A GIS-Based Study of Prehistoric Hunting Blinds:

Visibility Analysis and Terrain Modeling at Little Lake, Inyo County, California

by

Ryan Scott Gerstner

A Thesis Presented to the
FACULTY OF THE USC DORNSIFE COLLEGE OF LETTERS, ARTS AND SCIENCES
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

August 2022

A view of Little Lake (Photo by German Cervera)

Acknowledgements

This research was conducted within ancestral homelands of the Panamint Shoshone and Owens Valley Paiute - Native peoples who have called this place their home for thousands of years. I would like to thank my advisor Dr. Jennifer Bernstein and my committee members Dr. Laura Loyola and Dr. Lynn Dodd for their input and encouragement throughout this process. I would also like to thank Dr. Alan Garfinkel and the California Rock Art Foundation for their support. The opportunity to conduct this research was made possible by the Ridgecrest Bureau of Land Management and Little Lake Ranch. Special thanks to Carlos Gallinger for his insights on bighorn sheep habits and habitats. Many thanks my colleagues Justin Rivard and German Cervera for assisting with fieldwork at the site. Finally, I would like to thank my family and friends for their continued support.

Table of Contents

List of Tables

List of Figures

Abbreviations

2D	Two dimensional
3D	Three dimensional
B.P.	Years before present
BLM	Bureau of Land Management
DEM	Digital elevation model
DSM	Digital surface model
GCP	Ground control point
GIS	Geographic information system
GISci	Geographic information science
GNSS	Global navigation satellite system
GSD	Ground sampling distance
IDW	Inverse Distance Weighting
LiDAR	Light detection and ranging
LOS	Line of sight
RTK	Real-time kinematic
SfM	Structure from motion
SSI	Spatial Sciences Institute
UAV	Unmanned aerial vehicle
USC	University of Southern California
VRM	Vector ruggedness measure

Abstract

This thesis focuses on prehistoric hunting patterns for targeting desert bighorn sheep within the archaeological complex located at Little Lake in Inyo County, California. The study area is situated on the eastern margin of the Sierra Nevada and on the western edge of the Coso Range. Little Lake has long been of interest to archaeologists due to the density of rock art and prehistoric archaeological sites surrounding the lake. This study uses a geographic information systems (GIS)-based analysis to investigate the locational properties of five prehistoric stone features and to analyze how they may have been employed as hunting blinds to pursue the desert bighorn sheep (Ovis canadensis). Using elevation models and map algebra functions in ArcGIS Pro, I modeled the behavioral characteristics of bighorn sheep and performed a visibility analysis aimed at interpreting past hunting strategies. A 10-meter digital elevation model (DEM) was employed to visualize bighorn sheep escape terrain and produce macro-viewsheds, while an unmanned aerial vehicle (UAV)-derived three-dimensional (3D) model of the study area was used to generate micro-viewsheds using 3D visibility tools. Results indicate a relationship between hunting blind locations and escape terrain for desert bighorn sheep, and the visibility analysis at the local and landscape scale allows for the reconstruction of prehistoric hunting practices at Little Lake.

Chapter 1 Introduction

This thesis employs a landscape approach to inspect an archaeological complex located along the margins of Little Lake in Inyo County, California. A mixed-method analysis explores the locational properties of archaeological features within a small study area near Little Lake. The study area is on the mesa above the eastern edge of the lake and is composed of a lava flow of columnar basalt. The research design uses experimental methods in the fields of archaeology, human behavioral ecology, and wildlife biology, with analytical techniques based in geographic information systems (GIS). Data collected via remote sensing techniques are implemented into a visibility analysis using geoprocessing tools in Esri's ArcGIS Pro.

This GIS-based study applies terrain modeling to assess whether prehistoric stone features at Little Lake were constructed in effective locations to monitor and ambush the desert bighorn sheep, while both viewshed and line of sight (LOS) analyses are undertaken in order to examine past hunting strategies. Little Lake is a significant location for an analysis of this focus, in part due to ongoing debates surrounding the timing and prominence of prehistoric large-game hunting in eastern California (Broughton et al. 2008; Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005), as well as the nature of associated rock art imagery found at Little Lake and across the Coso Range (Garfinkel 2006; Grant et al. 1968; Heizer and Baumhoff 1962; Van Tilburg et al. 2012; Whitley 1982). GIS and remote sensing have not been previously applied to archaeological studies at Little Lake (cf. Van Tilburg et al. 2012).

This research considers Native American hunting practices for the acquisition of artiodactyls (specifically the desert bighorn sheep) at Little Lake. The goal of this thesis is to employ visibility analysis and terrain modeling tools with map algebra functions in ArcGIS Pro using elevation models to explore the landscape at Little Lake. Datasets utilized in this study include a 10-meter Digital Elevation Model (DEM) and an unmanned aerial vehicle (UAV) acquired Digital Surface Model (DSM) of the study area. The locations of five stacked stone features (Features 1-5) are investigated to explore their landscape context and how they likely functioned as hunting blinds for targeting the desert bighorn sheep. This study recognizes escape terrain of bighorn sheep as a significant habitat characteristic, which is modeled using slope and terrain ruggedness measures. Escape terrain is recognized by wildlife biologists as one of the key habitat elements required by bighorn sheep (Dunn 1996; McKinney et al. 2003). Visibility analysis is undertaken to map macro- and micro-viewsheds and to explore the line-of-sight (LOS) between features (intervisibility).

1.1. Project Overview

This thesis stems from an archaeological survey project conducted for the Ridgecrest Bureau of Land Management (BLM). The research was completed in collaboration with the California Rock Art Foundation and California State University, Bakersfield, as an inventory of the archaeological resources within an approximately 200-acre study area near Little Lake. During several field sessions at the site between 2018 and 2021, the Little Lake Archaeological Survey Project conducted an archaeological survey which resulted in several site updates and the identification of newly recorded sites containing both prehistoric stacked rock structures and rock art (petroglyphs).

It is protocol among the archaeological community that the precise locations of archaeological resources are not to be distributed to the general public. This consensus precludes the explicit identification of cultural resource locations examined within this thesis. Due to the sensitivity of cultural resources, figures depicting feature locations have been obscured in order to conceal their specific locations.

This study considers archaeological sites in the study area that appear to directly relate to prehistoric hunting strategies. These include five sites with stacked rock structures and associated lithic (flaked stone artifact) scatters, tentatively identified as prehistoric hunting blinds). By employing visibility analysis in ArcGIS Pro, the viewshed, aspect, and intervisibility of archaeological features are modeled, presenting a unique methodology for investigating the function of archaeological features at the site. Further, the application of exploratory 3D visibility analysis has not been applied previously to this particular field of study. Hence, the purpose this analysis is to understand whether the locations of each hunting blind afforded specific visual properties that inform as to how the features may have functioned during their period of use. This research considers the currently accepted interpretations regarding the importance of hunting-related subsistence behaviors during specific periods of regional prehistory (cf. Garfinkel et al. 2010).

Native American hunting practices for the acquisition of bighorn sheep in California's Mojave Desert are reconstructed through ethnographic and archaeological research. Prehistoric hunting activities at Little Lake are framed into the most likely chronological periods through literature review and by consideration of surface artifact assemblages and associated rock art imagery identified within the study area and at nearby sites in the region. This thesis places a significant focus on bighorn sheep hunting at Little Lake which is supported by a review of archaeological sites, rock art subject matter, and related features described in this research.

1.2. Motivation

Little Lake presents a unique opportunity to apply remote sensing and exploratory GIS analyses to a region of great interest to archaeologists across California and the Great Basin. This is due to the abundance of archaeological sites and prehistoric rock art surrounding Little Lake and found throughout the Coso Range (Grant et al. 1968; Pearson 1995; Van Tilburg et al. 2012). An aim of current anthropological research is the understanding of the archaeological record from a landscape perspective – specifically to identify how sites are situated within their unique geography and historical ecology, in relation to other archaeological features, and based on the cultural patterns of prehistoric Native people (Allen 2011). By investigating a potential large-game hunting complex at Little Lake, prehistoric land-use and regional hunter-gatherer lifeways are examined, contributing to past land-use interpretations at the site.

1.3. Study area

The study area is situated along a small, spring-fed lake in California's western Mojave Desert (Figure 1). Little Lake is located along present-day highway US-395, approximately 25 miles northwest from the City of Ridgecrest in Inyo County, California. The area immediately surrounding the lake is privately owned and managed by the Little Lake Duck Club, a 1,200-acre duck hunting club and ecological preserve.

Figure 1. Study Area Region

During the LLRAP field sessions between 2018 and 2021, two newly identified stacked stone features were documented on the eastern perimeter of Little Lake (Gerstner and Garfinkel 2018, 2019). This study considers a total of five stone features (F1-F5) that have now been recorded east of the lake.

These features consist of stacked stone structures of variable morphology and artifact associations, but all contain a linear, J-shaped, or circular alignment of rocks built up with locally available volcanic stones within the rocky basalt flow (See Figure 2, Feature 1 in foreground). Constructed with cobble to boulder-sized basalt stones, the features contain rock walls piled from one to four courses in height. Based on similarities with ethnographic and archaeological descriptions which are discussed in the following chapter, these features are identified as hunting blinds, or locations in which hunters would monitor or ambush large game from concealed positions.

Figure 2: Feature 1 at Little Lake

1.3.1. A Bighorn Sheep Hunting Hypothesis

Across the globe, during the prehistoric era, people left evidence of hunting related activities on the landscape. Throughout California and the Great Basin there are extensive scatters of flaked stone debitage representing flintknapping activity. Raw lithic material was reduced into stone stools which served a variety of functions, mainly centered on killing and processing game animals. In addition to artifactual evidence there exists stone features which aided hunters in pursuit of the large game animals including deer, pronghorn, and bighorn sheep. These features include linear alignments of stacked rock cairns that functioned as corrals or wing traps (and in some instances related dummy hunters), in addition to small rock structures that functioned as hunting blinds. Hunting blinds appear to have been utilized to target a variety of large game animals with a specific emphasis on bighorn sheep (Brook 1980; Driver 1937:61).

This thesis considers the hypothesis that the stacked stone features at Little Lake were constructed by prehistoric people as hunting blinds in order to target the desert bighorn sheep (Ovis canadensis). Archaeological and ethnographic evidence of bighorn sheep hunting tactics utilizing stone hunting blinds are examined (cf. Brook 1980; Driver 1937; Steward 1938) along with archaeological evidence of bighorn sheep hunting at Little Lake including rock art subject matter and archaeofaunal studies (cf. Garfinkel 2006; Grant 1980; Van Tilburg et al. 2012; Schroth 1994). The GIS analysis then models the behavioral characteristics of bighorn sheep as through escape terrain modeling. The subsequent analysis explores the behavioral characteristics of bighorn sheep as through escape terrain modeling and the visual properties of the hunting blinds on both the landscape and local scale (viewsheds and line of sight).

1.4. Methodological Overview

The methodology of this study consists of two distinct analyses, utilizing a 10-meter DEM and a UAV-derived DSM of the study area. The data acquisition for the DSM is outlined, and the first analysis models bighorn sheep habitat within the study area, considering escape terrain by analyzing slope and a measure of terrain ruggedness [Vector Ruggedness Measure (VRM)]. The purpose of this analysis is to model the microecology pertaining to the most relevant behavioral characteristics of the desert bighorn sheep, escape terrain, which relates to the watering behaviors and movements of these animals to and from Little Lake. Next, a series of visibility analyses are presented which model viewsheds and feature intervisibility. Results from these analyses are used to interpret hunting strategies, as well as relationships between the archaeological features (hunting blinds) and the natural landscape.

1.5. Thesis Structure

The remainder of this thesis is divided into four chapters. Chapter 2, Background and Related Work, presents a regional background to the study area and a literature review of large game hunting including ethnographic and archaeological descriptions of hunting blinds. Chapter 2 also introduces research concerning bighorn sheep habitat modeling and reviews studies using GIS and viewshed analysis as applied to archaeological research. Chapter 3, Methodology, outlines the data acquisition, terrain modeling, and visibility analyses conducted in ArcGIS Pro. Chapter 4, Results and Discussion, presents the results of the analysis and also includes reflections and interpretations. Chapter 5, Conclusion, summarizes the results and challenges encountered, and proposes future work.

Chapter 2 Background and Related Work

This chapter begins with a background of the study area which includes an environmental overview and the general anthropological context for this research. Next, an archaeological review of bighorn sheep hunting in eastern California includes a description of prehistoric hunting blinds. This chapter also introduces aerial photogrammetry and 3D modeling before a discussion of bighorn sheep habitat modeling which is employed in the analysis. Finally, this section reviews GIS and visibility studies in landscape archaeology.

2.1. Environmental Background

2.1.1. Geology

Little Lake is situated within the Rose Valley at the southern end of the Owens Valley at the interface of the Sierra Nevada and Coso Mountains. The study area occurs at the southwestern edge of the Great Basin in eastern California. A prominent basalt flow east of the lake extends two-miles to the north where it terminates at Fossil Falls, and just north of the lake there exists a prominent cinder cone volcano of red scoria that rises 3,952 feet in elevation. Little Lake itself is a shallow, spring fed lake which has existed for at least the past 5000 years (Mehringer and Sheppard, 1978). Prior to this, the area appears to have been a marshland that continuously supported prehistoric peoples in the area from the early Holocene and most likely even the late Pleistocene (Moratto et al. 2018).

Lava flows and volcanic deposits composed of basalt, rhyolite, and obsidian characterize this landscape. The study area is located atop a massive basalt lava flow that originated from nearby Volcano Peak approximately 140,000 years ago (Van Tilburg et al. 2012). The area remains seismically active, with a major 7.1 magnitude earthquake occurring on July 7, 2019.

2.1.2. Flora and Fauna

The study area at Little Lake is generally characterized by desert scrub vegetation community typical of the Mojave Desert. The area is dominated by creosote bush (*Larrea divaricata*) with a saltbush (*Atriplex* spp.) understory (Garfinkel 1976). Pearson (1995) identified numerous perennial shrubs at Little Lake among many plants, herbs, and grasses utilized by native people including wild rye (*Elymus* sp.), Mormon tea (*Ephedra nevadensis*), chia (*Salvia columbariae*), ricegrass (*Oryzopsis hymenoides*), and tansy mustard (*Descurainia pinnata*). A riparian zone along the lake includes willow (*Salix* sp.), cottonwood (*Populus* sp.), bulrush (*Scirpus robustus*, *S. acutus*, S. olynei), cattails (*Typha* sp.), and various other bulbs tubers, and grasses (Van Tilburg et al. 2012).

The fauna found within the study area as described by Pearson (1995) include several reptiles, numerous birds and migratory waterfowl including Canadian geese (*Branta canadensis*), teal (*Anas crecca*, *A. cyanoptera*), and mallard (*Anas platyrhynchos*). Numerous small mammals have been identified including Black-tailed jackrabbit (*Lepus californicus*), Cottontail rabbit (*Sylvilagus audobonii*), woodrats (*Neotoma* sp.), ground squirrels (*Ammospermophilus* sp.), pocket gophers (*Thomomys* sp.), skunk (*Mephitis mephitis* and *Spilogale putorius*), badger (*Taxidea taxus*), and racoon (*Procyon lotor*). Medium to large sized mammals include bobcat (*Lynx rufus*), coyote (*Canis latrans*), mule deer (*Odocoileus hemionus*), and now locally extinct pronghorn (*Antilocapra americana*) and bighorn sheep (*Ovis canadensis*).

2.1.3. Paleoenvironment

Today, the climate at Little Lake is an arid desert environment, receiving less than four inches of rainfall annually. Temperatures regularly exceed 100° F in the summer and drop below freezing in the winter months. However, over the millennia Little Lake has seen numerous climatic shifts which are briefly described here.

During the end of the last major glaciation, or the terminal Pleistocene (ca. 13,500 years before present (B.P.)), indigenous people first appeared on the landscape. During this time the region supported a series of interconnected large Pluvial lakes in what is now a vast desert, and the region experienced cool and moist conditions. During the Middle Holocene (8000 – 5500 B.P.) the record indicates a pervasive drought across the Great Basin (Wigand and Rhode 2002). Based on lake-core sampling at Little Lake (Mehringer and Sheppard 1978), researchers recognize the Neo-Pluvial Period in the northern Mojave Desert in which water availability dramatically increased during the Late Holocene (5500 B.P and 2000 B.P.), resulting in the rejuvenation of springs across the region (Wigand and Rhode 2002). Little Lake, as we know it today, likely appeared somewhere around 5000 B.P. Episodic droughts persisted for the first 1500 years of the Neo-Pluvial; however, conditions never returned to those which characterized the Middle Holocene. A notable major decline in precipitation also occurred between ca. 1150 to 600 B.P. (ca. AD 970 to 1350) during what is referred to as the Medieval Climatic Anomaly (MCA).

2.2. Anthropological Background

This research centers on a well-known archaeological complex in California's Mojave Desert. Little Lake is an oasis at the edge of the desert which Native American peoples occupied for thousands of years. Little Lake has received considerable interest over the past 80 years owing to discoveries at archaeological sites (notably the Stahl Site) and the extensive concentrations of prehistoric rock art which occur there on the basalt outcrops surrounding the lake (Garfinkel 1976; Harrington 1948a, 1948b, 1949, 1950, 1951, 1952, 1953, 1957; Pearson

1995; Van Tilburg et al. 2012). To appreciate the complex prehistory of the study area, a brief background is offered following a discussion of the archaeology at Little Lake.

