degrees (a number proposed in by Alejandro Güimil-Fariña and César Parcero-Oubiña [2015]) that would help the model avoid waterways and water features that should not be traversable (Güimil-Fariña and Parcero-Oubiña 2015:34; Rosenswig and Tuñon 2020:3–5). The second is incorporating the modified Tobler hiking function proposed by Devin Alan White (2015). While White admits it is imperfect, it better incorporates the difficulty of travel over a non-Euclidean surface, measuring true distance and impedance created by different degrees of slopes than the original proposed by Tobler (1993). In essence, different approaches will create different model paths.

Third, future model iterations should examine a broader range of sites within the sourcing areas. In the case of the Chumash in particular, a site (or sites) in the Cuyama Valley and its surrounding mountains may take a different route than the one modeled from *Syuxtun* or other coastal sites modeled in the future. A more comprehensive range of sites may show different preferences in travel comparable to the historic trails, providing greater insight into the northern *Syuxtun* LCP cutting across the western Mojave Desert instead of a route leading to the Mojave Trail near its western start point. Finally, the LCP model should be run from *Haliotis* sourcing areas, or larger Indigenous sites that traders would have visited to partake in exchange, to destination points, and between destination points. There are likely paths between destination sites that people actively used, unaccountable for in modeling between origin and destination.

Despite these future considerations to improve the model, a first attempt is necessary to determine further avenues of study for Indigenous exchange between Southern California and the U.S. Southwest. In that regard, this thesis represents an attempt to try and understand the connections between the two regions. Hopefully, it provides a starting point for future researchers to help uncover more information about trails and shell exchange from the coasts of Southern California around the Gabrielino and Chumash traditional extents to the Northern Arizona area.

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