Regional ethnographic data relevant to Little Lake was recorded in the early 20th century (Kroeber 1925; Steward 1938; Driver 1937). At the time of Euroamerican contact, the seasonally occupied village site of *Pagunda* [CA-INY-3826 (Smithsonian trinomial designation for archaeological sites)] existed just west of the lake, ethnographically attributed to the Panamint (Coso/Timbisha) Shoshone. The Panamint Shoshone represent the westernmost extent of the Shoshonean people, occupying desert areas in eastern California including Panamint, Coso, and Death valleys (Kroeber 1925: 589). The Panamint Shoshone speak a Numic language which is a branch of the Uto-Aztecan linguistic family.

Little Lake was also a recognized and shared resource attracting a variety of prehistoric people in the region (a number of different tribal or ethnolinguistic groups). The site was at times visited by the Owens Valley Paiute from the north, Desert Kawaiisu (Nüwa) from the south, the Tübatulabal in the Kern River Valley from the west, and possibly the Mohave (aha makav) from the Colorado River area in the far southeast. *Pagunda* was a component of the Shoshone District of *Kuhwiji*, and was reported to have about 50 to 60 people living in the village in the year 1870.

The early Native inhabitants of Little Lake were hunter-gatherers who, throughout much of prehistory, were highly mobile foragers following a seasonal round and an adaptive resource procurement strategy. Native people throughout this region exploited numerous plant and animal species including pine nuts, seeds, roots, tubers, small mammals, insects, fish, deer, bighorn sheep, antelope, jackrabbits, and waterfowl (Bettinger 1982).

2.2.1. Archaeology and Rock Art

The Mojave Desert region has likely seen more studies of prehistory than most areas in California. Past studies have attempted to model the cultural evolution of the region, with long-standing debate concerning regional chronology, settlement-subsistence changes, population movements, linguistic prehistory, and cultural ideology relating to rock art (cf. Garfinkel 2006, 2007, 2009; Garfinkel and Austin 2011; Garfinkel and Pringle 2015; Grant et al. 1968; Gilreath 2007; Gilreath and Hildebrandt 2008; Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005; Pearson 1995; Schroth 1994; Van Tilburg et al. 2012; Whitley 1982, 1998, 2000; Whitley and Dorn 1987).

Native American prehistory in the region spans at least the past 13,500 years (Table 1). There are numerous archaeological sites recorded in the Little Lake area, and it is one of the richest archaeological landscapes in the region. As such, researchers have opted to treat this area as a continuous archaeological landscape, and it is listed as the Fossil Falls Archaeological District on the National Register of Historic Places (Garfinkel 1976). Significantly, Little Lake is located immediately southwest of one of the most extensive toolstone quarries for obsidian (volcanic glass) in California, the Coso Volcanic Field. Obsidian from the Sugarloaf quarry was traded extensively across California and the Great Basin to fashion a variety of stone tools including projectile points used in the hunting of large game (Gilreath 1997).

Table 1: Chronological Sequence of the Mojave Desert Region (Adapted from Bettinger and Taylor 1974; Garfinkel 2007; Warren 1984)

Period	**Age Range in Years Before Present (B.P.)**	**Artifact Characteristics**
Late Pleistocene (Paleoindian)	13,500 – 12,000 B.P.	Fluted and Basally Thinned Concave Base points (Western Clovis)
Lake Mojave	12,000 – 8,000 B.P.	Western Stemmed points (Lake Mojave and Silver Lake points)
Little Lake (Pinto)	8,000 – 3,500 B.P.	Pinto and Leaf-shaped points
Newberry (Gypsum)	3,500 – 1350 B.P.	Gypsum, Elko, and Humboldt points
Haiwee (Saratoga Spring)	1350 – 700 B.P.	Rose Spring, Eastgate, and Saratoga Springs points
Marana (Late Prehistoric)	700 B.P. to ca. AD 1770	Desert Series (Cottonwood and Desert Side-notched) points and ceramics

Little Lake has more recently been the focus of an extensive archaeological documentation project for the rock art expressions surrounding the lake in a decade long inventory (Van Tilburg et al. 2012). That study, plus a number of others (Harrington 1957; Pearson 1995; Moratto 1984, p. 374-5), provides a working chronology and overall interpretation of the main site functions documented for the Little Lake archaeological district. A total of 288 petroglyph elements representing desert bighorn sheep were documented at Little Lake. Significantly, there is a depiction of a possible bighorn sheep hunt on a rock art panel within the Stahl Site Cave (CA-INY-205) at Little Lake (Figure 3; Heizer and Clewlow 1973: Figure 24-A).

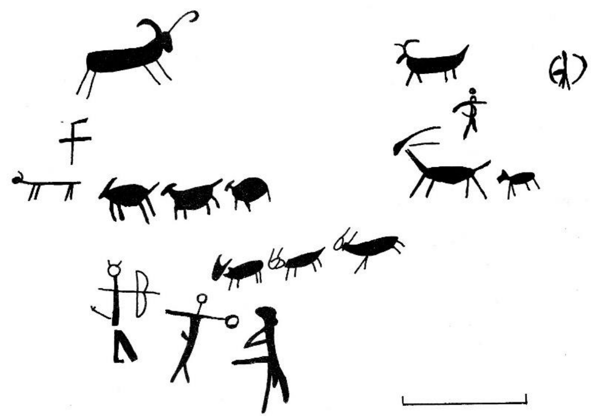


Figure 3: Rock Art Panel at Stahl Site Cave (Heizer and Clewlow 1973: Figure 24-A).

2.3. The Desert Bighorn Sheep

The following discussion introduces the topic of prehistoric large game hunting in eastern California and the Great Basin. First, this section discusses the behavioral characteristics of the desert bighorn sheep in order to justify the model, considering lines of evidence supporting the research site as an exclusive area of bighorn sheep habitat and not that of deer or pronghorn. Furthermore, this section considers various lines of evidence that support an emphasis on bighorn sheep hunting in eastern California particularly during the late Archaic (Newberry Period) (ca. 3500-1350 cal B.P.), which frames the temporal context for this research.

2.3.1. Habits and Habitats

Bighorn sheep population numbers and their natural habitats across the Desert West during prehistoric times were far greater than in the present day, with massive declines after Euro-American contact (Buechner 1960). The behavioral characteristics of bighorn sheep are such that they spend their lifetime near a perennial water source, and rarely travel more than 32 kilometers from their birthplace (Welles and Welles 1961). Both seasonal and daily movement patterns have been well documented (Simmons 1980), and sheep will water within close proximity to steep slopes which provide “escape terrain” in case they are ambushed by predators.

The importance of the perennial water source at Little Lake is a critical factor in hunting feature placement. A relationship between bighorn sheep ranges and water sources including Little Lake have been demonstrated (Ritter and Coombs 1990). Recent evidence for bighorn sheep occurrence at Little Lake comes from a sighting in 2006 in which several bighorn sheep rams from a reintroduced metapopulation (originally transplanted from the Old Dad Mountains) were documented watering at the lake (Van Tilburg et al. 2012).

Unlike the bighorn sheep, deer and pronghorn will run across open terrain in a flight response. The rocky cliffside east of the lake would have only been utilized by the desert bighorn sheep as escape terrain. Antelope in particular prefer lowland, open valleys (C. Gallinger, personal communication, September 11, 2021). For this reason, along with several lines of evidence discussed below, this study exclusively considers aspects of bighorn sheep habitat for the present research.

2.3.2. Hunting in the Archaeological Record

During the Late Holocene (Newberry Period or Gypsum Complex, ca. 3500-1350 cal BP) the archaeological record across California and the Great Basin indicates considerable interregional variability in land-use practices among prehistoric populations. Various models related to Late Holocene resource intensification center on the presence, intensity, and relevance of large game hunting in the subsistence-settlement patterns of Native peoples. Land-use changes during the late Archaic are expressed in a variety of ways, and likely relate to fluctuations in environmental conditions during this time (Broughton et al. 2008). Favorable climatic conditions during the Neo-Pluvial appear to have been drivers for an increase in large game on the landscape, which are reflected in an emphasis on hunting (Warren 1984, Garfinkel et al. 2016). Intensive manufacturing of obsidian bifaces at large obsidian quarries, including quarries in the Coso Volcanic Field, are also evident during this time (Gilreath and Hildebrandt 1997). Other researchers suggest that the changing archaeofaunal record during the late-Archaic also signifies prestige hunting of large game (Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005).

In eastern California, several lines of evidence point to the bighorn sheep as being one of the most sought-after large game animals during the late Archaic, as opposed to deer or antelope. Archaeofaunal data from 90 sites in the Sierra Nevada show bighorn sheep faunal elements dominating artiodactyl assemblages on the east side of the range, while sites west of the Sierran crest contain predominantly deer (McGuire et al. 2012). Additionally, archaeofaunal evidence from excavations near Little Lake at Portuguese Bench (CA-INY-2284), indicate that a substantial portion of artiodactyl faunal elements represent bighorn sheep (Gilreath 2000).

One of the challenges in determining the presence of bighorn sheep in faunal assemblages is that their bones are difficult to differentiate from other large mammals when they are highly fragmented. Direct evidence for bighorn sheep hunting at Little Lake comes from residue analysis from a Pinto style projectile point at the Stahl Site in which bighorn sheep proteins were detected (Schroth 1994). There is also some evidence of bighorn sheep recovered during excavations at *Pagunda* at Little Lake (Van Tilburg et al. 2012).

Evidence points to bighorn sheep hunting in the Mojave Desert region as most prominent during the Newberry Period (ca. 3500 to 1350 B.P.) (Garfinkel 2006), with a significant decrease during the early Haiwee Period and a virtual cessation of this hunting activity during the Marana Period from 700 B.P to Euro-American contact (Gilreath and Hildebrandt 2008:16-17). Some significant sites have been identified in the region that relate to a bighorn sheep hunting culture (cf. Garfinkel 2006) including findings at Newberry Cave (Garfinkel et al. 2016) and the Rose Spring site (CA-INY-372) (Yohe and Garfinkel 2012) that support intensification of bighorn sheep hunting during the Late Archaic. High elevation bighorn sheep hunting in the White Mountains northeast of Little Lake has also been recognized during this same time span (Morgan et al. 2014). Given this archaeological evidence and the behavioral characteristics of bighorn sheep previously discussed, this thesis study specifically considers the central focus of the hunting blind features at Little Lake as being employed for bighorn sheep hunting.

Coinciding with a hunting prominence is the proliferation of bighorn sheep petroglyph (rock art) production within the Coso Range during the middle to late Archaic (Van Tilburg et al. 2012). Explanatory platforms for the abundance of bighorn sheep petroglyph motifs relate to increase rites or “hunting magic” in which petroglyph production functioned to increase the success of the hunt (Garfinkel 2006; Grant et al. 1968; Heizer and Baumhoff 1962). This interpretation has been challenged, with others averring that petroglyphs in the Mojave Desert relate predominantly to shamanism and the recording of visions by shamans during altered states of consciousness (Lewis-Williams and Dowson 1988; Whitley 1982, 1998, 2000).

2.4. Hunting Blinds

Hunting blinds are a recognized archaeological feature found in large numbers throughout the Mojave Desert. While numerous circular rock ring features representing wikiup foundations (habitation features) also occur on the landscape, there are key distinctions between these and hunting blinds. They typically consist of stacked rock enclosures constructed from locally available stone. Hunting blinds were generally large enough to support one or more individuals and are usually ovate to circular in shape, with variable dimensions ranging from approximately one to four meters in diameter. It is believed that the stones may have supported a brush superstructure. Hunting blinds are typically found in association with lithic debitage (flaked stone) and projectile point fragments (Belardi et al. 2017; Hoffman 1878:474; Hunt 1960:19), and the stone blinds were employed in order to conceal hunters on the landscape from the view of large game animals.

In numerous instances, hunting blinds have been documented to occur in association with linear alignments of rock cairns which may have functioned as game intercept drive sites – also known as wing traps (Blair and Fuller-Murillo 1997; Altschul and Ezzo 1994; Schneider et al. 2014). One such feature is known on the north base of Naval Air Weapons Station China Lake, not far from Little Lake (A. Garfinkel, personal communication, 2021). Hunting blinds can consist of J and U-shaped stacked-rock features which are found throughout the Great Basin, Sierra Nevada, and Rocky Mountains (Canaday 1997; Grant et al. 1968; LaBelle and Pelton 2013; Lubinski 1999; Morgan et al 2014).

Ethnographic data which relates to hunting blinds in the Owens Valley was recorded by Steward (1938), who described hunting practices among the Owens Valley Paiute. During communal hunts a trap was employed for both bighorn sheep and deer, in which the animals were driven down trails with other individuals hiding in stone enclosures. Across the Great Basin and much of California, hunting practices utilized built landscape features including hunting blinds, rock cairns, corrals, pits, and fences (Fowler 1986:79; Hockett et al. 2013; McGuire and Hatoff 1991). Brook (1980) mapped hunting blind locations across the southwestern Great Basin and indicated six hunting blind loci within the Coso Range located at Upper Centennial Spring as well as Coso Peak, Big Petroglyph Canyon, Sheep Canyon, and Renegade (Little Petroglyph) Canyon (Grant et al. 1968), in addition to Sugarloaf Mountain (Clewlow et al. 1980). The hunting blinds at Little Lake can be considered an extension to those recognized loci within the Coso Range.

Hunting practices for bighorn sheep in the Great Basin involved triggering the flight response of bighorn sheep to ascend to high rocky points where they would be met by hunters waiting in blinds (Driver 1937, Grant 1980, Brook 1980). Driver (1937:61) noted that according to his ethnographic consultants, hunting blinds at the tops of mountains were used specifically to target bighorn sheep and that the large-scale V-traps composed of rock cairns were the only effective means for pursuing pronghorn or deer. According to Steward (1938:33) both deer and bighorn sheep would have been hunted by an individual or a small group, whereas pronghorn were pursued by large hunting parties. Ethnographic accounts have noted that an arrow “smeared with decayed blood from an animal's heart” was used to poison the animal once shot (Brook 1980; Wallace 1977, p. 41; Grosscup 1977, p. 124).

A component of the visibility modeling in this thesis considers the distance at which hunting weaponry would have been effective in targeting the bighorn sheep from the hunting blind locations. One consideration of this distance is whether the hunters occupying these blinds were using atlatl (spear throwers) or bow and arrow technology. We know that in Eastern California the atlatl persisted as the dominant form of projectile weaponry until approximately 2000 B.P. The best ethnographic account of bow and arrow range comes from observations of Ishi, the last known member of California’s Yahi Tribe. Ishi could hit targets with some accuracy up to 60 yards (54 meters), although shots would generally be taken from just 10-50 yards for fear of losing or breaking an arrow (Pope 1974). As for atlatl distance, there are several experimental studies on this matter, suggesting that the atlatl would be accurate up to 64 meters, but with the most successful range between 10 to 30 meters (Hutchings and Brüchert 1997). For purposes of this study at Little Lake, a maximum range of 54 meters was used for the micro-viewsheds of Features 1- 3, to represent the maximum distance at which large game could have been targeted.

2.5. Aerial Photogrammetry and 3D Modeling

This thesis integrates remote sensing and GIS analysis in order to examine archaeological questions. This section briefly outlines the principals of aerial photogrammetry and the processing steps that render aerial photographs into 3D models which can then be analyzed in GIS. Advances in UAV technology now allow for the accurate, efficient, and cost-effective collection of photogrammetric datasets. Combined with survey grade global navigation satellite system (GNSS) receivers, employing UAVs for data acquisition can render accurate 3D models, and is being widely adopted into archaeology studies (Remondino 2014).

Photogrammetry is the science of obtaining reliable measurements from digital images in which a collection of images are processed by software in order to produce a 3D model. Photogrammetry utilizes the principle of structure from motion (SfM), in which a series of overlapping photos are analyzed to create a 3D model. Software recognizes similar points between the overlapping stereo imagery, referred to as tie points, which then allows for the construction of the volumetric model (Figure 4; GISGeography 2021).

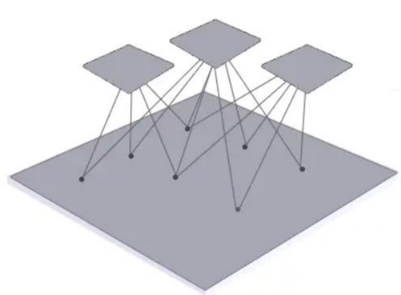


Figure 4: Aerial photogrammetry principle (GISGeography. 2021).

Highly accurate DSMs can be rendered from aerial images using aerial photogrammetry software. While there are numerous software platforms available for collecting and processing photogrammetric datasets, this thesis utilized the Pix4D Capture and Pix4D Mapper software. Pix4D mapper uses complex photogrammetry algorithms in order to take aerial imagery and produce volumetric 3D models. Flight planning is completed within the Pix4D Capture application in which the user establishes the flight parameters including the extent, flight path and altitude, percent overlap of images, and camera angle. Image capture settings will vary on each use case and the resulting resolution, or ground sampling distance (GSD), which is a factor of flight altitude and the camera sensor (focal length and resolution). Pix4D recommends that for 3D modeling, a double grid pattern is flown with 70-degree camera angle, 80% front overlap, 70% side overlap, and auto white balance (Pix4D 2022).

Before taking flight and processing the imagery, it is important to introduce the concept of ground control points (GCPs). GCPs are locations on the landscape with known coordinates which are visible in the imagery. Unless equipped with a real-time kinematic (RTK) GNSS receiver, most consumer grade UAVs can only geotag aerial imagery to plus or minus 10 feet. In order to minimize this degree of error, GCPs are utilized to ultimately georectify the 3D model to survey grade standards. Prior to image acquisition, a minimum of three visible GCP targets must be laid out across the project area and recorded with a survey grade GNSS receiver (discussed further in this section). Once mission planning is complete, and GCPs are placed, Pix4D Capture completes the flight and image acquisition autonomously, resulting in a grid of aerial photographs over the project area (Figure 5).

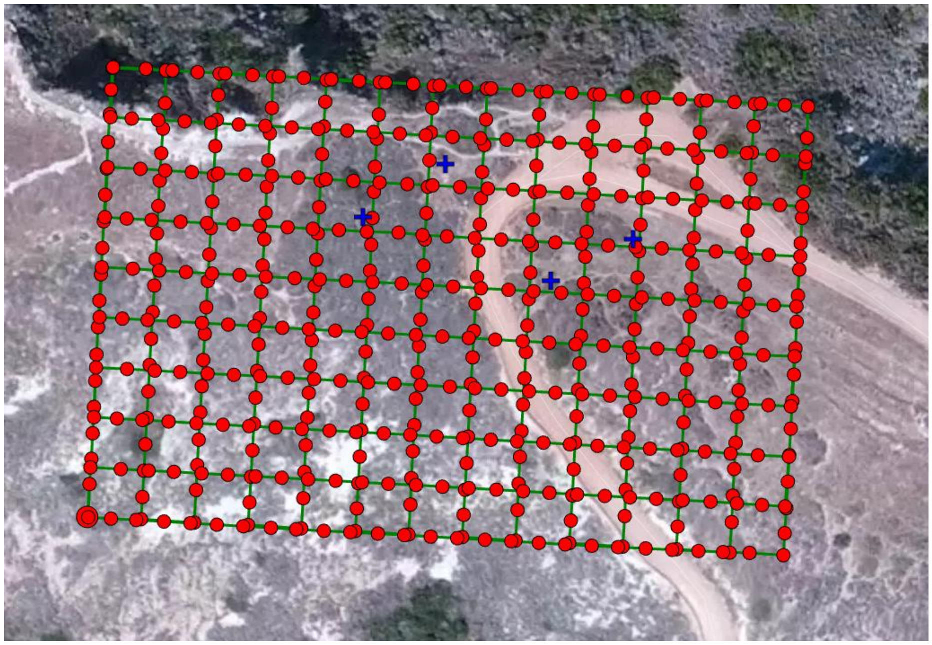


Figure 5: Example Double grid mission in Pix4D (red dots represent image locations, blue crosses represent GCPs) (Gerstner 2018)

Next, the imagery is processed in Pix4D mapper, in which there are three main processing steps. In initial processing, images and GCPs are utilized for keypoints extraction, keypoints matching, camera model optimization, geolocation (using GCPs), and the generation of automatic tie points (Figure 6).

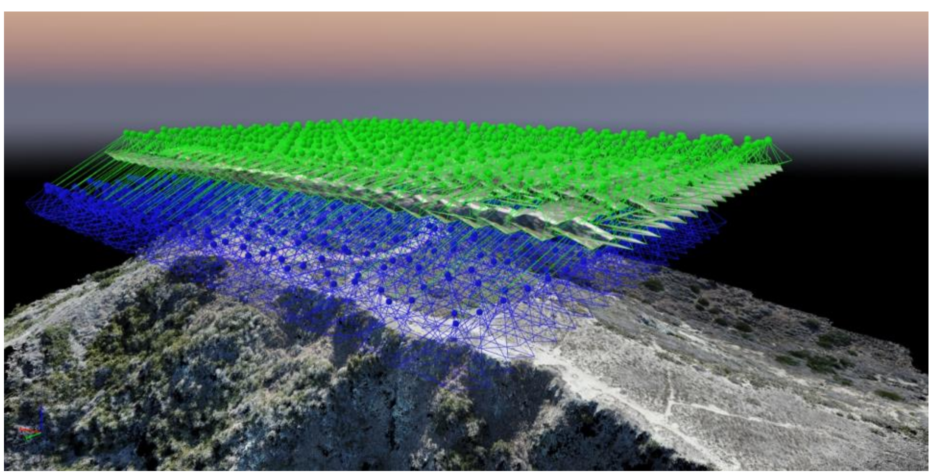


Figure 6: Example Initial Processing in Pix4D (green dots represent image locations, blue dots represent tie points) (Gerstner 2018)

Next, the point cloud and mesh are processed, in which the previously generated automatic tie points allow for point densification to produce a densified point cloud and finally the 3D textured mesh (Figure 7).

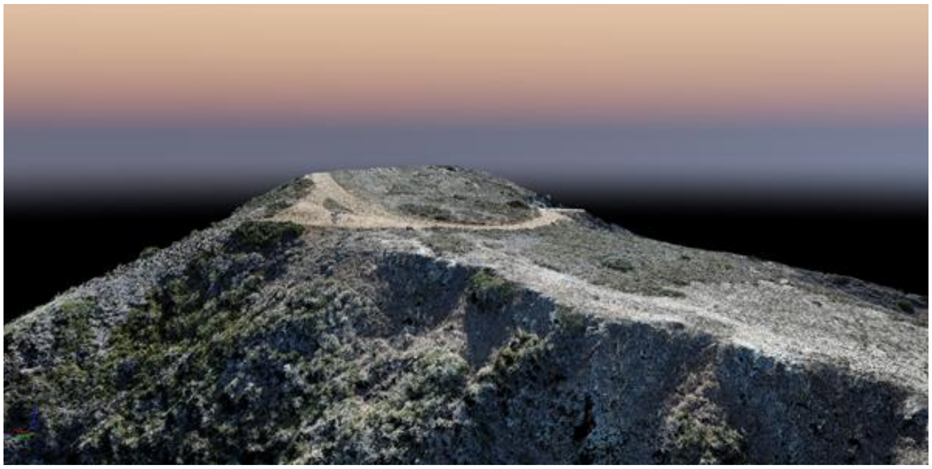


Figure 7: Example 3D textured mesh in Pix4D (Gerstner 2018)

The final step enables the creation of a DSM, Orthomosaic, Reflectance Map, and Index Map. For this thesis project, a DSM was rendered and imported into ArcGIS Pro for the resulting GIS analysis.

As previously discussed in this section, implementing GCPs into mission planning is a critical step to ensure high absolute accuracy within the derived 3D model. This is particularly important when integrating archaeological site data that is located within the extent of the model, which is performed in this thesis analysis. The use of sub-meter GNSS receivers to collect both the GCP locations as well as archaeological site data is the best practice. While there are numerous types of receivers, this thesis study utilizes the EOS Arrow 100 to collect this data. The Arrow 100 is a portable GNSS receiver that links via Bluetooth to a smart device, with data collected on the ESRI Collector app.

2.6. Bighorn Sheep Habitat Modeling

This section discusses two studies regarding bighorn sheep habit modeling which this thesis analysis draws from. In an effort to reintroduce populations of bighorn sheep across the western United States, numerous studies have aimed at modeling bighorn sheep habitat to assess habitat suitability. A GIS-based study of Rocky Mountain and desert bighorn sheep measures both habitat and impacts, and ranks the potential suitability of transplant sites (Dunn 1996). By modeling habitat patches, human disturbance, and proximity to other ranges, Dunn identified critical factors related to viability of bighorn sheep suitability, namely the inherent capability of an area to support them. In low elevations habitats, like that at Little Lake, this included total habitat, escape terrain, escape terrain contiguity, and water availability. Escape terrain coverage was calculated by extracting cells with slopes greater than 60% from the total habitat coverage (Dunn 1996).

The study area at Little Lake adopted the parameters of this study with regards to escape terrain. The study area meets the parameters of vegetation coverage (less than 25% canopy cover) and water availability (total habitat less than or equal to 3.2 kilometers from a perennial water source within 200 meters of escape terrain).

A 2007 study that modeled desert bighorn sheep habit across three mountain ranges in the Mojave Desert identified terrain ruggedness as an important variable in habitat modeling (Sappington et al. 2007). The study employed a vector ruggedness measure (VRM), which takes into account both slope and aspect, and characterized local variation in terrain more independently than slope alone. The model integrates VRM, slope, distance to water, and the mapped locations of desert bighorn sheep (*Ovis canadensis*). VRM values range from 0 (flat) to 1 (most rugged), with rugged terrain defined as values greater than 0.2. Using logistic regression, results indicate the importance of terrain ruggedness in habitat selection, “whereas the relative importance of slope varied according to the characteristic physiography of each range” (Sappington et al. 2007). The study resulted in the development of a new geoprocessing tool located within the Arc Hydro toolset in ArcGIS Pro to quantify the characteristics of terrain ruggedness. This tool was used in this project to model bighorn sheep escape terrain at Little Lake.

2.7. GIS-Based Visibility Studies in Archaeology

This section describes visibility studies utilizing GIS as applied to archaeological research. First, a brief history and theory of archaeological visibility studies are introduced. Next, visibility studies integrating UAV-derived 3D models are discussed, and finally this section describes a few studies applying visibility analysis to the investigation of prehistoric hunting landscapes. The methodology developed in the study of hunting blinds at Little Lake is adopted from these studies.

Landscape Archaeology is concerned with relationships between archaeological sites and the natural landscape. Analyzing visibility using GIS functions is now a common practice in landscape archaeological studies. Visibility analysis involves generating a line of sight between two points over an elevation surface, and a viewshed is generated for every raster cell in a neighborhood from an observer location. Visibility studies recognize that visual properties between archaeological sites and the surrounding landscape are important in understanding past indigenous activities (Gillings 2020). Past studies have varied from describing visual relationships between locations and modeling cumulative viewsheds on the landscape (Llobera 2003; Wheatley 1995), to statistical examination and probability testing of visual relationships (Eve 2014; Wright et al. 2013).

An interesting line of inquiry in visibility studies models the frequency of locations from which a location can be seen, which provides data on the most and least visible locations on the landscape (Gillings 2015, See 2.6.2 for a discussion on this study). Viewshed calculations of variable distances have also been undertaken in order to characterize archaeological sites and landscapes (Verhagen 2017). This visibility analysis at Little Lake conducts traditional viewshed analysis at several distances and maps sight lines between feature locations in order to model visibility on the local and landscape scale.

2.7.1. Utilizing UAV-derived 3D Models

With recent advances in UAV technology, the deployment of drones to collect highly accurate 3D models is becoming more widespread in archaeological studies. This is of particular relevance to visibility studies, which rely on high quality elevation models in order to render accurate viewsheds, especially at a local scale. While GIS functions have previously been limited when analyzing complex 3D models, software packages such as DroneDeploy and Pix4D can now export data products that can be readily analyzed in a GIS such as ArcGIS Pro.

O'Driscoll (2018) describes a case study employing a UAV-derived 3D model for use in GIS analysis at an early Medieval archaeological site in Ireland. A DJI Mavic Pro was used to derive a 3D model of the fortress of Cahercommaun. The study applies visibility analysis to further understand the layout of the fort and how it functioned which, “highlighted that views from the interior of the inner enclosure are restricted by the substantial defences [sic] even at the north, where the wall is less substantial” (Figure 8).

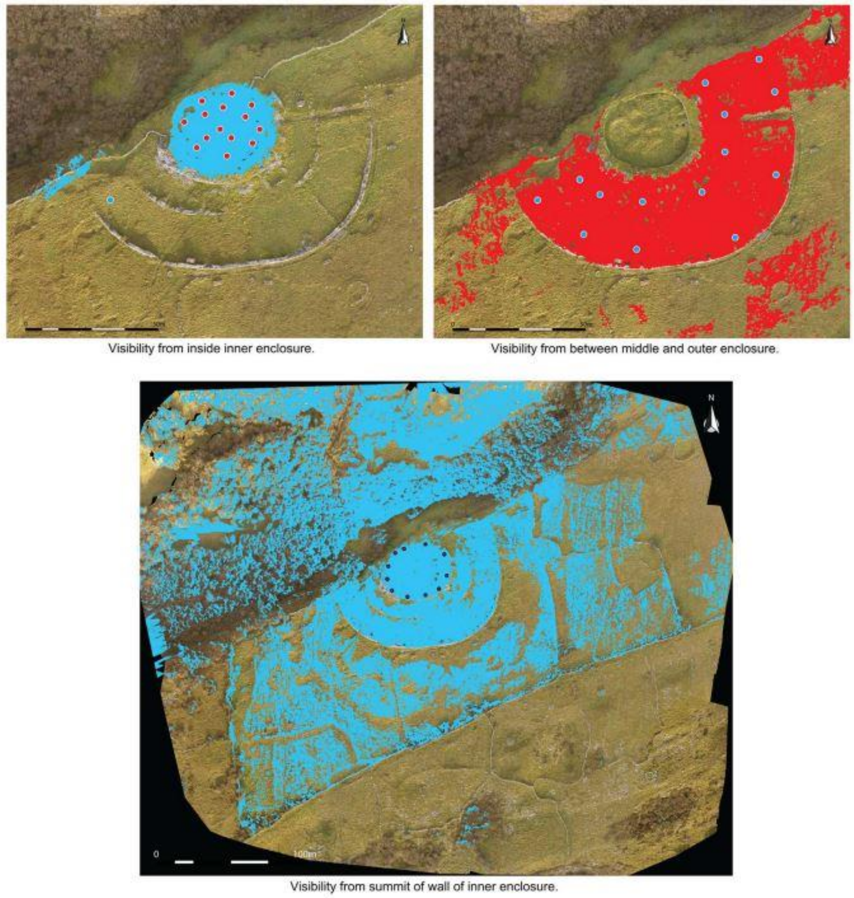


Figure 8: Viewshed Analysis at Cahercommaun (O'Driscoll 2018, Fig. 8).

Visibility analysis was further used to model viewsheds on the landscape scale, which showed good visibility of the eastern and western approaches to the fort and the valley to the north. The results of the visibility analysis suggest that while the outer walls of the fort are defensive in nature, the middle and outer defenses may have served “principally as status symbols that could have had a secondary defensive function” (O'Driscoll 2018).

The data collection methodology and visibility analysis used by O’Driscoll are paralleled in the study of hunting blinds at Little Lake. The generated viewsheds in the case study are used for an interpretive discussion of the sites’ function, and the study at Little Lake takes a similar investigative approach to explore a different subject area. The same UAV, the DJI Mavic Pro, is also employed in this thesis analysis, and a similar photogrammetric software utilized.

Importantly, the study area at Cahercommaun and Little Lake have very little in the way of vegetation, making photogrammetric derived DSMs appropriate for use in visibility analysis at these locations.

2.7.2. Visibility Analysis of Prehistoric Hunting Blinds

The methodology employed in this thesis analysis builds upon visibility studies discussed below, of which there have been just a couple studies applied specifically to prehistoric hunting complexes.

A study of prehistoric megalithic monuments in England sought to understand patterns of hiding and exposure within an archaeological landscape (Gillings 2015). The study developed a methodology rooted in understanding locational properties of landscape invisibility and concealment in order to test whether stone monuments in the study area may have functioned as hunting blinds. Using a python script developed by the author combined with map algebra functions, the study found that the locations of the monuments did not appear to be deliberately hidden nor located within areas with good viewsheds combined with high levels of concealment (Figure 9).

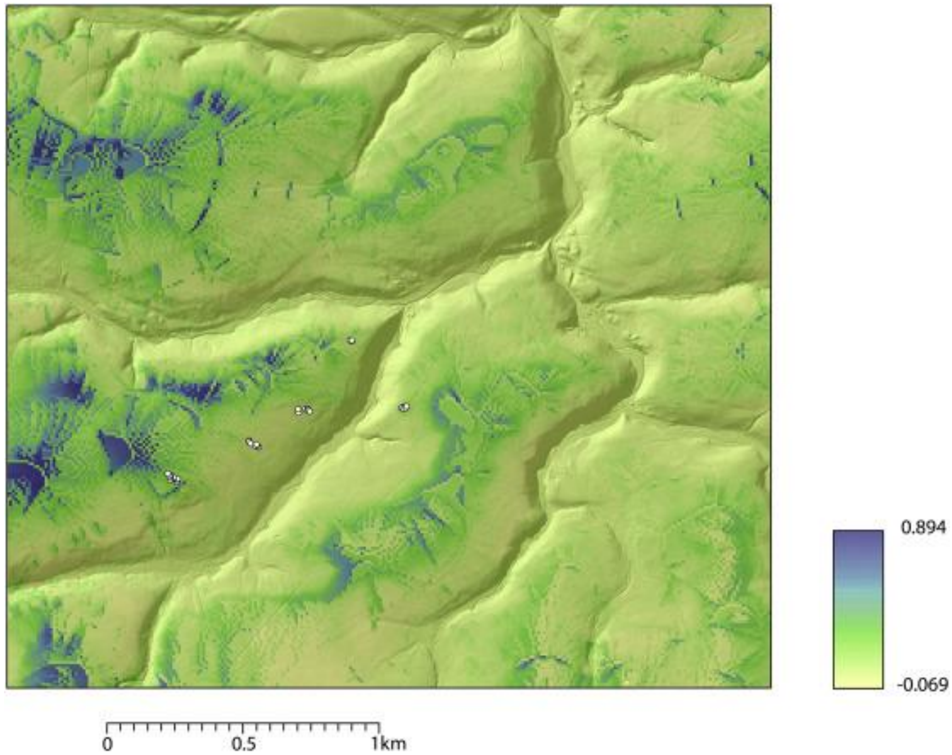


Figure 9: Views-to/views-from analysis (Gillings 2015, Figure 7).

The methodology developed by Gillings (2015) is applicable to studying hunting blinds elsewhere. The study of hunting blinds at Little Lake adopted viewshed parameters from this study including the macro-viewshed distance of 3440 meters and an observer height of 1.65 meters. It was determined however, that generating cumulative viewshed products as described in the Gillings study was out of the scope of this thesis analysis after encountering numerous issues when attempting to run the python script (RCVA emulator adapted from the GRASS GIS Plug-in developed by Mark Lake) for the views-to/views-from analysis at Little Lake. Although the feature locations in the study by Gillings did not meet the expectations of ambush locations (good viewsheds combined with high levels of concealment), the study found these locations to be located on the tops of hills, which interestingly defines a few of the feature locations at Little Lake.

Visibility studies of hunting blinds in southern Patagonia model collective hunting strategies of the Guanaco (Franco et al. 2021; Magnin et al. 2015). Using a DEM, traditional viewshed analyses are undertaken to evaluate spatial relationships between hunting blinds and to calculate landscape viewsheds. Combined with artifactual evidence, this study conducts LOS, viewshed, and least cost paths analysis in order to interpret the possible hunting strategies employed (Magnin et al. 2015). The study found that hunting blinds were, "located in places higher than the surroundings, with and without direct visibility of the nearby shallow lakes" (Franco et al. 2021). A collective, planned hunting strategy is further supported by viewshed analysis. Results from studies in Patagonia suggest that three different hunting strategies were employed including, "the use of a rock structure to monitor sectors with a high natural accessibility; the use of more than one structure to monitor sectors of high natural accessibility, as part of possible group hunting strategies; and the hunting in open spaces or the use of special topographies" (Franco et al. 2021, p. 317).

Interpretations from the viewshed and LOS calculations at Little Lake are drawn in a similar manner to the Patagonia study, which found that hunting blinds would have functioned in different ways depending on their location and visual properties. The analysis in this thesis uses viewshed and LOS tools to explore the visual properties of the feature complex at Little Lake. Past hunting strategies are explored with regard to intervisibility of features and viewsheds; however, least cost path analysis does not seem particularly useful to modeling movements for bighorn sheep, as these animals will choose difficult routes as part of their flight response from predators. As such, the analysis at Little Lake combines viewshed analysis with escape terrain modeling.

Chapter 3 Methods

The goal of this project was to use remote sensing and GIS analysis to reconstruct prehistoric hunting activity within the study area, namely the relationship between prehistoric hunting blinds and bighorn sheep. This mixed method analysis was aimed at interpreting the archaeological record at Little Lake through modeling bighorn sheep escape terrain and conducting a visibility analysis. The methodology developed in this study could be relevant to researchers studying prehistoric hunting activity elsewhere.

First, this section outlines the data acquisition and processing. The methodology is broken down into two analyses in ArcGIS Pro, each employing an elevation model (a 10-meter DEM and high-resolution DSM) and a vector point layer collected during field sessions within the study area. The first analysis modeled escape terrain for desert bighorn sheep using both slope and VRM toolsets, with values extracted using the raster calculator. Next, a series of visibility analyses were carried out, applying the Geodesic Viewshed and Linear Line of Sight geoprocessing functions in ArcGIS Pro.

3.1. Data Acquisition and Processing

This section describes the datasets utilized in the following analysis which includes a Vector Point Layer and 1/3 Arc Second (10-meter) DEM. This section also details the data acquisition and processing of a UAV-derived 3D model for use in terrain modeling and 3D visibility analysis. Two types of elevation models were utilized in this study, a DEM and DSM. A DEM is a raster grid representing the bare-earth elevation/surface referenced to a vertical datum. A DSM is similar to a DEM but captures both natural and built environment features such as trees and buildings.

3.1.1. Feature Locations

The vector dataset implemented in this study is a point layer collected by the author during field sessions between 2019 and 2021. This data was collected with an EOS Arrow 100 Global Navigation Satellite System (GNSS) receiver with the ESRI ArcGIS Collector app on an iPhone 10. Horizontal accuracy was less than 0.5 meters and vertical accuracy was less than 1 meter. This point layer consists of eight points, four of which were collected at the Feature locations (Features 1, 2, 3 and 5). Feature 4 could be not accessed during field visits due to the steep rocky terrain. Therefore, the point was digitized from the 1991 site record, and the UTM coordinates provided are consistent with its mapped location on the site sketch map (Jobson 1991). However, since sub-meter data was not collected at Feature 4, there are limitations to the results related to this feature, particularly the visibility analysis which is sensitive to subtle changes in location. Feature 4 is therefore excluded from the micro-viewshed analysis. The remaining three points were taken at the location of the three ground control points (GCPs) during the 2019 collection of the UAV imagery in order to georeference the 3D model for increased accuracy (See *3.1.3 UAV-derived 3D Model, Figure 12*).

3.1.2. 1/3 Arc-Second DEM

This study utilized a 1/3 Arc-Second DEM acquired from the 3D Elevation Program (3DEP) website (USGS 2019). This DEM is composed of one, 1000 x 1000-meter tile from the National Elevation Dataset (NED) which provides elevation data for The National Map. The spatial resolution is 1/3 arc-second, or approximately 10 meters. Each cell encodes an elevation value in meters, with 1 pixel representing an approximately 10 x 10-meter area. This dataset is derived from diverse source data processed to decimal degrees (North American Datum of 1983 (NAD 83)) and units of vertical measure (North American Vertical Datum of 1988 (NAVD 88)).

The 3DEP is in the process of replacing DEMs derived from topographic maps with light detection and ranging (LiDAR) datasets.

3.1.3. UAV-derived 3D Model

The final dataset utilized in this study was acquired by the author utilizing a UAV, or drone, in order to render a high-resolution 3D model of the study area for use in the following analysis. This dataset was processed into a DSM in order to perform fine grained terrain modeling and visibility analysis (micro-visibility). Unlike the 10m DEM which was collected via LiDAR, this data acquisition utilizes principles of aerial photogrammetry. These data were collected using a DJI Mavic Pro with Pix4D mapper software. The complete flight plan data is shown in Table 2 below.

Table 2: Pix4D UAV Flight Plan

Drone Type	Mavic Pro
Date, Time	November 10, 2019, 9.26 AM
Flight Type	Double Grid
Flight Time	31 Minutes 17 Seconds
Dimensions	366ft x 1855ft
Overlap	80% - 70%
Camera Angle	70 degrees
Look Grid Center	No
Altitude	200ft
Path	2144ft

The flight resulted in 537 overlapping photos collected over a 52-acre area within the study area. Three GCPs collected with the EOS Arrow 100 GNSS receiver as outlined previously were utilized to geolocate the 3D model. The model was processed in Pix4D mapper software and yielded a 3D model with a ground sampling distance (GSD) of 3.86 cm per cell/pixel (See Appendix A for data Quality Report). The Pix4D mapper software automatically recognized the geographic coordinate system as WGS 84 (EGM 96 Geoid), and the Projected Output Coordinate System of WGS 84 / UTM zone 11N (EGM 96 Geoid) was selected. The automatic tie points from processing Step 1 allow for point densification to produce a densified point cloud and finally the 3D textured mesh (Figure 10 and Figure 11).

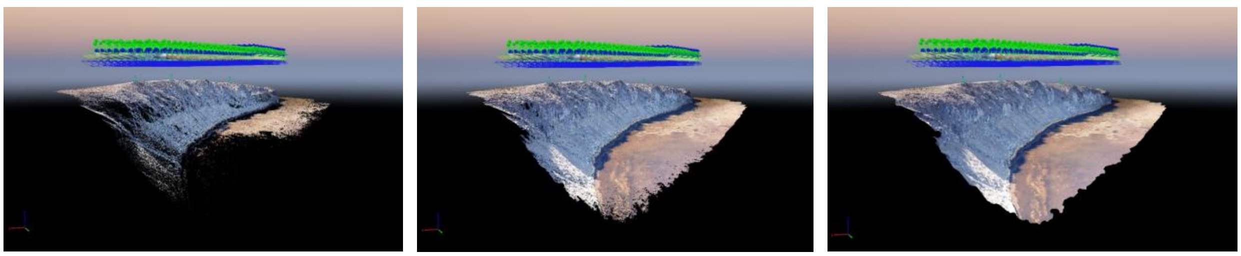


Figure 10: Point Cloud, Densified Point Cloud, and 3D Textured Mesh (left to right)

Figure 11: 3D Textured Mesh of Study Area, Detail.

Finally, processing Step 3 enabled the creation of a DSM (Figure 12), which was generated using an Inverse Distance Weighting (IDW) interpolation method. This DSM was imported into ArcGIS Pro for the fine-grained terrain modeling and micro-viewshed analysis. The 3D textured mesh was also exported as an SLPK (Esri Scene Layer Package) in order to import it into an ArcGIS 3D Scene for use in Exploratory 3D Analysis (See 4.3.1. Exploratory Visibility Analysis)

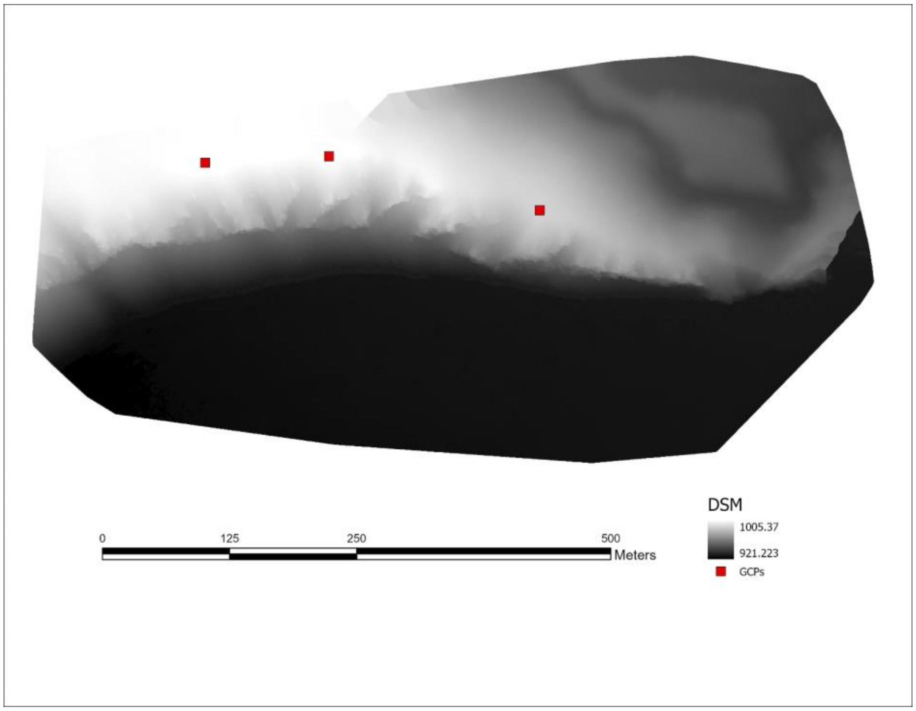


Figure 12: UAV-derived DSM of Study Area.

This high-resolution model provides the basis for an analysis that otherwise would not be possible with the coarse grained 10m DEM. The shortcomings of this acquisition (discussed further in Conclusions chapter) include the number, distribution, and size of GCPs used, in addition to the particular camera sensor employed, both of which introduce potential sources of error into the model. This 3D model was collected prior to fieldwork being completed at the site and as a result, Feature 5 was not included within the extent of the model. Therefore, Feature 5 is excluded from the fine-grained escape terrain modeling and the micro-visibility analysis.

3.2. Data Analysis

3.2.1. Bighorn Sheep Terrain Modeling

The first analysis explored bighorn sheep escape terrain using the Vector Ruggedness Measure (VRM) and Slope toolsets along with map algebra functions utilizing the raster calculator. This analysis modeled areas within the study area which meet the criteria for bighorn sheep escape terrain in order to visualize and measure the proximity of escape terrain to the location of hunting blind features. The 10-meter DEM was employed in ArcGIS Pro to model the habitat suitability of bighorn sheep using slope and VRM toolsets. To run this analysis, the 1000 x1000 meter DEM was clipped to the study area boundary using the 'Clip Raster' tool in ArcGIS Pro.

The VRM analysis employed a geoprocessing workflow developed by Dr. Barry Nickel at University of California Santa Cruz (ESRI 2020). Located in the Arc Hydro extension in ArcGIS Pro, the VRM analysis "measures terrain ruggedness as the variation in three-dimensional orientation of grid cells within a neighborhood…" (ESRI 2020), in which slope and aspect are both considered. The resulting VRM is a raster surface in which values range between 0 (flat) and 1 (most rugged), with rugged landscape generally greater than 0.02. The raster calculator is then used to extract values greater than .02.

Next, both the 10m DEM and high-resolution DSM were analyzed using the Slope tool, with the output measurement unit set at Percent Rise, and slopes greater than 60% were extracted using the raster calculator to represent bighorn sheep escape terrain. These results augment the results of the VRM analysis.

3.2.2. Visibility Analysis

Visibility analysis was employed in this study to model viewsheds and intervisibility to consider whether the stone hunting blinds are positioned on the landscape in particular ways that might maximize visibility of specific landforms or blind features. The Geodesic Viewshed tool was run at each of the five viewing locations. The Geodesic viewshed tool calculates a binary raster surface of cells visible/not-visible to a set of observer features. Observer Parameters were set to an Observer Offset of 1.65 meters which represents the theoretical height of an individual standing within each of the features. In order to understand feature visibility on the landscape scale (macro-visibility), the Outer Radius was set to 3440 meters, with default settings for horizontal start/end angles (0 and 360 degrees) as well as vertical upper/lower angles (90 and -90 degrees). 3440 meters was chosen as the viewing range for the macro-visibility, which represents the recognition acuity of a 1-meter-wide object under normal 20/20 vision (Gillings 2015; Ogburn 2006). Combining the macro-viewsheds also yields useful results. Next, the Linear Line-of-Sight function in ArcGIS Pro was employed to measure intervisibility between features relative to the surface DEM. Observer height was again set to 1.65 meters. Results of this analysis show which features are visible from one another across the landscape.

For the fine-grained visibility analysis on the local scale (micro-visibility), the Geodesic Viewshed tool was also employed to model micro-visibility of Features 1 – 3, with the same parameters chosen as outlined above with the exception of the Outer Radius. For this analysis, six Outer Radius distances were chosen to represent the distances at which hunting weaponry would have been effective. This includes an Outer Radius of 54-, 44-, 34-, 24-, 14-, and 4-meter distance intervals, with 54-meters indicating the maximum range and each descending interval correlating to increased target probability. The Outer Radius of 54-meters, and 44-meters for

Features 1 and 2 have portions that overlap with Little Lake, and these areas were clipped to dry land only.

The final part of the analysis explored the data further by analyzing the overlap between the micro-viewshed calculations and escape terrain as measured by slope. The Weighted Overlay geoprocessing tool was used for this, and both the DSM generated slope raster and 54-meter viewsheds were imported to the Weighted overlay table. This table was structured such that visible cells within 54 meters of features were weighted at 50%, and cell values greater than 60% slope were also weighted at 50%. This tool created a raster dataset which shows areas within the 54-meter viewsheds that overlap with slopes greater than 60%. In order to calculate the percent of overlap between visibility and slope-based escape terrain at feature locations (F1-F3), the number of cells greater than 60% slope within 54-meters was divided by the total number of visible cells within 54-meters. The attributes of this overlap are explored in the Results and Discussion chapter. Finally, the 3D textured mesh of the study area is imported into a 3D scene in ArcGIS Pro and the interactive viewshed tool is employed to further demonstrate the utility and potential value of 3D modeling and new GIS analysis tools.

Chapter 4 Results and Discussion

This section presents the results of the analysis as detailed in Methods and provides an interpretive discussion. First, the results from the escape terrain modeling are presented, which was undertaken in order to visualize bighorn sheep habit characteristics overall and in relation to the location of hunting blind features. Next, the results of the macro-viewsheds and LOS analyses are discussed. The macro-viewshed analysis is used to consider the visual properties of the feature complex on the landscape scale, while the LOS analysis measures intervisibility between features. Finally, the micro-viewshed analysis offers an experimental method of visualizing hunting practices on the local scale and includes exploratory 3D visibility analysis tools in ArcGIS Pro.

4.1. Escape Terrain Modeling

Escape terrain of the desert bighorn sheep was modeled using both VRM and Slope, with significant values extracted using the raster calculator. The VRM was only generated using the 10m DEM, as ArcGIS Pro crashed when attempting to process with the high-resolution DSM. Results from the VRM are displayed in Figure 13, with VRM values symbolized in yellow (low VRM) grading into red (high VRM). VRM values greater than 0.2 (representing rugged terrain) were then extracted (Figure 14), revealing that all of the feature locations (F1-F5) are located within or less than 13 meters from VRM-measured escape terrain. These values, as indicated in the Background and Related Work section, correspond to suitable escape terrain of desert bighorn sheep.

Figure 13: Vector Ruggedness Measure

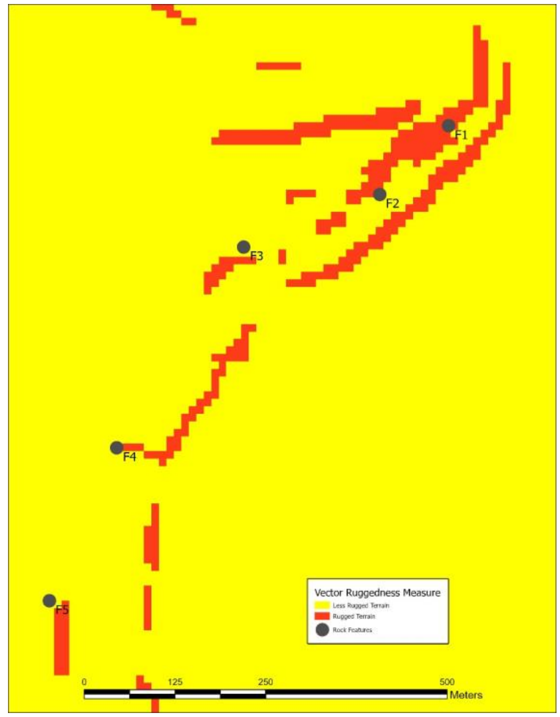


Figure 14: VRM Values > 0.2

Next, the 10-meter DEM is analyzed for slope, with values greater than or equal to 60% extracted using the raster calculator (Figure 15). Again, this measure further indicates a relationship between all five feature locations and escape terrain for desert bighorn sheep.

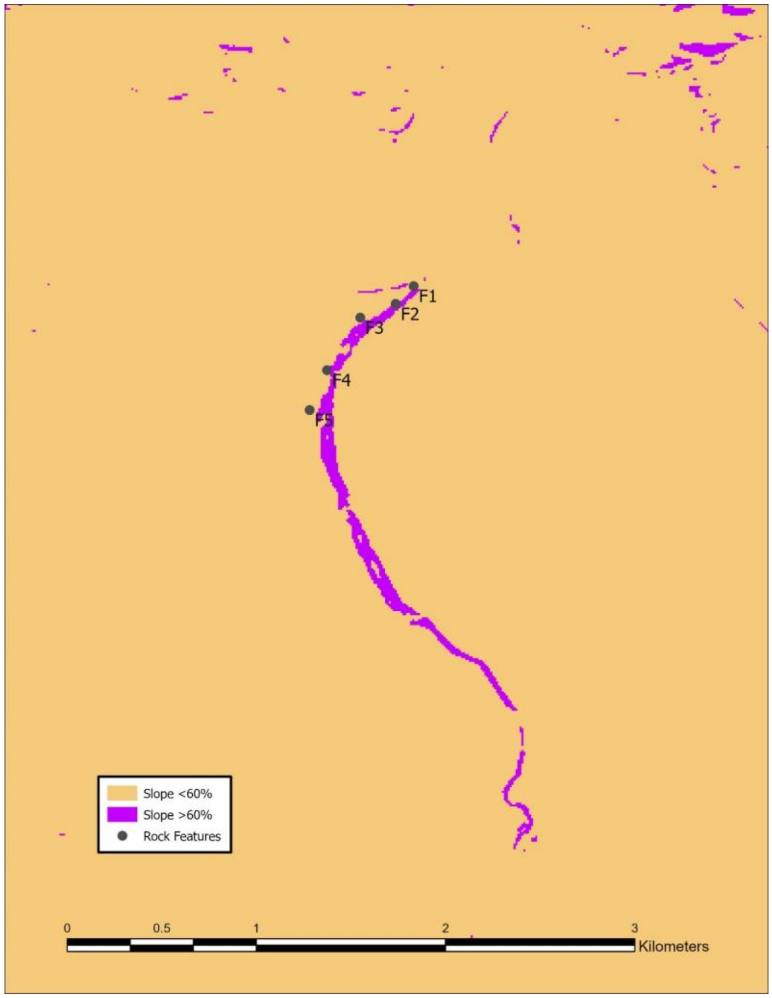


Figure 15: Slope Values > 60%

The proximity between feature locations and escape terrain as measured by slope is clearly visualized within the high-resolution DSM (Figure 16). Only Features 1-4 were included here, as the extent of the DSM only encompasses these four feature locations. This figure shows that F1 and F3 occur on the periphery of slopes greater than 60%, while F2 and F4 occur within slopes greater than 60%.

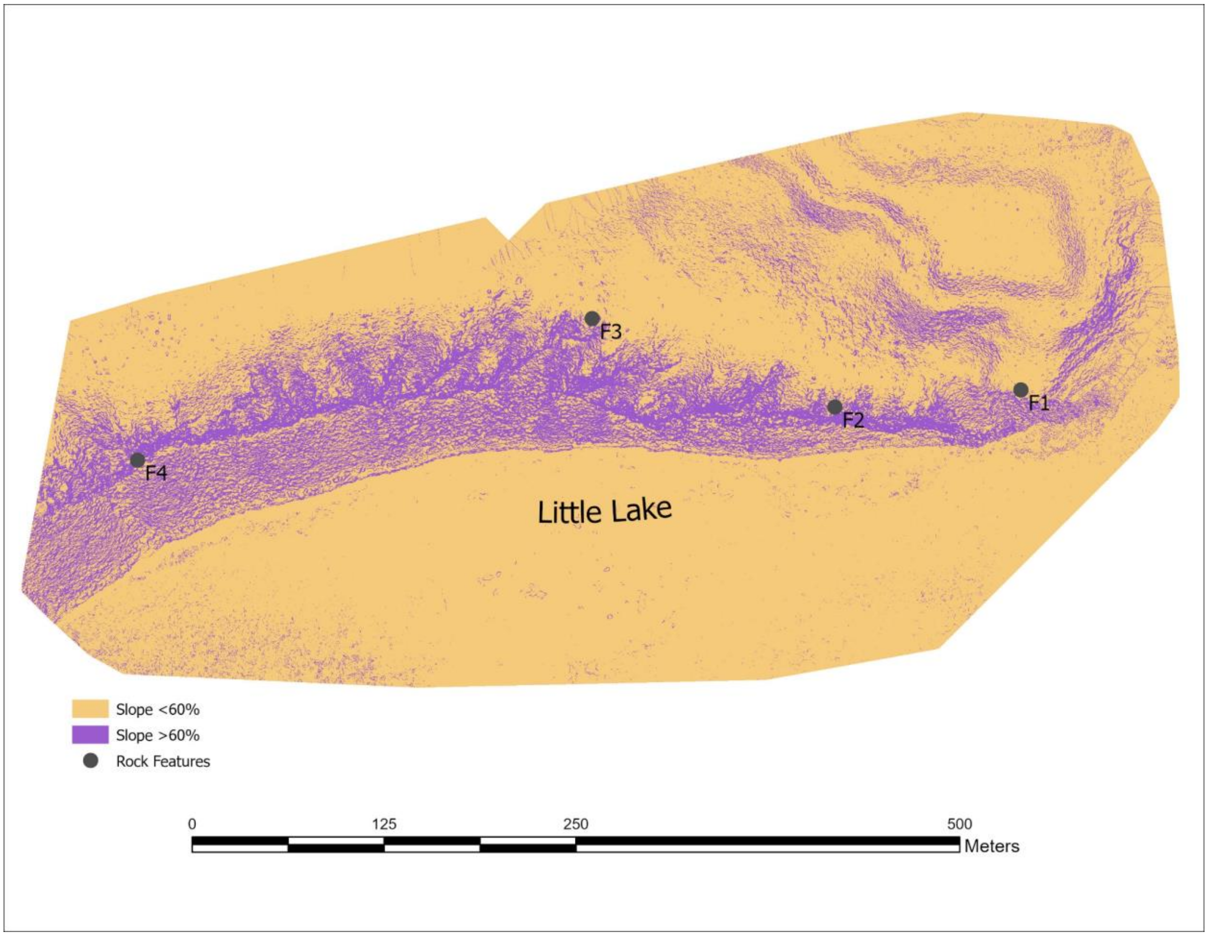


Figure 16: DSM Slope Raster

This Slope raster demonstrates that Features 1-4 are located within and along the upper margin of bighorn sheep escape terrain. The VRM and Slope modeling combined provide two different means of demonstrating the proximity of feature locations to suitable escape terrain within the study area.

Results from this analysis helps support the premise that the hunting blinds are situated on the landscape such that animals watering at the lake would likely be driven upslope and within proximity to the feature locations. This scenario is further supported ethnographically on the regional scale, with several researchers observing that when frightened, bighorn sheep will run uphill to the highest prominence on the landscape. Both Feature 3 and Feature 5 occur at the highest point on the landscape above Little Lake, and it seems likely that these features specifically would have operated as the main hunting blinds at the site complex. Feature 3 in particular seems to have been utilized extensively as evidenced by a dense lithic scatter within the feature.

4.2. Macro-viewsheds and Line of Sight

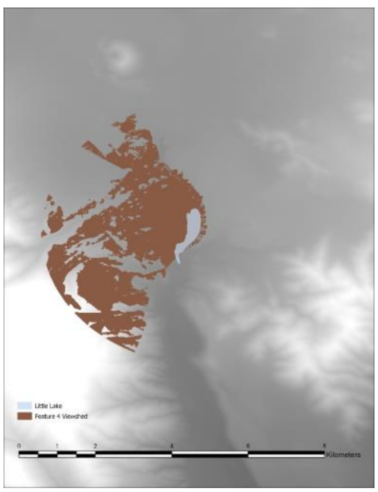
This section presents the results of the macro-viewshed and LOS analysis. This landscape scale analysis models individual viewsheds from a hypothetical observer situated within each of the features, and calculates sight lines between features. Both viewshed and LOS (intervisibility) between hunting blinds has implications regarding the function of these features and related hunting strategies. The aim of this analysis is to model which specific landforms are visible from feature locations as well as the degree of intervisibility, in order to further understand feature placement with implications as to whether they may have been operated individually or in a collective manner.

The macro-viewsheds from the five feature locations at 3440 meters show largely overlapping viewsheds predominantly to the west, southwest, and southeast (Figure 17a-f). These macro-viewsheds represent the visible areas on the landscape in which a hunter could monitor the landscape for game animals. All features have partial visibility of Little Lake and the Rose Valley and could have monitored the movements of game animals as they approached the lake from numerous directions.

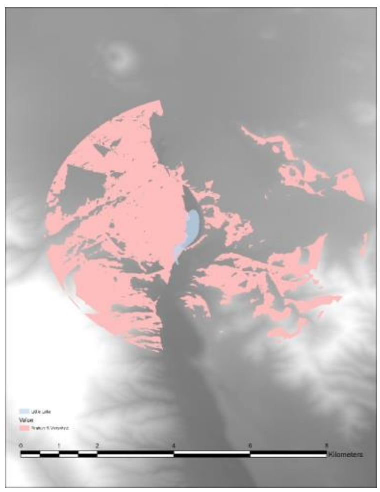
a. Feature 1 Viewshed

b. Feature 2 Viewshed

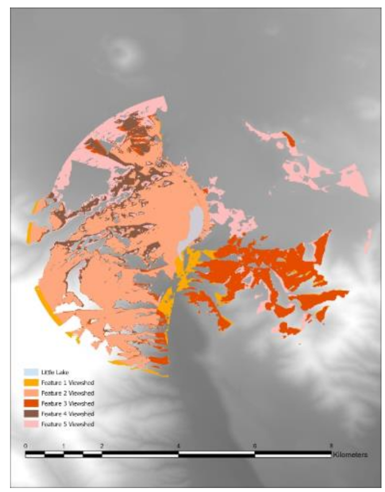
c. Feature 3 Viewshed



d. Feature 4 Viewshed



e. Feature 5 Viewshed



f. Feature 1-5 Viewsheds

Figure 17: Feature 1-5 Macro-viewsheds at 3440 meters.

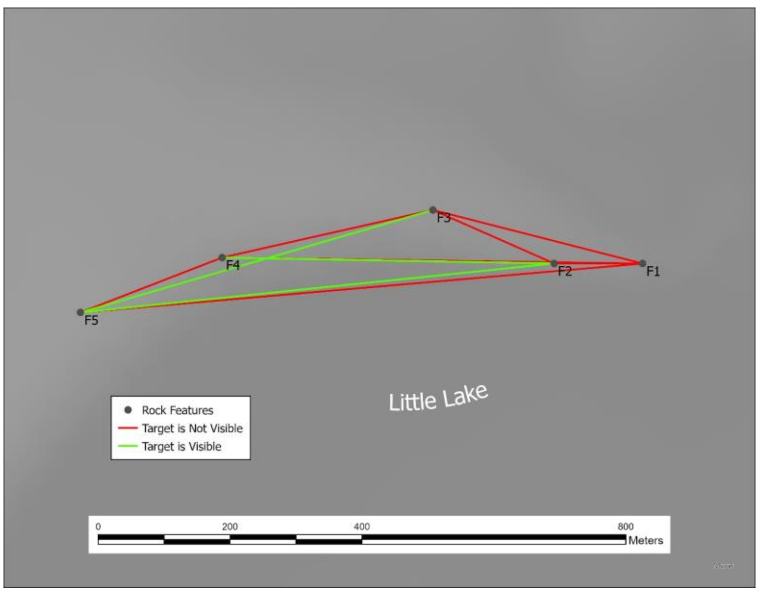
These viewsheds indicate that Feature 1, 3, and 5 afford more commanding views of the landscape including the eastern skirt of the Sierra Nevada to the west and southwest, in addition to the foothills the Coso Range to the southeast. These features are located on the tops of the basalt ridgeline. Features 2 and 4 by contrast, have more restrictive views only to the west and overlooking the lake, as they occur along the western sloping cliffside along the basalt flow.

The combined macro-viewsheds from Features 1-5 show the visual patterning of the surrounding landscape if all of the blinds were occupied at the same time (Figure 17f). This shows a solid zone of visibility west of the features, while much of the landscape to the northeast and south of the features contains zones that are not visible to a viewer within any one of the features. This viewshed modeling may suggest that animals would be moving from west to east to be intercepted by hunters in the blinds. This is due to the limited visibility of the landscape immediately to the east when compared to the west.

One expectation of feature visibility is that individuals within the hunting blinds can see animals watering and then approaching the features. The macro-viewshed analysis indicates however that that the majority of the blinds do not have direct visibility of the east edge of the lake, which would be the most probably watering location with immediate access to escape terrain. Feature 1 has partial visibility of watering locations. Feature 2 and 4 have direct visibility of watering locations. Feature 3 and 5 have no direct visibility of watering locations. A few implications arise out of this observation. One is that although hunters would not have direct visibility of animals watering from within the blinds, the animals would also not have visibility of hunters waiting to ambush. Another implication is the suggestion of a collective hunting strategy. In this scenario, hunters waiting in blinds would not need direct visibility of the animals watering. Other individuals near the lake could startle the watering animals up the escape terrain past hunters in the blinds at which point they would be targeted. This scenario is supported in the ethnographic literature as discussed previously.

One consideration of this discussion is the observation that the water level of Little Lake fluctuated over time, and the current level does not represent its precise extent throughout prehistory. This is indicated by the presence of rock art panels which occur at the edge of the lake, which extend under the current water line (Gerstner and Garfinkel 2018).

Next, this analysis models LOS, or intervisibility between features. Feature 1 is not visible from any of the other features. Sight lines exist between F2 – F5 (Figure 18). This suggests that there may have been some interaction between blinds, further supporting a communal hunting practice. However, this would assume the features were all constructed and in use contemporaneously, and it is certainly possible that the features also functioned independently of one another during different periods of prehistory.



Features	Visibility
Feature 1	n/a
Feature 2	F4, F5
Feature 3	F5
Feature 4	F2
Feature 5	F3, F2

Figure 18 : Feature 1-5 Intervisibility and LOS Calculations

4.3. Micro-viewsheds

The final analysis presented in this study is the calculation of micro-viewsheds. This analysis utilizes the UAV-derived DSM and considers Features 1-3. The micro-viewsheds for F1-F3 shows buffered viewshed distances at 4, 14, 24, 34, 44, and 54-meters, the latter representing the maximum target range at which the bow and arrow would be effective (Figure

19). This application of visibility analysis presents a unique way to visualize the zones in which it would be possible for a hunter to target animals as they move within proximity of the blind locations.

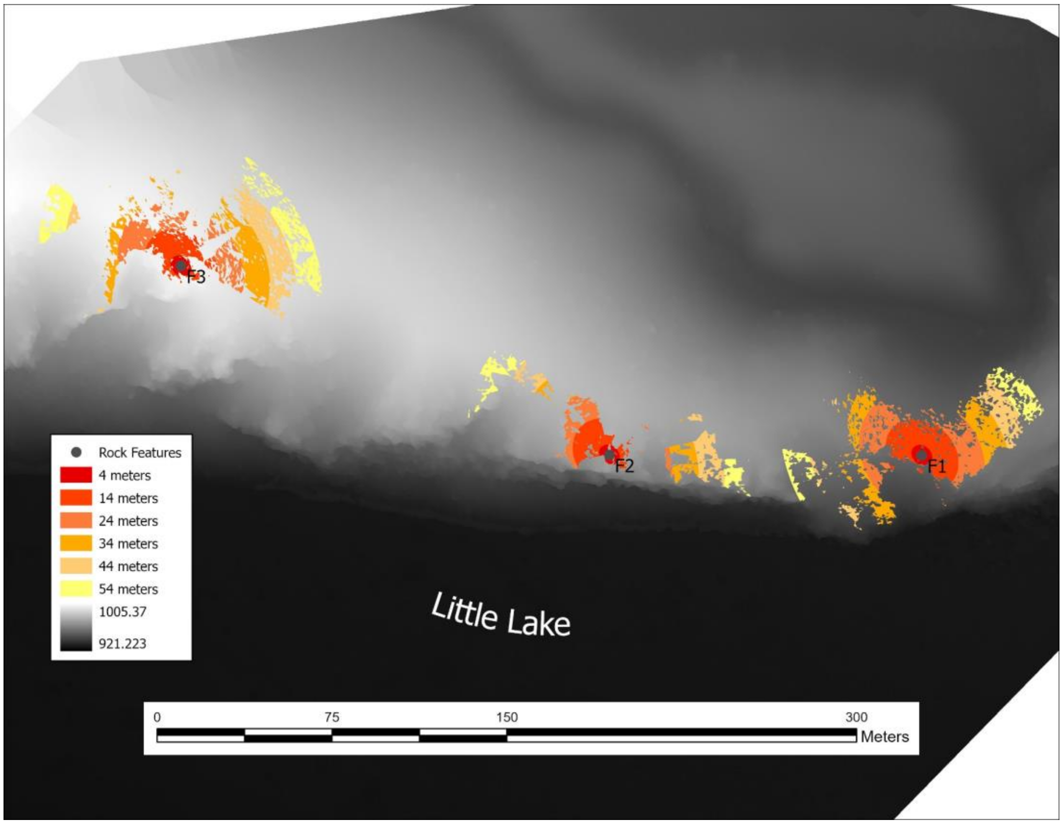


Figure 19: Micro-viewshed of Feature 1-3 (54 meters)

Another consideration of this analysis is the overlap between micro-viewshed and escape terrain. One expectation is that if bighorn sheep are being targeted while they are utilizing escape terrain, then there should be a significant overlap between viewshed and measures of escape terrain. Using the Weighted Overlay function in ArcGIS Pro, the overlap between slope-based escape terrain and the micro-viewshed at 54 meters were modeled for F1-F3 (Figure 20), resulting in 20.8% overlap of the two parameters between all three features combined.

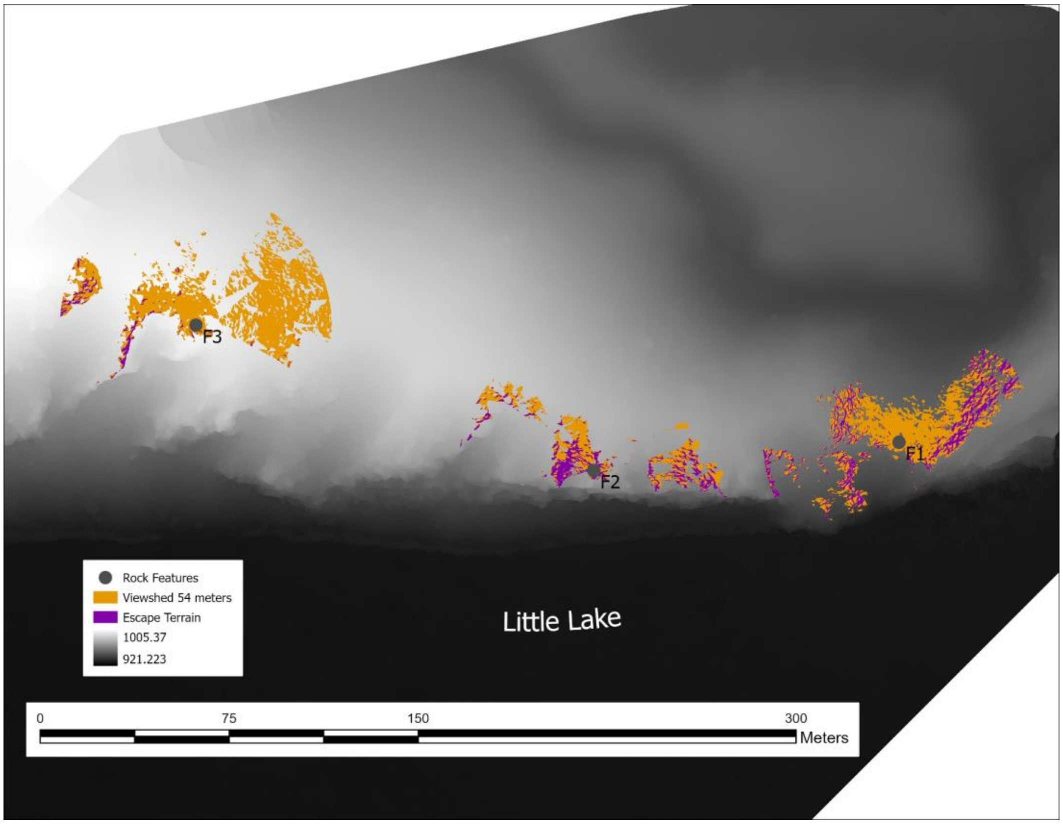


Figure 20: Micro-viewsheds at F1-F3 and Escape Terrain

There is also a high degree of variability of escape terrain and visibility overlap between features. Feature 1 contains 29.8% overlap, Feature 2 contains 37.3% overlap, and Feature 3 contains just 5.3% overlap. This was an unexpected result, but also leads to further insights about how the features may have functioned. It is possible that the differences in percent overlap between escape terrain and visibility at 54 meters relates to different strategies employed between blinds. For example, the low degree of overlap measured at Feature 3 might suggest that this blind functioned as a monitoring location rather than a close-encounter ambush site, whereas the higher percentage of overlap and Features 1 and 2 could support these locations being primarily ambush locations. The overall low degree of overlap between visibility and escape terrain could also suggest that the animals are targeted only once they have made it to less steep and rugged terrain within sight of the blinds.

4.3.1. Exploratory 3D Analysis

Finally, this analysis briefly explores a new toolset in ArcGIS Pro using the 3D textured mesh of the study area. The SLPK exported from Pix4D Mapper was imported into a 3D scene in ArcGIS Pro in order to utilize the Exploratory 3D Analysis function. This toolset presents a novel way to interact with the data. Within this toolset the Viewshed tool was utilized with interactive placement and orientation creation methods. A 44-meter viewshed was generated to simulate the visibility of an individual standing within Feature 3 (Figure 21).

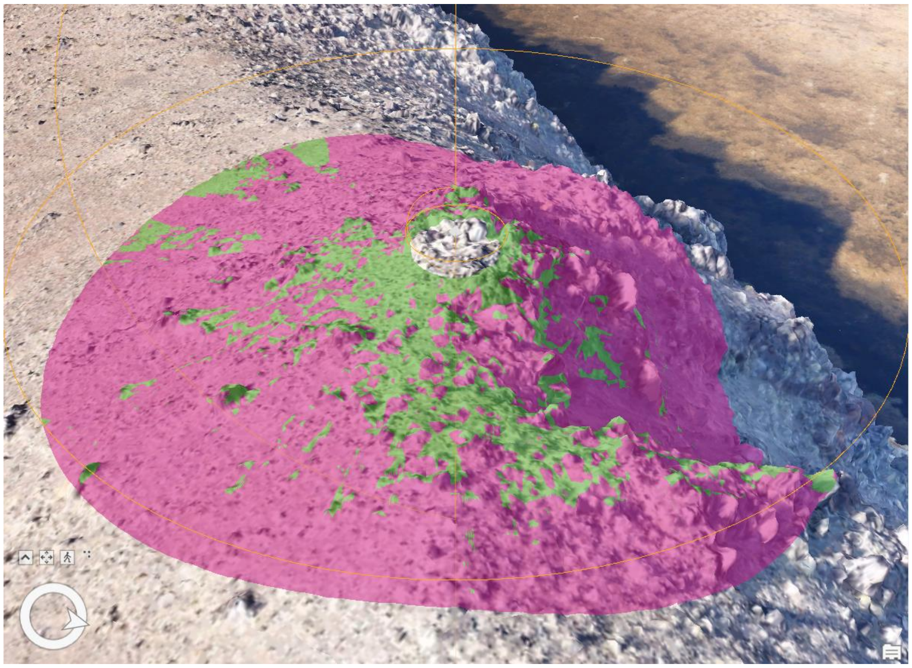


Figure 21: Exploratory 3D analysis, Feature 3 at 44 meters (Visible areas represented in green and non-visible areas represented in pink).

What makes this tool powerful is the ability to pan and zoom into the scene with full range of motion and to set viewshed parameters and instantly generate viewshed results. Unlike the two dimensional (2D) viewshed products generated from a DSM, this 3D visualization tool is interactive and allows for a wide range of data exploration. While this preliminary analysis simply explores the function of this type of 3D analysis as applied to an archaeological study, the full utility of exploratory 3D analysis tools has yet to be realized.

Chapter 5 Conclusion

This thesis project used remote sensing data and GIS analysis in order to study an important archaeological landscape in California's Mojave Desert. Using geoprocessing tools in ArcGIS Pro, the methodology employed both terrain modeling and visibility analysis with map algebra in order to consider the function of stone features within the study area. This project investigated the historic strategic hunting for procurement of desert bighorn sheep as explored through applications of GIS combined with ethnographic and archaeological research.

Locations of the stone features at Little Lake facilitated the hunting of desert bighorn sheep. Habitat modeling established that the five stone features were situated within and along the periphery of bighorn sheep escape terrain as measured by slope and vector ruggedness. The macro-viewshed modeling demonstrated that the feature locations afford viewsheds that were predominantly west and overlooking the lake and the eastern foothills of the Sierra Nevada. Differences in visibility patterning among the features may reflect different hunting strategies being employed. Features 1, 3, and 5 afford more commanding views of the landscape and may have been spotter locations for monitoring animal movement, while blinds with more restrictive viewsheds such as Features 2 and 4 potentially functioned as close-encounter ambush locations.

The commanding viewsheds from feature locations atop the basalt ridgeline would have allowed hunters to monitor the movement of animals within portions of the Rose Valley and foothills of the Sierra Nevada and Coso Range. Limited visibility of the watering locations along the east edge of the lake would necessitate the use of a communal hunting practice involving multiple individuals or parties. Sight lines between some of the features may also indicate the use of multiple blinds simultaneously.

The micro-viewsheds presents a unique way to visualize the target zones from the stone feature locations and also indicate a varying degree of overlap with escape terrain, further indicating that different tactics may have been carried out between blinds. The precise strategy may never be fully recognized, but it is clear that applications of terrain modeling and visibility analysis are useful tools to investigate this type of phenomenon.

The hypothesis that hunting blinds at Little Lake functioned to specifically target the desert bighorn sheep is supported by a review of relevant ethnographic and archaeological evidence in tandem with the geospatial analysis performed in this study. Considering all lines of evidence, this study indicates that the strategy for targeting the desert bighorn sheep at Little Lake would involve frightening the animals while they are watering at the lake and naturally channeling them past hunters who are waiting within the stone blinds.

Applications of visibility analysis are used to discern the ways in which prehistoric features may have been utilized in the past. Visibility analysis presents a unique and powerful way to understand how prehistoric people interacted with the landscape. Evidence presented in this research suggests that the stone features at Little Lake would have functioned in similar ways to those at Yaqui Pass in the Colorado Desert (Schneider et al. 2014) and also in the nearby Saline Valley (Brook 1980), where hunting blinds are positioned both to monitor the movements of large game as well as acting as game intercept locations for concealed hunters.

While the results of the micro-viewsheds are experimental, these viewsheds provide a unique visualization of how ambush hunting may have been practiced at feature locations. Lastly, the application of exploratory 3D analysis tools provides a novel way to interact with and visualize the archaeological landscape at Little Lake.

5.1. Other Considerations

5.1.1. Prevailing Winds

The sensitivity of animals such as the bighorn sheep to the scent of predators is often overlooked. Modern day hunters will mask their scent in order to avoid spooking their prey, and this was certainly true in prehistoric times. Regarding the use of hunting blinds, Muir (1894:320-321) states that animals were driven to blind locations with the wind, which means the hunters scent would be carried away from the approaching animals. This factor was also noted by Julian Steward who reported that hunters in California's Owens Valley kept animals "to their lee to keep the human odor from reaching them" (Steward 1938). Other researchers have noted that hunting blinds in Patagonia were also oriented towards prevailing winds (Belardi et al. 2017).

Relevant wind data is available from a weather station at nearby Naval Air Weapons Station China Lake. Based on hourly data between 1992 and 2002 from the China Lake-Armitage Field Station, the annual average prevailing wind direction is south-southwest (WRCC 2022). This would mean that from the feature locations, the scent plume of hunters would be carried off to the north-northeast, which would be away from the approaching prey (assuming a west to east movement of Bighorn sheep which is suggested in this study). This prevailing wind pattern likely influenced the placement of the hunting blinds at Little Lake.

5.1.2. Seasonality

The seasonality of bighorn sheep would have played a major role in what time of year they would have been targeted. In the winter months, the lake would not have been an attraction, as bighorn sheep can get all of their water from their diet (C. Gallinger, personal communication, September 11, 2021). During the birthing season in early spring, ewes with a lamb will avoid water sources due to risk of predators. It seems likely that bighorn sheep hunting at Little Lake would be been most prominent during the summer months when the water source was critical.

5.1.3. Game Trails

The identification of game trails in relation to hunting blinds can be a valuable inference regarding their function (Brook 1980). Attempts to identify remnant large game trails in the study area was not successful, as feral burros in the area appear to have obscured trails on the landscape, as well as the processes of weathering and erosion over the centuries.

5.2. Lessons Learned

This project presented numerous opportunities to learn lessons throughout the data acquisition and analysis process. Regarding the data acquisition for the 3D model, several shortcomings were recognized as a result of this data collection involving GCPs, camera sensor, and spatial extent of the model.

First, the GCP targets were not as large as they should have been and did not have contrasting colors such that the center point was clearly discernable in the imagery. While the GCPs were still visible to allow for geolocation, the exact center was not clearly discernable in two of the GCPs, which introduced a degree of error. Furthermore, the number and spatial distribution of GCPs was not appropriate for a project of this scale. While three GCPs were utilized and somewhat regularly spaced across the study area, there should have been 5-10 GCPs spaced at approximately 500 feet intervals for this approximately 50-acre acquisition (Pix4d 2018). This would have resulted in increased relative horizontal accuracy. GCPs were only placed along the top of the basalt landform, whereas they should have been placed across the study area including the lowest elevations along the lakeshore. This would have resulted in increased vertical accuracy.

Another consideration was the type of UAV and associated camera sensor utilized. This acquisition utilized the DJI Mavic Pro which has a 1/2.3-inch CMOS sensor which employs a linear rolling shutter. This type of sensor is not ideal for 3D modeling as it essentially records an image frame line by line. This is problematic when the camera is in motion, such as during a drone mapping mission, and can lead to distortions of the image which are amplified during the photogrammetric reconstruction process. Pix4D Mapper software does account this this sensor type during the camera model optimization stage of Step 1 processing, which mitigates the degree of error, but still represents a source of potential error. The most appropriate UAV camera sensor for 3D modeling utilizes a global shutter, in which the entire image frame is acquired instantaneously. The final and obvious shortcoming of the 3D data acquisition was the extent of 3D model, which did not include the entire feature complex.

One issue encountered during the data processing stage is that ArcGIS Pro would crash when trying to process the high-resolution DSM during Linear Line of Sight analysis and also when running the VRM tool. This could likely be corrected by utilizing a more powerful processor.

5.3. Future Work

Within this area of steep slopes and high vector ruggedness measures there are certainly portions that would simply be too steep and inaccessible for bighorn sheep. Slopes above a certain percentage could also be excluded from the habitat modeling. Future modeling could also involve generating cost paths from the lakeshore up the basalt flow to investigate whether feature locations occur along or within visual range of these modeled routes. Other studies could also model deer and pronghorn movements on the landscape. Finally, by analyzing a study area containing a larger number of feature locations would allow for the use of spatial statistics to analyze patterns. By integrating new theoretical dimensions of GIS analysis in the study of Little Lake, the landscape placement of hunting blinds can be better understood in terms of function and visibility.

The use of UAVs in archaeological studies is becoming commonplace for both researchers and resource managers. The ability to collect high resolution topographic data quickly and affordably has opened new opportunities for research, digital preservation, and management of cultural resources. The applications of UAV-based photogrammetry combined with GIS analysis are rapidly expanding, and this study presents just one way in which modeling of a prehistoric landscape can assist in reconstructing past lifeways.

References

Allen, Mark W. 2011. “Of Earth and Stone: Landscape Archaeology in the Mojave Desert.” *California Archaeology* 3(1):11-30.

Altschul, Jeffery H. and Joseph A. Ezzo. "The expression of ceremonial space along the Lower Colorado River." *Recent research along the Lower Colorado River* (1994): 51-68.

Bettinger, Robert L. 1982. "Aboriginal exchange and territoriality in Owens Valley, California." In *Contexts for prehistoric exchange*, pp. 103-127. Academic Press, 1982.

Bettinger, Robert L. and R. Ervin Taylor. 1974. “Suggested Revisions in Archaeological Sequences of the Great Basin and Interior Southern California.” *Nevada Archaeological Survey Research Papers* 5:1–26.

Blair, Lynda M. and Megan Fuller-Marillo. 1997. “Rock Circles of Southern Nevada and Adjacent Portions of the Mojave Desert.” Report submitted to the Nevada Dept. of Transportation. Cultural Resource Section, Environmental Services Division, Nevada Department of Transportation.

Brook, Richard A. 1980. “Inferences Regarding Aboriginal Hunting Behavior in the Saline Valley, Inyo County, California.” *Journal of California and Great Basin Anthropology* 2(1):60–79.

Broughton, Jack M., David Byers, Reid Bryson, William Eckerle, and David B. Madsen. 2008 “Did Climatic Seasonality Control Late Quaternary Artiodactyl Densities in Western North America?” *Quaternary Science Reviews* 37:1916-1937.

Buechner, Helmut K. 1960. "The bighorn sheep in the United States, its past, present, and future." *Wildlife monographs 4*: 3-174.

Canaday, Timothy W. 1997. *Prehistoric alpine hunting patterns in the Great Basin.* University of Washington.

Clewlow, C. William, Jr., Helen Wells, and David S. Whitley. 1980. Cultural Resources Technical Report on the Coso Geothermal Study Area. Manuscript on file at the Bureau of Land Management, Bakersfield.

Dunn, William C. 1996. “Evaluating Bighorn Habitat: A Landscape Approach”. *Technical Note 395*. Department of Game and Fish, State of New Mexico. September 1996. U.S. Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Information and Communications Group.

Driver, Harold E. 1937. “Culture Element Distributions: VI, Southern Sierra Nevada.” *University of California Anthropological Records* 1(2):53–154. Berkeley.

Esri. 2020. “Terrain Ruggedness Index (TRI) and Vector Ruggedness Measurement (VRM) - Two new Arc Hydro functions that quantify ruggedness on a DEM.” Esri Community. https://community.esri.com/t5/water-resources-blog/terrain-ruggedness-index-tri-and-vector-ruggedness/ba-p/884340.

Eve, Stuart J. and Enrico R. Crema. "A house with a view? Multi-model inference, visibility fields, and point process analysis of a Bronze Age settlement on Leskernick Hill (Cornwall, UK)." *Journal of Archaeological Science* 43 (2014): 267-277.

Franco, Nora V., Lucas Vetrisano, Brenda L. Gilio, Natalia A. Cirigliano, and Pablo E. Bianchi. 2021. "Hunting Blinds in the Southern End of the Deseado Massif: Collective Hunting Strategies During the Late Holocene." In *Ancient Hunting Strategies in Southern South America*, pp. 313-341.

Lubinski, Patrick M. 2000. "Of Bison and Lesser Mammals: Prehistoric Hunting Patterns in the Wyoming Basin." *Intermountain Archaeology*: 176-188.

Garfinkel, Alan P. 1976. *A Cultural Resource Management Plan for the Fossil Falls/Little Lake Locality*. Bakersfield District Office, Bureau of Land Management. Bakersfield, California.

--- 2007. “Archaeology and Rock Art of the Eastern Sierra and Great Basin Frontier.” *Maturango Museum Publication* 22. Maturango Museum, Ridgecrest, California.

---. 2006. “Paradigm Shifts, Rock Art Theory, and the Coso Sheep Cult of Eastern California.” *North American Archaeologist* 27: 203–244.

Garfinkel, Alan P. 2009. “Myth, Ritual, and Rock Art: Coso Decorated Animal-Humans and the Animal Master.” *Rock Art Research* 26(2):179-197.

Garfinkel, Alan P. and Donald R. Austin. 2011. “Reproductive Symbolism in Great Basin Rock Art: Bighorn Sheep Hunting, Fertility, and Forager Ideology.” *Cambridge Archaeological Journal* 21(3):453-471.

Garfinkel, Alan P. and J. Kenneth Pringle. 2015. “Dating the Rock Drawings of the Coso Range: Revisiting the Projectile Point Petroglyphs of the Cosos: Chronology and Function.” *California Rock Art Foundation Newsletter*, Winter Edition.

Garfinkel, Alan P., Donald Austin, Adella Schroth, Paul Goldsmith, and Ernest H. Siva. 2016. "Ritual, Ceremony and Symbolism of Archaic Bighorn Hunters of the Eastern Mojave Desert: Newberry Cave, California." *Rock Art Research: The Journal of the Australian Rock Art Research Association (AURA)* 33, no. 2:193-208.

Garfinkel, Alan P., David A. Young, and Robert M. Yohe II. 2010. "Bighorn Hunting, Resource Depression, And Rock Art In The Coso Range, Eastern California: A Computer Simulation Model." *Journal of Archaeological Science* 37, 1: 42-51.

Gerstner, Ryan. 2018, “3D Visualization and Digital Surface Modeling at the Little Harbor Site: A Prehistoric Shell Midden on Santa Catalina Island.” USC Catalina Island Excursion, SSCI 587 Spatial Data Acquisition. Poster and Presentation. October 22-28, 2018

Gerstner, Ryan and Alan P. Garfinkel. 2018. Little Lake Rock Art Inventory. Update to the Ridgecrest Bureau of Land Management. On file California Rock Art Foundation Archive, Springville, CA.

--- 2019. Little Lake Rock Art Inventory. Update to the Ridgecrest Bureau of Land Management. On file California Rock Art Foundation Archive, Springville, CA.

Gillings, Mark. 2015. “Mapping Invisibility: GIS Approaches to the Analysis of Hiding and Seclusion.” *Journal of Archaeological Science*, 62:1-14.

Gilreath, Amy J. 2000. “Archaeological and osteological report in support of the Native American Graves Protection and Repatriation Act, Naval Air Weapons Station, China Lake.” On file, Naval Air Weapons Station, China Lake, California.

--- 2007. “Rock Art in the Golden State: Pictographs and Petroglyphs, Portable, and Panoramic.” In *California Prehistory: Colonization, Culture, and Complexity*, edited by Terry l. Jones and Kathryn A. Klar, pp. 273-291. Altamira Press, Lanham.

Gilreath, Amy J. and William R. Hildebrandt. 1997. *Prehistoric Use of the Coso Volcanic Field.* Contributions of the University of California Archaeological Research Facility No. 56. University of California, Berkeley.

--- 2008. “Coso Rock Art within its Archaeological Context.” *Journal of California and Great Basin Anthropology* 28(1):1-22.

GISGeography. 2021. “What is Photogrammetry?” Accessed February 20, 2022. https://gisgeography.com/what-is-photogrammetry/

Grosscup, Gordon L. 1977. "Notes on Boundaries and Culture of the Panamint Shoshone and Owens Valley Paiute." *University of California Archaeological Research Facility Contributions 35*: 109-150.

Grant, Campbell, J. W. Baird, and J. K. Pringle. 1968. “Rock Drawings of the Coso Range, Inyo County, California: An Ancient Sheep-hunting Cult Pictured in Desert Rock Carvings.” *Maturango Museum Publication* 4, China Lake, California.

Grant, Campbell. 1980. “The Desert Bighorn and Aboriginal Man. In *The Desert Bighorn: Its Life History ; Ecology, and Management*, Edited by G. Monson and L. Sumner, pp. 7-39. University of Arizona Press, Tucson.

Harrington, M. R. 1948b. “America's Oldest Dwelling. Southwest Museum.” *Masterkey*, 20(5):148-52.

--- 1953. “A Cave near Little Lake.” *Masterkey* 27(3):77-82

--- 1949. "A New Old House at Little Lake. Southwest Museum." *Masterkey*, 23(5):135-136.

--- 1948a. "A New Pinto Site. Southwest Museum." *Masterkey* 22(4):116-118.

--- 1957. "A Pinto Site at Little Lake, California." *Southwest Museum Papers* 17.

--- 1951. "Latest from Little Lake. Southwest Museum." *Masterkey* 25(6):188-191.

--- 1950. "Pinto man at Little Lake." *Desert Magazine* 13(11):22-24.

--- 1952. "The Fossil Falls Site." Southwest Museum," *Masterkey* 26:191-195.

Heizer, Robert F. and M. A. Baumhoff. 1962. *Prehistoric rock art of Nevada and eastern California.* University of California Press, Berkeley.

Heizer, Robert F. and C W. Clewlow, Jr. 1973. *Prehistoric Rock Art of California*. 2 vols..Ballena Press, Ramona, California.

Hildebrandt, William R. and Kelly R. McGuire. 2002. "The ascendance of hunting during the California Middle Archaic: an evolutionary perspective." *American Antiquity* 67(2):231-256.

Hockett, Bryan, Cliff Creger, Beth Smith, Craig Young, James Carter, Eric Dillingham, Rachel Crews, and Evan Pellegrini. 2013. "Large-scale trapping features from the Great Basin, USA: the significance of leadership and communal gatherings in ancient foraging societies." *Quaternary International* 297:64-78.

Hoffman, Walter J. 1878. "Miscellaneous Ethnographic Observations on Indians Inhabiting Nevada, California, and Arizona." *Tenth Annual Report of the United States Geological and Geographical Survey,* pp. 461-478. Government Printing Office, Washington, D.C.

Hunt, Alice. 1960. "Archaeology of the Death Valley Salt Pan, California." *University of Utah Anthropological Papers* No. 47. Salt Lake City.

Hutchings, W. Karl, and Lorenz W. Brüchert. 1997. "Spearthrower performance: ethnographic and experimental research." *Antiquity* 71(274):890-897.

Jobson, Robert. 1991. Archaeological Site Record for CA-INY-7627. On File at Bureau of Land Management, Ridgecrest, California.

Kroeber, Alfred Louis. 1925. *Handbook of the Indians of California.* Vol. 78. US Government Printing Office.

LaBelle, Jason M. and Spencer R. Pelton. "Communal hunting along the Continental Divide of Northern Colorado: Results from the Olson game drive (5BL147), USA." *Quaternary International* 297:45-63.

Lewis-Williams, J. David, Thomas A. Dowson, Paul G. Bahn, H-G. Bandi, Robert G. Bednarik, John Clegg, Mario Consens et al. 1988. "The signs of all times: entoptic phenomena in Upper Palaeolithic art [and comments and reply]." *Current anthropology* 29(2):201-245.

Llobera, Marcos. 2003. "Extending GIS-based visual analysis: the concept of visualscapes." *International Journal of Geographical Information Science* 17(1):25-48.

Lubinski, Patrick M. 1999. "The communal pronghorn hunt: a review of the ethnographic and archaeological evidence." *Journal of California and Great Basin Anthropology*, pp. 158-181.

Magnin, L., D. Hermo, and C. Weitzel. 2015. "Estrategias de caza en la localidad arqueológica de La Primavera, Santa Cruz (Argentina). Análisis de visibilidad y accesibilidad mediante SIG." In *González H, Sepúlveda M (comp), Libro de las Actas del XIX Congreso Nacional de Arqueología Chilena. Ediciones Universidad de Tarapacá y Sociedad Chilena de arqueología*, pp. 63-67.

McGuire, Kelly R. and William R. Hildebrandt. "Re-thinking Great Basin foragers: prestige hunting and costly signaling during the Middle Archaic period." *American Antiquity* 70(4):695-712.

McGuire, Kelly and Brian Hatoff. 1991. “A Prehistoric Bighorn Sheep Drive Complex, Clan Alpine Mountains, Central Nevada.” *Journal of California and Great Basin Anthropology* 13(1):95-109.

McGuire, Kelly R., Kimberly Carpenter, and Jeffrey S. Rosenthal. 2012. “Great Basin Hunters of the Sierra Nevada.” In *Meetings at the Margins: Prehistoric Cultural Interactions in the Intermountain West*. Edited by David Rhode. Uiversity of Utah Press.

McKinney, Ted, Sue R. Boe, and James C. deVos Jr. 2003. "GIS-Based Evaluation of Escape Terrain and Desert Bighorn Sheep Populations In Arizona." *Wildlife Society Bulletin*, pp. 1229-1236.

Mehringer, Peter J., John C. Sheppard, and E. L. Davis. 1978. "Holocene history of Little Lake, Mojave Desert, California." *The ancient Californians: Rancholabrean hunters of the Mojave Lakes Country* 29:153-176.

Moratto, M. J. 2014. *California Archaeology*. Academic Press.

Moratto, M. J., A. P. Garfinkel, J. M Erlandson, A. K. Rogers, M. F. Rondeau, J. Rosenthal, and R. M. Yohe, 2018. “Fluted and basally thinned concave-base points of obsidian in the Borden Collection from Inyo County, Alta California: Age and significance.” *California Archaeology* 10(1):27-60.

Morgan, Christopher, Robert L. Bettinger, and Mark Giambastiani. 2014. "Aboriginal Alpine Ceremonialism in the White Mountains, California." *Journal of California and Great Basin Anthropology*, pp. 161-179.

Muir, John. 1894. “A Near View of the High Sierra.” *The Mountains of California*, pp. 26-39.

O'Driscoll, James. 2018. "Landscape Applications of Photogrammetry Using Unmanned Aerial Vehicles." *Journal of Archaeological Science: Reports* 22:32-44.

Ogburn, Dennis E. 2006. "Assessing the Level of Visibility of Cultural Objects in Past Landscapes." *Journal of Archaeological Science* 33(3): 405-413.

Pearson, James. 1995. *Prehistoric Occupation at Little Lake Inyo County, California: A Definitive Chronology*. M.S. Thesis, Loyola University of Los Angeles.

Pix4D. 2018. “Do more GCPs equal more accurate drone maps?” Accessed May 26, 2022. https://www.pix4d.com/blog/GCP-accuracy-drone-maps.

--- 2022. Manual and Settings (iOS) - PIX4Dcapture. Accessed May 26, 2022. https://support.pix4d.com/hc/en-us/articles/204010419-Manual-and-Settings-iOS-PIX4Dcapture#label5

Pope, Saxton T. 1974. "Hunting With Ishi-The Last Yana Indian." *The Journal of California Anthropology* 1:2.

Remondino, F. 2014. “UAV: Platforms, Regulations, Data Acquisition and Processing”. In 3D Recording and Modelling in Archaeology and Cultural Heritage: Theory and Best Practice. British Ar*chaeological Report International Series* 2598, pp. 73-88.

Ritter, Eric W. and Gary B. Coombs. 1990. “Southern California Desert Archaeology: Prospectus for Settlement-Subsistence Studies.” *Pacific Coast Archaeological Society Quarterly* 26(1):24-41.

Sappington, J. Mark, Kathleen M. Longshore, and Daniel B. Thompson. 2007. “Quantifying Landscape Ruggedness for Animal Habitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert.” *Journal of Wildlife Management* 71(5):1419-1426.

Schneider, Joan S., Robert S. Begole, Mark Jorgensen, Esther S. Rubin, and L. Louise Jee. 2014. "Prehistoric Bighorn Sheep Procurement Tactics in the Colorado Desert: A Hypothesis for a Stone-Feature Complex in Yaqui Pass, Anza-Borrego Desert State Park, California." *Journal of California and Great Basin Anthropology*, pp. 181-210.

Schroth, Adella B. 1994. *The Pinto Point Controversy in the Western United States*. Ph.D. Dissertation, Department of Anthropology, University of California, Riverside

Simmons, N. M. 1980. “Behavior.” In *The desert big-horn, its life history, ecology, and management*, pp. 124-144. Edited by G. Monson and L. Sumner, University of Arizona Press, Tucson, Arizona.

Steward, Julian H. 1938. *Basin-plateau aboriginal sociopolitical groups*. Vol. 120. US Government Printing Office.

U.S. Geological Survey. 2019. USGS 13 arc-second n36w118 1 x 1 degree: U.S. Geological Survey.

Van Tilburg, Jo Anne, Gordon E Hull, and John C. Bretney. 2012. *Rock Art at Little Lake: An Ancient Crossroads in the California Desert*. University of California, Los Angeles. Cotsen Institute of Archaeology Press: Los Angeles.

Verhagen, Philip. 2018. "Spatial analysis in archaeology: moving into new territories." In *Digital Geoarchaeology*, pp. 11-25.

Wallace, William J. 1977. *Death Valley National Monument's Prehistoric Past: An Archaeological Overview*. Manuscript on file at the U.S. National Park Service, Western Archaeological Center, Tucson.

Warren, Claude N. 1984. "The Desert Region." In *California Archaeology*, by Michael J. Moratto, pp. 339–430. Academic Press, Orlando, Florida.

Welles, Ralph E. and Florence B. Welles. 1961. *The Bighorn of Death Valley.* No. 6. US Government Printing Office, 1961.

Wheatley, David. 1995. "Cumulative Viewshed Analysis: A GIS-Based Method for Investigating Intervisibility, and Its Archaeological Application." *Archaeology and geographic information systems: A European perspective*, pp. 171.

Whitley, David S. 2000. *The Art of the Shaman*. University of Utah Press, Salt Lake.

--- 1998. "Meaning and Metaphor in the Coso Petroglyphs: Understanding Great Basin Rock Art." In *Coso Rock Art: A New Perspective,* Edited by Elva Younkin, pp. 109-168. *Maturango Museum Publication* Number 12. Indian Wells Valley, Ridgecrest, California.

--- 1982. *The Study of North American Rock Art: A Case Study from South-Central California*. Ph.D. Dissertation, Department of Anthropology, University of California, Los Angeles.

Whitley, David S. and Ronald I. Dorn. 1987. "Rock art chronology in eastern California." *World Archaeology* 19(2):150-164.

Wigand, Peter E. and David Rhode. 2002 "Great Basin vegetation history and aquatic systems: the last 150,000 years." *Great Basin Aquatic Systems History. Smithsonian Contributions to the Earth Sciences* 33:309-368.

Wright, David K., Scott MacEachern, and Jaeyong Lee. 2014. "Analysis of Feature Intervisibility and Cumulative Visibility using GIS, Bayesian and Spatial Statistics: A Study from the Mandara Mountains, Northern Cameroon." *PloS one* 9(11):e112191.

Yohe, Robert and Alan P. Garfinkel. 2012. "Great Basin Bighorn Ceremonialism: Reflections on a Possible Sheep Shrine at the Rose Spring Site (CA-INY-372), Rose Valley, Alta California." *California Archaeology* 4(2):201-224.

Appendix Pix4D Data Quality Report

Quality Report

Generated with Pix4Ddiscovery version 4.7.5

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	Little Lake 3D
Processed	2022-03-20 13:16:39
Camera Model Name(s)	FC220_4.7_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	3.86 cm / 1.52 in
Area Covered	0.210 km^2 / 21.0118 ha / 0.08 sq. mi. / 51.9481 acres

Quality Check

Images	median of 50098 keypoints per image	✓
Dataset	537 out of 537 images calibrated (100%), all images enabled	✓
Camera Optimization	1.2% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 16658.6 matches per calibrated image	✓
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0.186 m	⚠

Preview

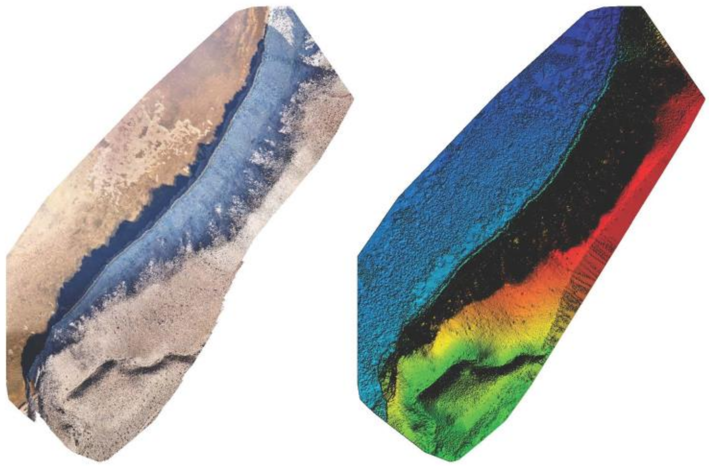


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	537 out of 537
Number of Geolocated Images	537 out of 537

Initial Image Positions

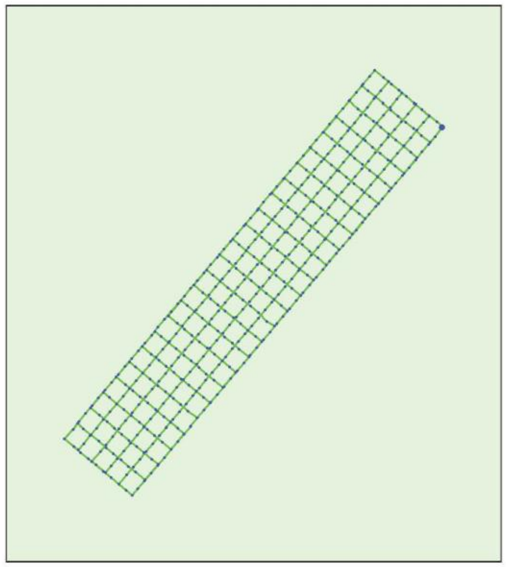
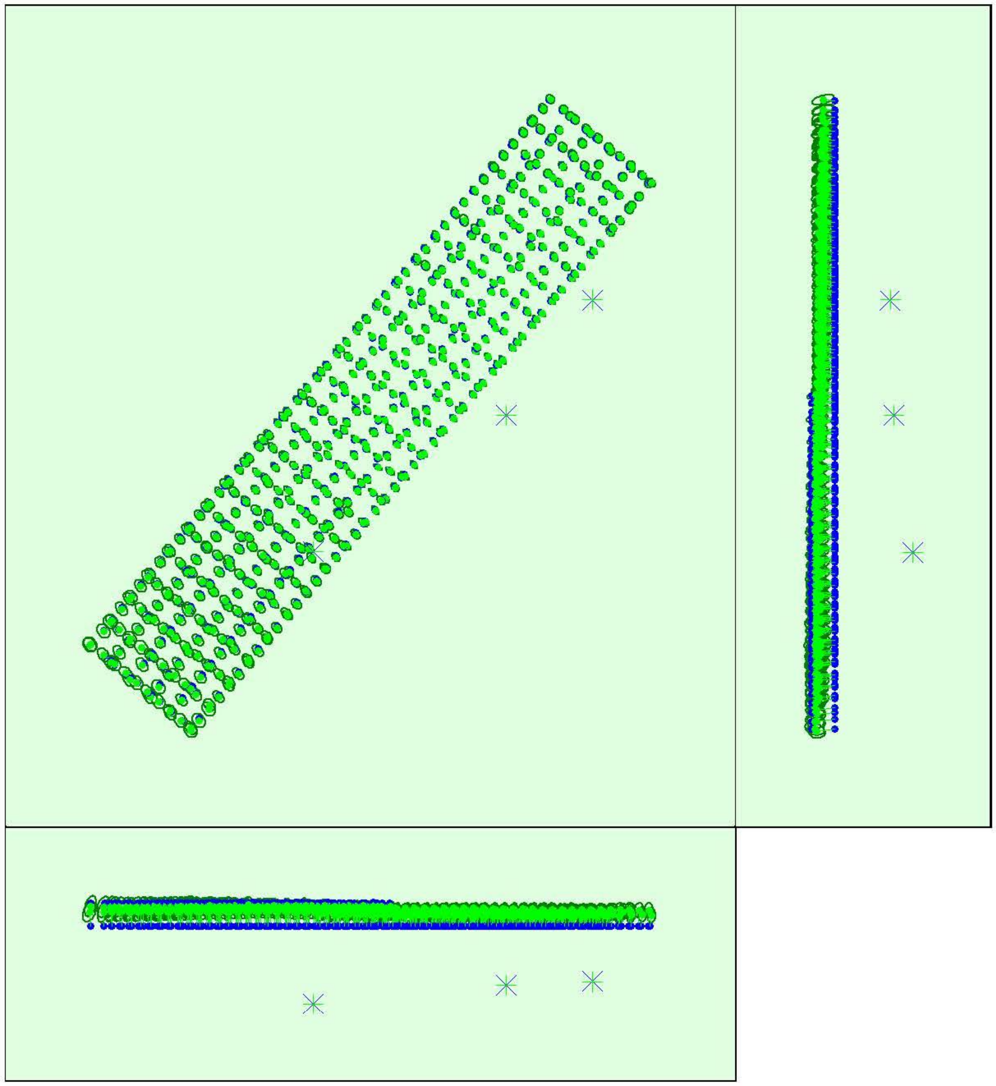


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 50x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.071	0.075	0.114	0.041	0.052	0.023
Sigma	0.013	0.013	0.028	0.005	0.003	0.003

Overlap

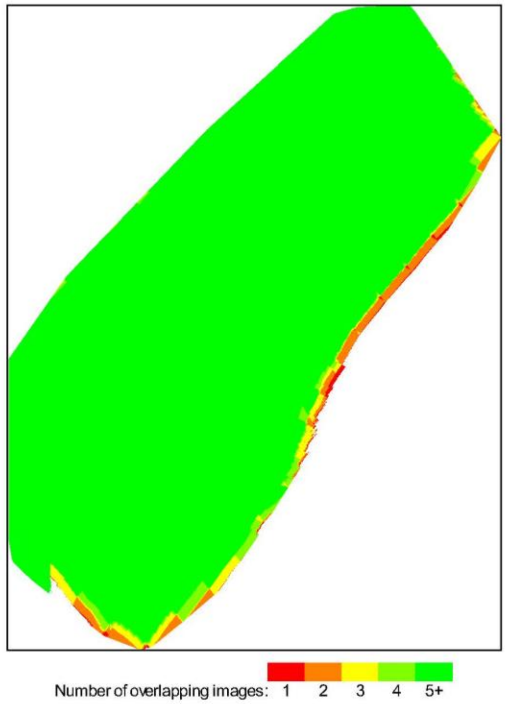


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

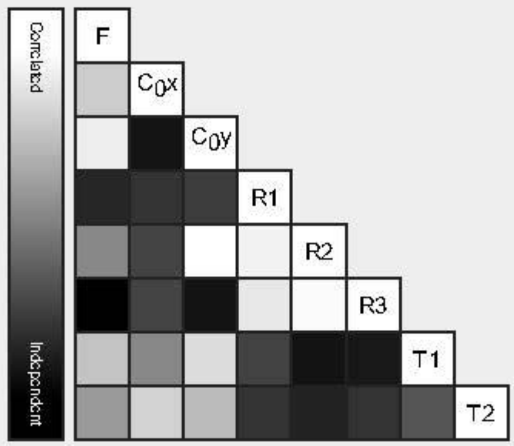
Number of 2D Keypoint Observations for Bundle Block Adjustment	9411632
Number of 3D Points for Bundle Block Adjustment	3058326
Mean Reprojection Error [pixels]	0.193

Internal Camera Parameters

FC220_4.7_4000x3000 (RGB). Sensor Dimensions: 6.327 [mm] x 4.745 [mm]

EXIF ID: FC220_4.7_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3073.410 [pixel] 4.861 [mm]	1917.790 [pixel] 3.033 [mm]	1485.800 [pixel] 2.350 [mm]	0.033	-0.086	0.078	0.000	-0.001
Optimized Values	3110.474 [pixel] 4.920 [mm]	2014.703 [pixel] 3.187 [mm]	1437.232 [pixel] 2.273 [mm]	0.062	-0.176	0.179	-0.001	0.000
Uncertainties (Sigma)	0.322 [pixel] 0.001 [mm]	0.109 [pixel] 0.000 [mm]	0.238 [pixel] 0.000 [mm]	0.000	0.001	0.001	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.

The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	50098	16659
Min	28240	2627
Max	77011	46266
Mean	51053	17526

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1784219
In 3 Images	602872
In 4 Images	274163
In 5 Images	142294
In 6 Images	83107
In 7 Images	50388
In 8 Images	32173
In 9 Images	21978
In 10 Images	16086
In 11 Images	11477
In 12 Images	8836
In 13 Images	6426
In 14 Images	4986
In 15 Images	3758
In 16 Images	2989
In 17 Images	2437
In 18 Images	1950
In 19 Images	1588
In 20 Images	1266
In 21 Images	1023
In 22 Images	758

In 23 Images	595
In 24 Images	523
In 25 Images	432
In 26 Images	339
In 27 Images	272
In 28 Images	219
In 29 Images	199
In 30 Images	156
In 31 Images	149
In 32 Images	108
In 33 Images	82
In 34 Images	75
In 35 Images	71
In 36 Images	63
In 37 Images	49
In 38 Images	46
In 39 Images	37
In 40 Images	25
In 41 Images	18
In 42 Images	8
In 43 Images	17
In 44 Images	10
In 45 Images	6
In 46 Images	9
In 47 Images	2
In 48 Images	5
In 49 Images	7
In 50 Images	4
In 51 Images	7
In 52 Images	2
In 53 Images	4
In 54 Images	3
In 56 Images	3
In 57 Images	1
In 58 Images	2
In 59 Images	1
In 63 Images	1
In 65 Images	1

2D Keypoint Matches

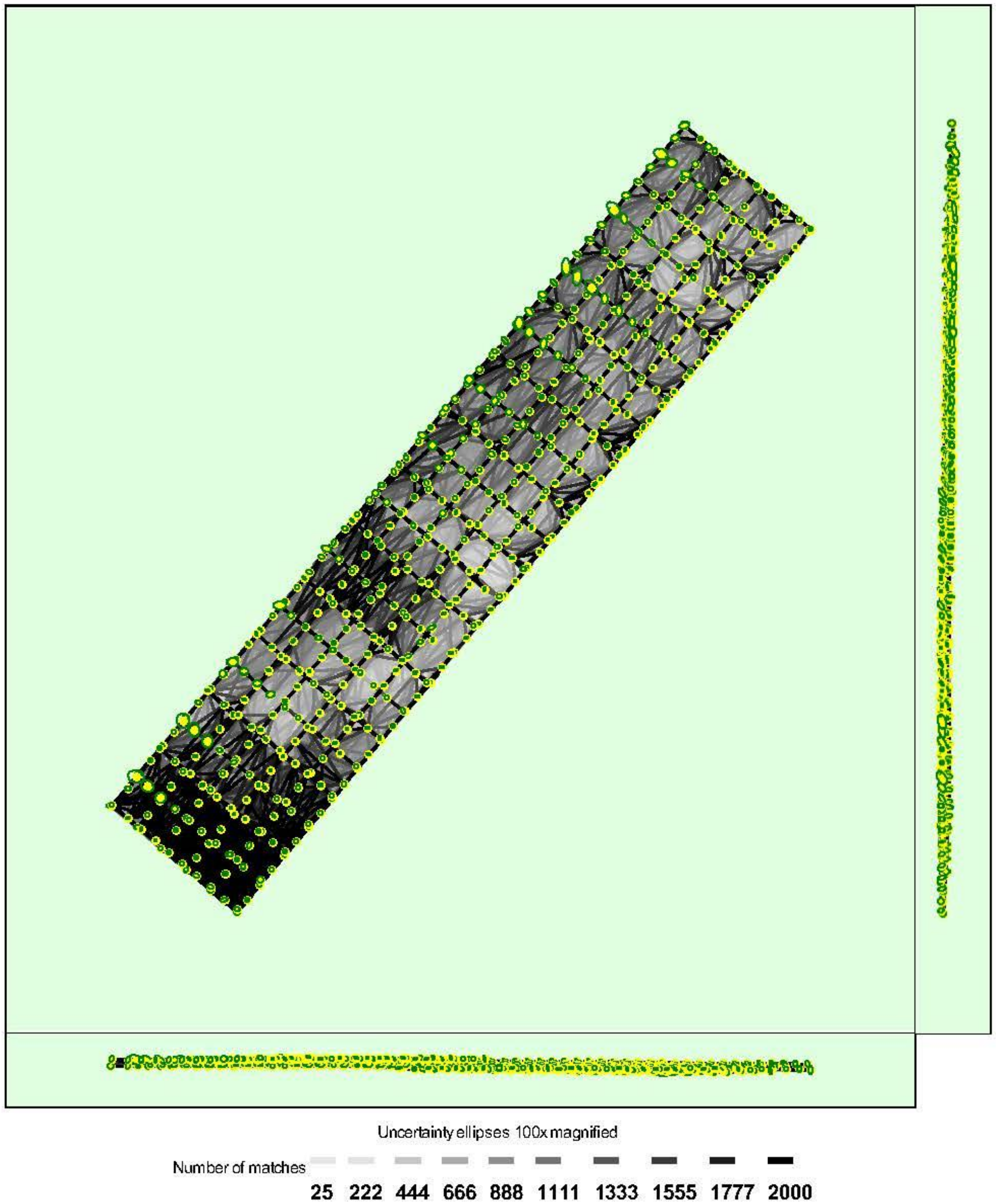


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.014	0.014	0.013	0.009	0.008	0.005
Sigma	0.006	0.006	0.004	0.003	0.003	0.001

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP 1 (3D)	0.320/ 0.650	0.159	-0.048	0.394	0.492	8 / 9
GCP 3 (3D)	0.360/ 0.710	-0.012	-0.090	-0.214	0.732	41 / 41
GCP 2 (3D)	0.370/ 0.740	-0.201	0.161	-0.277	0.400	2 / 2
Mean [m]		-0.018108	0.007564	-0.032233		
Sigma [m]		0.147200	0.110024	0.302387		
RMS Error [m]		0.148310	0.110284	0.304100		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	4.10
-6.00	-3.00	0.00	0.00	37.99
-3.00	0.00	52.51	50.47	32.03
0.00	3.00	47.49	49.53	3.72
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	22.16
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.443684	0.212648	-7.827235
Sigma [m]		0.526011	0.774461	5.928389
RMS Error [m]		0.688144	0.803124	9.818931

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Geolocation Bias	X	Y	Z
Translation [m]	-0.443684	0.212648	-7.827235

Bias between image initial and computed geolocation given in output coordinate system.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	78.58
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	0.803
Phi	0.638
Kappa	3.228

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz RAM: 32GB GPU: NVIDIA GeForce GTX 1070 (Driver: 26.21.14.3086)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS 84 (EGM96 Geoid)
Ground Control Point (GCP) Coordinate System	WGS 84 / UTM zone 11N (EGM96 Geoid)
Output Coordinate System	WGS 84 / UTM zone 11N (EGM96 Geoid)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, no

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes

Results

Number of Generated Tiles	1
Number of 3D Densified Points	33000882
Average Density (per m^3)	123.89

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (3.86 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp