Journal of Archaeological Science 41 (2014) 523–532

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Modeling site location patterns amongst late-prehistoric villages in the Wind River Range, Wyoming

Matthew Stirn

Department of Archaeology, University of Sheffield, Northgate House, West Street, Sheffield S1 4ET, United Kingdom

ARTICLE INFO

Article history:
Received 4 February 2013
Received in revised form
16 September 2013
Accepted 24 September 2013

Keywords:
Northwest Wyoming
Alpine archaeology
GIS
Predictive modeling
Late prehistoric period

ABSTRACT

The recent discovery of six high-altitude villages and their noticeably similar microenvironments suggest potential site location patterning in Wyoming's high mountains. This pattern, centered upon abundant Whitebark Pine stands further suggests that initial village locations were targeted specifically for the optimal procurement of pine nuts. Through the GIS analysis of topographical, arboreal, and spatial variables accompanied by two ground-truthing field surveys, this project interpreted potential causalities of the locational pattern amongst these villages and, based on the hypothesized model, successfully predicted the locations of 13 new cut-and-fill lodge villages above 10,000 feet in Wyoming's Wind River Range.

1. Introduction

The recent discovery of prehistoric high-altitude villages in Wyoming's Wind River Range has generated a growing interest in the chronology of alpine occupation in North America (i.e. Adams, 2010; Koenig, 2010; Losey, 2012; Morgan et al., 2012; Stirn and Adams, 2012; Thomas, 2013a,b). These villages (defined below), appear rather suddenly in the archaeological record (c. 700–2000 BP) and have been interpreted by some (Bettinger, 1991; Morgan et al., 2012) as evidence of a sudden intensification event that followed nearly 10,000 years of marginal and superficial utilization of the alpine zone. Under this perspective, the creation of alpine villages was likely the result of population pressure (Bettinger, 1991) or environmental degradation (Morgan et al., 2012; Thomas, 2013a,b) that forced settlement in an otherwise marginal and previously avoided landscape. A contradictory perspective (Adams, 2010; Koenig, 2010; Stirn et al., unpublished manuscript) however, suggests alpine environments are not marginal and high-altitude villages are simply an alternative expression of alpine utilization that do not necessarily represent intensification. Despite the debate surrounding their formation, these intriguing sites have provided enlightening information into an otherwise opaque understanding of human occupation in the mountains of the Western United States. While the chronology, purpose, and formation processes of the villages continue to perplex archaeologists, the site locations of these alpine residences are beginning to offer an interpretable pattern. The 19 villages recorded thus far in the Wind River Range (Adams et al., 2009; Stirn and Adams, 2012) occur in similar geographical and topographical environments particular to abundant and healthy Whitebark Pine. Additionally, all villages provide artifacts associated with pine nut consumption. Considering the similarities in site locations and assemblages, it seems probable that the alpine villages of the Wind River Range were systematically placed for the optimization of subsistence opportunities centered on Whitebark Pine nuts. GIS analysis and predictive modeling were conducted to test the strength of this proposed pine nut optimization model and, as will be explored below, the results from these methods concluded that pine nut consumption likely played a significant role in determining the location of late-prehistoric village sites. It is hoped that if the intention underlying the formation of these sites can be better understood, a more accurate representation of prehistoric human and mountain relations can be reached.

1.1. Alpine archaeology in North America

Prehistoric archaeology in the mountains of North America is a relatively recent research focus beginning in the 1960s (Husted, 1965) and gaining strength throughout the next forty years (i.e.

E-mail addresses: mastirn1@sheffield.ac.uk, mastirn@gmail.com.

0305-4403/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jas.2013.09.018

Benedict, 1974; Bender, 1980; Bettinger, 1991; Thomas, 1982). A combination of tedious logistics, unpredictable weather, and a general academic dismissal of prehistoric alpine occupation generated little interest in high-altitude archaeology. It was not until the late 1970s and early 1980s that the first alpine villages were stumbled upon in the White Mountains, California (Bettinger, 1991), and Alta Toquima Range, Nevada (Thomas, 1982). An alpine village, for this study, is defined as a site above 10,000 feet in elevation that is composed of five or more residential structures constructed with multiple stone courses and/or platform cut-and-filling (see Adams, 2010; Bettinger, 1991). These large sites at high altitudes were soon invoked as a diagnostic of Numic speaking groups (Bettinger, 1991: See Thomas, 1994 for a contradictory perspective and Madsen and Rhode, 1994 for a wider discussion of Numic affiliation) and have recently played key roles in a reinterpretation of the chronology and direction of the Numic linguistic spread (Morgan et al., 2012). The three main locations of alpine village sites in North America are the Alta Toquima Villages, NV, White Mountain Villages, CA, and Wind River Villages, WY.

The Alta Toquima site was the first alpine village to be documented in North America. It is located above 11,000 feet and was discovered by David Hurst Thomas in 1978 (Thomas, 1982, 2013a). 70 radiocarbon dates from excavated houses at Alta Toquima span roughly 2500–150 BP (Thomas, 2013a). The discovery of Alta Toquima and six other nearby villages reignited interest in the prehistoric occupation of alpine zones among North American archaeologists.

In the White Mountains of California, a group of a dozen alpine villages were tested between 1982 (Bettinger, 1991: 657), and 1989 (661). Similar to the villages in Nevada, the White Mountain sites exhibit “multiple course stone footings representing the remains of well-built dwellings” (675). All White Mountain villages were dated post 1400 BP (665). The discovery of these villages was significant to both the Numic spread debate, and the development of a subsistence driven model to prehistoric mountain adaptation in Western North America. Bettinger interpreted the prehistoric White Mountain subsistence paradigm to have been initially fueled by the hunting of ungulates with a later intensification of foraging (1991). In other words, prehistoric people first traveled into the mountains specifically to hunt but also ate pine nuts because they were there. Bettinger’s model labels the alpine ecotone as marginal and assumes that late-prehistoric peoples were pushed into the mountains by social and/or economic pressures that resulted in a subsistence adaptation. Bettinger’s model was developed to explain specific patterns observed in the White Mountains, and has been met with both support (Morgan et al., 2012) and contention (Thomas, 1994).

Between 2003 and 2011, 19 alpine villages were discovered in the Wind River Range of Wyoming. Two of those, the Burnt Wickiup Site and High Rise Village represent an astonishing range of occupation from 4000 (1800) to 420 BP with a mean radiocarbon date of 1870 BP (Adams, 2010: 73). See Morgan et al. (2012), however, for a suggestion that the very early dates might be explained by the burning of 'old wood' and not Archaic era occupations. Even with the old wood dilemma, the early occupations of the High Rise Village are particularly startling as they predate the White Mountain and Alta Toquima villages by over 600 years. An archaeological survey team assisted by volunteers discovered the High Rise Village site in the summer of 2006. The site is situated on a steep, south-facing slope between 10,560–10,880 feet in elevation (Adams, 2010: 50), and contains over 70 cut and fill lodge pads and an extraordinarily dense artifact assemblage typical of the Numic speaking Mountain Shoshone or Sheepeaters (See: Larson and Kornfield, 1994; Schroeder, 2010b). The dry environment of the Wind River Range has, in the case of four lodges, preserved remains of the original wooden superstructures (Adams, 2010: 50–51). During the first few seasons of excavation at High Rise Village over 60 groundstone tools were recorded within the site (Adams et al. 2009). The occurrence of groundstone in Northwest Wyoming has, on multiple occasions, been tied to nut processing (Frison, 1978; Sheperd, 1992) and Adams (2010) believes that the groundstone tools uncovered at High Rise Village were utilized for a similar purpose.

2. Methodology

A primary goal of this experiment was to explore the potential of using remote sensing to identify patterns from which paleo-economical inferences can be formulated. The results of this experiment, identifying a site location pattern, does not represent an end, but rather a package of complimentary evidence to be used heuristically for future research (See Llobera, 2012). A preferable supplement would have been the excavation of newly discovered villages, but, considering the geographical isolation of the sites, cost of alpine fieldwork, and fragility of the terrain, mass excavation and analysis are not feasible. However, the combination of surface surveying and remote sensing offered highly efficient and low cost preliminary investigation.

In a similar, earlier, experiment, Thomas and Bettinger (1976) developed a predictive model for Piñon Pine harvesting camps in the Upper Reese River Valley of Central Nevada. Their methodology identified seven topographic variables (eg. elevation, slope, proximity to water, etc.) that were combined to form a single polythetic definition of influence towards the location of archaeological sites (p. 271–273). As presented by Thomas and Bettinger, “The essence of polythetic procedure is that several variables are incorporated in one definition, but the concern is with the overall implications of all variables, rather than any specific variable” (p. 271). Following this paradigm, the Reese River model assumed that several independent and noncultural variables could simultaneously, but at varying degrees, influence the decision of site location. Thomas and Bettinger thus generated the predictive model of probable site ‘loci’ based on where their influencing variables existed together or within close proximity. The model was then ground-truthed and validated, proving that polythetic definitions can accurately predict the locations of patterned archaeological sites. Given its success in the nearby Great Basin, the polythetic approach offered an ideal framework to approach the Wind River alpine villages.

To test the significance of Whitebark Pine consumption’s impact on site location, a GIS predictive model was developed to hypothesize likely locations of undiscovered villages in the Wind River Range. Brandt et al. (1992: 270) note that if patterns exist between site locations and “one or more regionally distributed variables,” a model can be constructed based upon those correlations. Based on additional theory of Brandt et al. (1992: 270), it is a “fundamental premise of modern archaeology that human behavior is patterned,” and the location of new sites should be predictable based upon similarities among previously recorded villages. Following the scientifically oriented methodology presented by Verhagen and Whitley (2012: 56) and the theoretical paradigm of Thomas and

Table 1
Attributes of the first six villages discovered in the Wind River Range, Wyoming.

Site name	Elevation	Slope	Aspect	Approx size
High Rise Village	10,600 ft	20–30%	SSE	70+ Lodges
Burnt Wickiup Site	10,450 ft	20–35%	S	30+ Lodges
Mano Heaven	10,400 ft	20–25%	SSW	5–6 Lodges
Mano-in-Stump	10,300 ft	25–30%	SSE	5–10 Lodges
Camp Overlook	10,300 ft	25–30%	SE	5+ Lodges
TFB Village	10,500 ft	10–25%	ESE	20+ Lodges

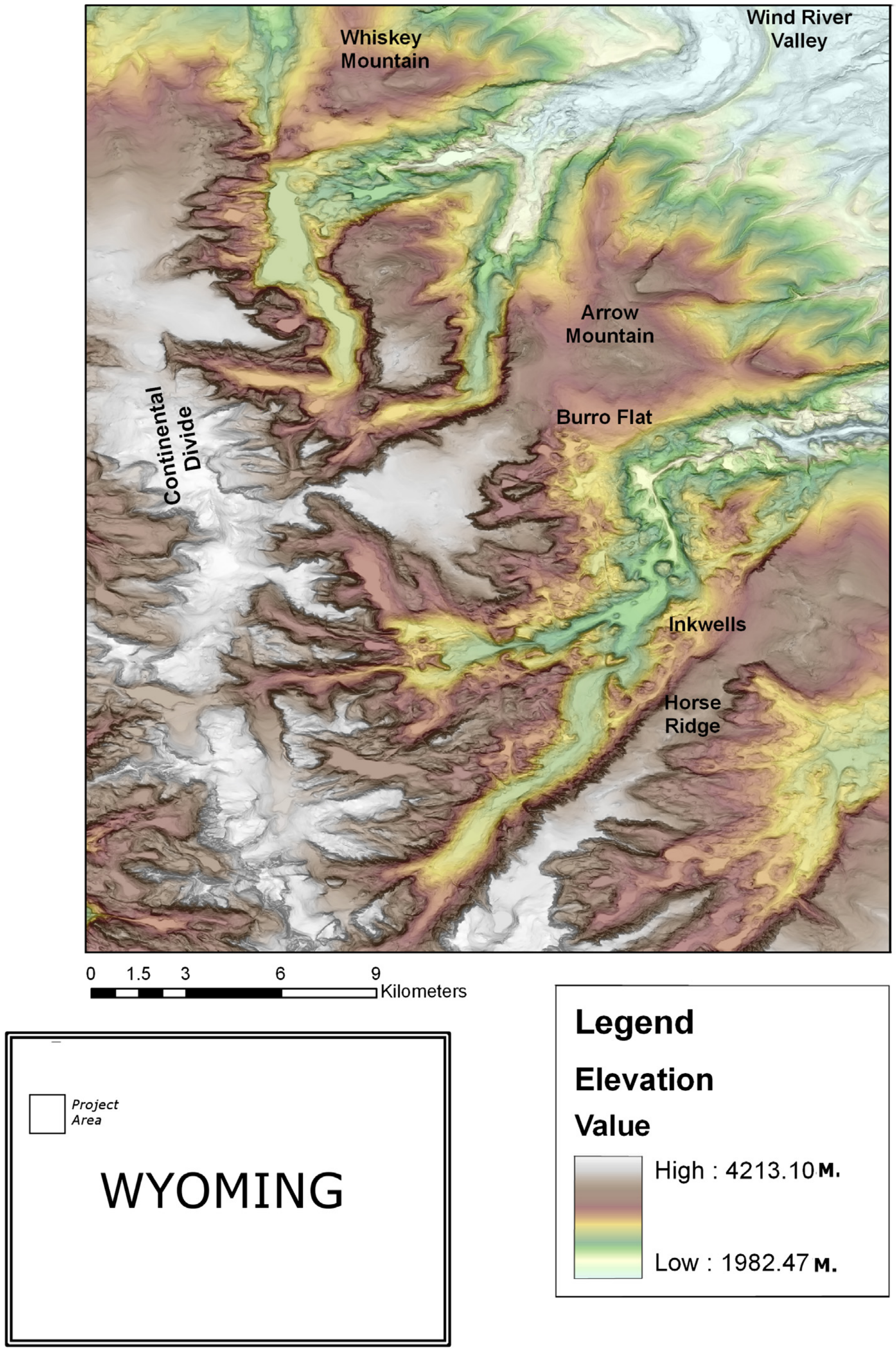

Fig. 1. Project study area, Northern Wind River Range, Wyoming.

Bettinger (1976), this projected was conducted in three stages; 2.1) data analysis 2.2) model building, and 2.3) model testing and theory building.

2.1. Data analysis

Before the 2010 and 2011 ground truthing sessions, six alpine villages were previously recorded in Northwestern Wyoming. Upon first glance it was immediately apparent that every village was situated within similar microenvironments as every new village, recorded often miles from the last, was located in an almost identical setting. Each is located at an altitude between 10,500 and 11,500 feet in elevation, in areas of high sun exposure, and on a slight to moderately inclined slope (See Table 1). As such, the variables used to develop the predictive model include: elevation, sun exposure, and slope. During past field seasons we observed that in the Wind River Range, elevation and particularly sun exposure are both traits characteristic of healthy Whitebark Pine stands (Stirn Field Notes, 2009). With some exceptions, south facing slopes in the Wind River Range receive the most sun. Thus site aspect was taken into account along with solar exposure. The occurrence of villages on slopes however remains a mystery, as large and accommodating flat benches often exist nearby. Because, however, the location on an inclined slope remains an attribute uniform across the villages, slope is assumed to have been a factor in site location choice and was thus included in the model.

2.2. Model building

Before commencing large bouts of data acquisition and analysis, it was first necessary to establish a geographical boundary large enough to cover many previously unsurveyed blocks, and yet, small enough to manage during a single field season. The Wind River Mountains stretch approximately 100 miles longitudinally across the Western side of the state of Wyoming. They are exceptionally vast and present some of the most isolated wilderness within the continental United States. The study area for this project concentrated on the Northern-most drainages of the Wind Rivers because of their relative ease of accessibility and high concentration of high-altitude plateaus (as opposed to rugged and rocky outcrops typical of the southern Wind River Mountains). The model projection covers six United States Geographical Survey Wyoming topographical quadrangles (c. 337 square kilometers). Roughly a quarter of the entire area had been archaeologically surveyed in the past (the northernmost quadrangles) (See Fig. 1) and the southern quadrangles offered an ideal, topographically similar area to ground truth the accuracy of the model.

After identifying the geographical parameters, a successful GIS analysis of the variables common amongst alpine villages could be initiated. To accomplish this task, rasters displaying elevation, slope, and aspect were independently extracted from Digital Elevation Models (DEM). Next, spatial displays of these three variables were rendered using ArcGIS's *Spatial Analysis* tool. Each variable raster was then reclassified to a numerical scale of 0–9 corresponding to that variable's hypothesized significance to site location choice (Table 2). It was this step that had the most potential for creating an error in the model as this reclassification procedure relied on intuition, deductive reasoning, and field observations rather than statistical analysis. In order to condense the abundance of information extracted from the DEM, it was necessary to weight the many sub-categories within each raster. As such, the pixels of each raster were reclassified and geocoded from 0 (considered the least likely to host a village) to 9 (most probable to host a village site).

The weights of variables were applied by observing the six previously recorded villages. Taking into consideration the individual characteristics of each variable, the importance of the attributes was not weighted ordinaly by linear multiple regression but rather through logistic multiple regression. This allowed for a scale to be used that would fit the polythetic definition by acknowledging characteristics and ranges of variation unique to each variable without skewing the others (See: Thomas and Bettinger, 1976; Wheatley and Gillings, 2002: 173–174).

The final and most difficult raster to create was that of Whitebark Pine locations within the survey area. An ideal situation would have displayed a preexisting Whitebark Pine shapefile that could be reclassified and geocoded with pixels defined as 9 = Whitebark Pine and 0 = Other Vegetation. However, interest in Whitebark Pine stands in the Wind River Range is relatively new and a spatial distribution has yet to be recorded. In lieu of recording every pine tree in the Northern Wind River Range, remote sensing offered an acceptable alternative.

Table 2
D.E.M. Reclassification values.

Geocode value	Aspect	Slope (%)	Elevation (ft.)
0	North	neg. (Water)	0–8000
1	–	40+	–
2	–	–	–
3	NE, NW	–	–
4	–	–	–
5	E, W	–	–
6	–	–	–
7	ESE, ESW, WSW, WSE	35–40	8000–9000
8	SW, SE	20–35	9000–10,000 and 11,000–12,000
9	South	0–20	10,000–11,000

Both the *High Rise Village* and *Burnt Wickiup* sites are located in large Whitebark pine stands, which allowed for a relatively simple procedure based on field observations. As different plant species reflect unique infrared signatures in orthoimagery, it was assumed that Whitepark Pine could be isolated from other plant taxa. From the Landsat-12 orthoimagery, *High Rise Village* produced a mean grayscale pixel value of 68, while *Burnt Wickiup* hosted a mean pixel value of 116 (Multispectral imagery was considered but, did not produce high enough contrast to differentiate pine from other alpine plant species). Based upon field observations, the difference in mean pixel values in the orthoimagery was the result of impure Whitebark Pine stands contaminated by either burned trees or other, intermixed species. As it was certain that both values contained Whitebark Pine, the values from both the High Rise Village and Burnt Wickiup sites were used in the reclassification (Table 3).

The first reclassification of the Landsat-12 imagery produced an unexpected problem. It identified Whitebark Pine signatures throughout the survey area between the elevations of 7000–12,000 feet. This broad altitude range includes areas that are far too low in elevation for Whitebark Pine to grow and far above current treeline (Kershaw et al., 1998: 35). Despite this problem, the initial reclassification did correctly identify Whitebark Pine stands where they are known to exist. To extract the true Whitebark from the phantom signatures, a weighted overlay with the reclassified elevation model was conducted (See Brandt et al., 1992: 272). In the Wind River Range, our team has recorded that the highest density of Whitebark Pine stands exist between 10,300–11,300 feet. This elevation happens to be the highest value area of the reclassified elevation model. Thus, by producing a weighted overlay with Whitebark Pine weighted at 20% and Elevation at 80%, a new raster was produced that displayed only trees between 10,000–12,000 feet. In the lab we assumed that the signatures identified by the new raster are Whitebark Pine and ground-truthing demonstrated the validity of that assumption. In other mountain ranges where intermixed tree species extend to the treeline, this assumption would not have been particularly safe. But, as Whitebark Pine represents, by far, the most common species at treeline, our hypothesis was not overly dangerous.

Once the individual variable rasters were generated, they were combined using a "weighted map-layer approach" (Brandt et al., 1992: 272) to create the final predictive model. As with the Whitebark Pine and Elevation weighted overlay, the weights in the final were generated initially through deductive reasoning and field observations. In constructing the weighted overlay, I hypothesized that locational attributes observed to be constant amongst many villages were likely to have been more significant in location choice than attributes consistent amongst only a few. Thus, the attributes were weighted on a scale of observed frequency with unanimous weighted highest and occasional, lowest. The six original villages exist in Whitebark stands, as such the Whitebark/Elevation raster was weighted highest at 50%. As more villages were located on similar slope gradients than aspects, the slope raster was weighted at 30% and aspect at 20% (Table 4).

The final projection appeared to be successful. This projection geocoded pixel values representing 30 m^2 each, from 0 (least probable village location) to 9 (most probable village location) (Fig. 2). Nearly every known alpine village in the Wind River Range at that time was situated in an area classified as an 8 or 9 (Table 5). Though the model appeared flawless in its predictive capabilities, a potential bias was present considering the small sample set. As

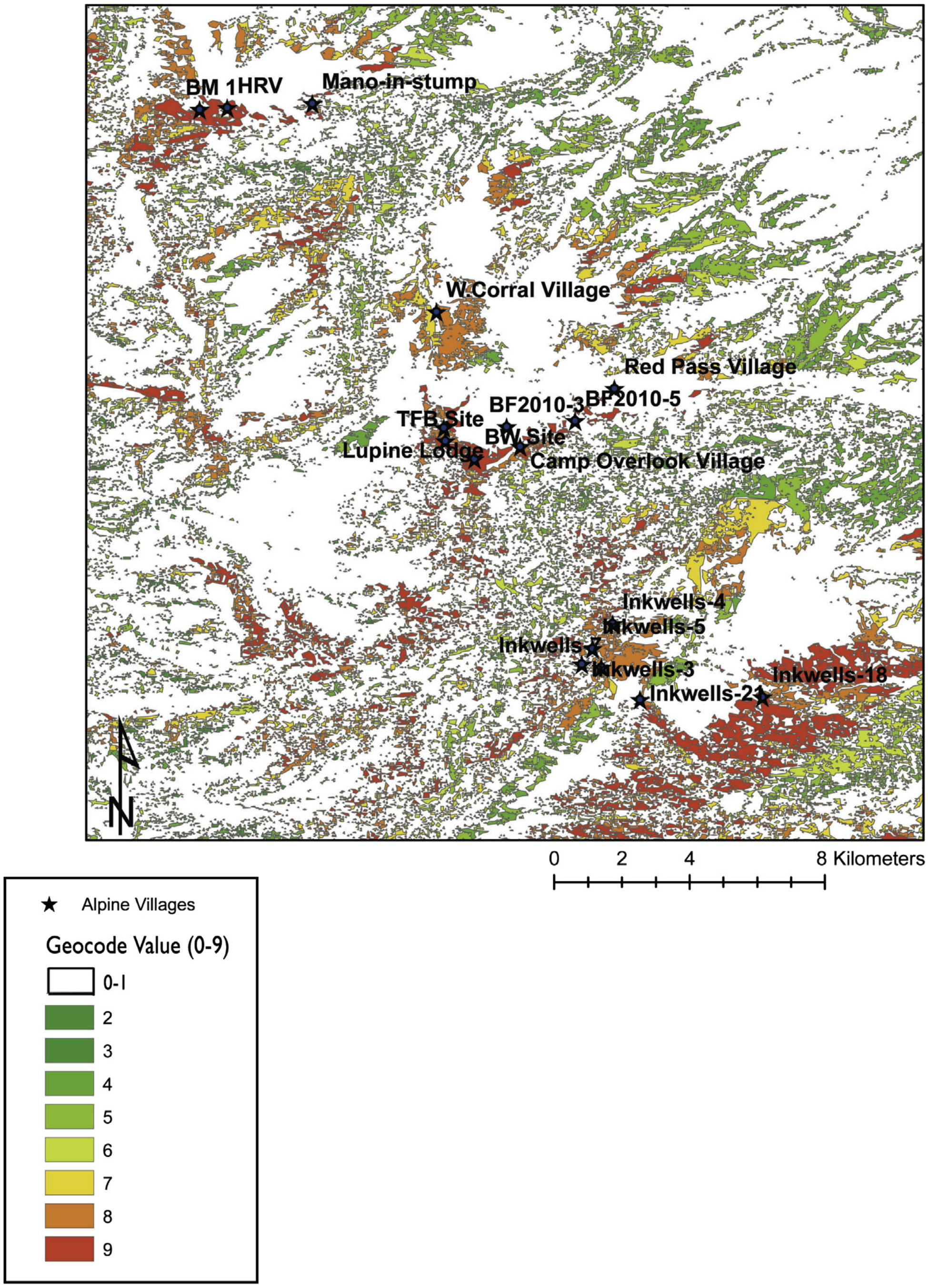

Fig. 2. Final Predictive Model Displaying Geocode Distribution and Alpine Village Locations. Considering the extremity of recreational looting in the area, maps, topography, and geographical features were purposefully excluded from this figure.

each of the six villages was nearly identical in topography and ecology, they conveniently fit a Whitebark centered subsistence model and left no room for exceptions. The model assumed that every village is situated above 10,500 feet, on a sunny inclined slope, and in a Whitebark Pine stand. In order to determine the true validity of the model and eliminate the possibility of coincidental patterning, the model needed to be ground-truthed.

2.3. Model testing

During the summers of 2010 and 2011, four 8-day trips were launched with the goals of ground truthing the model and conducting the first archaeological survey in an area previously unexplored. Three 5 × 5 km blocks from the larger study area were chosen in the Shoshone National Forest based on the their abundance of high-probability areas (geocode level 8–9) to host alpine villages, and the fact archaeologists had never surveyed them (Fig. 1).

To avoid missing outliers or exceptions to the model, it was necessary to survey areas seemingly unlikely to host prehistoric villages. Traditional survey techniques in the mountains are difficult and in many cases waste valuable time. Considering the extreme topographical variability, linear surveys and transects for example often bisect uninhabitable areas including lakes, cliffs, and

Table 3
Landsat orthoimagery reclassification values.

Geocode value	Grayscale value (0–225)	Definition
0	0–60, 120–225	No Whitebark Pine
8	60–100	Mixed Stand with Whitebark/Burned Whitebark
9	100–120	Mostly Pure Whitebark Pine Stand

Table 5
Predictive geocode values of original six Wind River Villages.

Site name	Geocode value
High Rise Village	9
Burnt Wickiup Site	9
Mano Heaven	8
Mano-in-Stump	7
Camp Overlook	9
TFB Village	9

boulder fields. As expeditions into the mountains are exceptionally expensive with little time to conduct fieldwork, a less formal but extremely effective survey strategy was utilized. We blocked the survey area by geographical feature, which were assigned to multi-person teams to investigate. In this manner our team was able to focus on terrain that was likely to have hosted prehistoric occupants. Though not as meticulous as a formalized survey, our method proved to be efficient and successful.

During the four eight-day survey periods, over 50 archaeological sites were recorded spanning a comprehensive chronology of Wind River occupation from late-paleoindian to historic period (Stirn and Adams, 2012). Also accomplished was the recording of the highest archaeological site in Wyoming, and the first archaeological survey in Wyoming over 12,000 feet. The sheer amount of archaeological material recorded during this survey period was successful in highlighting the potential of our wilderness survey methodology. A combination of pre-season model building, horse supported expedition style camping, and geographical feature oriented surveying allowed for a large area to be covered while minimizing the expenditures and extra manpower usually required for investigating such an expansive landscape. However, of the many sites and artifacts that were recorded, most exciting discovery was that of 13 new alpine villages (Table 6).

Upon first glance, the predictive model appeared to be successful. Every one of the 13 newly recorded prehistoric villages was located within the two highest probability levels of the model (Table 6). Not every ‘hot spot’ (high probability area) identified by the model necessarily needed to host a village but rather, in order for success, every newly discovered village should be located in an identified ‘hot spot’. Simply because the villages are located in areas the model highlights does not mean the project was successful and a Whitebark Pine based settlement pattern could be confirmed. Without statistical confirmation, the results of the model could have been the result of a coincidental pattern or, a misinterpretation of the results. To be more certain of the predictive capabilities of the final model, the data was analyzed with a binomial test.

3. Determining predictive capabilities

To determine the mode’s predictive abilities, the survey area was first subcategorized by geocoding value, the site locations were analyzed with a binomial test, and the results were interpreted under other potentially influential variables.

The survey block represented an area of 234.2 km^2 labeled by geocode values 2 through 9 (low values least likely to host a village, high values most likely to host a village). The geocode values within the survey block were distributed normally (Table 7). Areas coded 8 and 9, in which every alpine village is located, represented 26% of the total survey area. In order to prove that the location of alpine villages was the result of a true pattern, it was first necessary to disprove the possibility that they could be explained by random coincidence. A null hypothesis assuming a random location model for alpine villages would argue that their distribution within the survey area is equally proportional to the distribution of the geocode categories throughout the survey area (see Table 7). In other words, if the distribution of alpine villages were truly random, we would expect that 1% be located in areas with geocode values of 2, 4% be located in geocode 3 areas, 15% in geocode 4 areas, and so on. This null hypothesis, however, does not accurately depict the distribution of alpine villages as 100% are located in areas with geocode values of 8 and 9, together representing only 26% of the survey area. A binomial test was conducted to determine the probability of this distribution.

Binomial Test:
Number of Trials (n): 19
Number of Successes (site located in level 8 or 9 zone): 19
Probability of Success (probability of a site being located in level 8 or 9 zone): .26
Probability of Results (probability of n-sites being located in level 8 or 9 zone): .00000000000076

Table 4
Raster weights for final model.

Weight (%)	Raster
50%	Whitebark pine/elevation
30%	Slope
20%	Aspect/solar rad.

4. Discussion

The binomial test identifies that the probability of all 19 sites (100% of the sample group) being located within an area representing only 26% of the survey block to be .00000000000076%. As such, the location of alpine villages in the Northern Wind River Range represent a statistically significant pattern and are not randomly distributed or the result of sheer coincidence. The specificity of the identified pattern suggests that a particular factor

Table 6
Brief description of new villages discovered during 2010 ground truthing sessions. Note that only obvious lodge pads were recorded. Villages with a size of ‘1 Lodge’ likely contain more, but, these were not verified during the initial 2010 survey.

Site name	Site number	Size	Geocode value (Centerpoint)
Inkwells-3	48FR7042	8+ Lodges	9
Inkwells-4	48FR7043	5+ Lodges	8
Inkwells-5	48FR7044	1 Lodge	8
Inkwells-7	48FR7046	10+ Lodges	8
Inkwells-18	48FR7057	1 Lodge	9
BM-1		1 Lodge	9
BF2010-3	48FR7033	2+ Lodges	9
BF2010-5	48FR7035	8–10 Lodges	9
Red Pass Village		6+ Lodges	9
K. Stirn Village	48FR7038	8+ Lodges	8
Williamson Corral	–	20+ Lodges	8
Lupine Lodge Site	–	3+ Lodges	8
RF-4 Village	–	5+ Lodges	8

Table 7
Distribution of geocode areas within survey blocks.

Geocoding value	Area within survey block (km^2)	Percent of total survey area
2	2.77	1.18%
3	9.93	4.24%
4	36.79	15.70%
5	54.11	23.09%
6	30.29	12.93%
7	37.58	16.04%
8	45.01	19.21%
9	17.75	7.57%

weighed heavily in determining the location of alpine villages. If a wider variety of variables acted upon the decision of initial village locations, more variation amongst their locations would be expected. It is dangerous to assume single-factor decision models, as most human activities are polythetic. However, the locations of the villages are so particular that the possibility of a task-specific settlement model cannot be ignored. This data by itself can be misconceiving though as it merely identifies *a* pattern, not necessarily *the* pattern of optimal Whitebark Pine access, which is hypothesized by the model. To discriminate against equifinality problems, the locations of the Wind River Villages were first scrutinized in terms of alternative models identified amongst other mountain ranges in the Western United States. These include Hunting (Steward, 1938; Benedict, 1992), lithic source proximity (Thomas, 2012), and water source proximity (Thomas and Bettinger, 1976).

4.1. Hunting

Hunting was undoubtedly a key component in the late-prehistoric utilization of the Wind River Range. In a single cut and fill lodge excavated at High Rise Village, over 50 projectile points were recovered within a 3 × 3 m. platform (Koenig, 2010). In addition, many lodges have revealed butchering and processing tools, hundreds of isolate projectile points have been recorded on survey, and some hunting structures including concealment pits and wooden sheep traps have been recorded in the alpine zone near village sites (Adams, 2010; Koenig, 2010; Schroeder, 2010a; Stirn and Adams, 2012). It should be noted though that in comparison to the Colorado Rockies where stone game drives are found on nearly every pass (Benedict, 1996), or Alta Toquimas in Nevada where hunting blinds are quite prevalent (Thomas, 2011), the high altitudes of the Wind River Range have provided very little evidence of large-scale communal hunting activities. High Rise Village however is located adjacent to a large Big Horn Sheep migration corridor offering easy access to hunting opportunities and at first glance, a conceivable intentionality towards a close proximity to hunting opportunities. However, upon considering modern and historic mammal distributions in the area, hunting opportunities above tree line in the Wind River Range are ubiquitous with most of the high plateaus and alpine passes offering high probabilities of hunting success.

Throughout eight years of fieldwork in the Wind River Range, an abundance of ungulates including big horn sheep (*Ovis canadensis*), moose (*Alces alces*), elk (*Cervus canadensis*), and antelope (*Antilocapra americana*) have been observed above tree line. The presence of our team has had little effect on these animals that are hunted frequently each year and in some cases, an entire herd of big horn sheep grazed comfortably throughout our active camp and excavation. In other words, there are animals seemingly omnipresent above tree line in the Wind River Range that are not only unafraid, but allow a known predator within close proximity. If taking into consideration the accounts of early explorer Osborne Russel, who saw "thousands of sheep from one location" (Russel, 1955) near the survey area, the number of ungulates in the Wind River Range was massive during the latest known occupation of some Wind River Villages. Considering the sheer blanket distribution of hunting opportunities that were likely present above tree line in the late prehistoric Wind River Range, it seems that successful hunting could have occurred nearly anywhere and there would have been no advantage to a strategic placement of villages based upon hunting. The additional possibility has been considered that villages were located in pine stands for concealment so that animals would not be frightened and could graze nearby. If this were the case however, we would expect, once again, a less specific distribution in the locations of villages throughout wooded areas at treeline. Because such a distribution does not exist, hunting and/or concealment cannot, on their own, explain the tight pattern observed amongst village locations.

4.2. Lithic resource proximity

The alpine ecotone of the Wind River Range offers bountiful lithic resource opportunities. A combination of *Madison Limestone* and *Flathead Sandstone* provide ample and distinguishable sources of high quality chert, quartzite, and steatite that have been utilized routinely throughout human occupation of the range (See Adams, 2006, 2010; Stirn and Adams, 2012). There does exist though a distinct pattern of lithic utilization between Archaic and late-prehistoric occupants of the area. Nearly every Archaic era site recorded above 10,000 feet in the Wind River Range is composed of lithic debitage, chipped, and groundstone tools made from extremely local if not on-site sources.

Whereas the Archaic site assemblage is entirely local, the late-prehistoric site assemblage is represented by more exotic materials that were acquired from distant sources. While some local material was acquired and used, a high proportion of chipped stone artifacts recorded in alpine village sites are cherts and obsidian from at least 70 miles away with some exceptions transported from even further sources (Adams, 2010; Koenig, 2010). In addition, the massive amount of ground-stone recorded within the villages are almost all *Absarokan Basalt* cobbles acquired over 20 miles to the north. The only local lithic material used in abundance by late-prehistoric villagers was steatite which was used to construct bowls, pipes, and other artifacts (Adams, 2006, 2010). However, not enough villages are located within close proximity to steatite sources to suggest a distinct correlation. Considering that late-prehistoric villagers of the Wind River Range primarily utilized materials from distant sources, lithic proximity can be discredited in explaining the observed settlement pattern.

4.3. Water proximity

Close accessibility to a sustainable water source is often a large concern for the modern camper, a mindset which has materialized as a bias within the analysis of prehistoric archaeological sites in conceivably inhospitable environments. This is certainly not the case for all hunter-gatherers and not even ubiquitous in North American alpine archaeology, however, interpretations of some late-prehistoric sites in Wyoming argue that water was not always *the* primary concern in site location. The Alcova Redoubt (Schroeder, 2010a) for example, is a late-prehistoric fortification likely constructed and inhabited by the occupants of some Wind River Villages. This particular site is located atop a highly sloped butte, was used for defensive purposes, and is nearly two miles from the closest water source. The Shirley Basin Site (Zeimans, 1975; Schroeder, 2013) is a late-prehistoric village site located in a similarly waterless environment. While the methods remain unknown, it does seem that late-prehistoric villagers in Wyoming were able to sustain large sites distanced from water sources.

Furthermore, hydrologically speaking there exists no need for a water based settlement pattern in the high Wind River Range. Water sources are abundant with springs, snow melt, glaciers, lakes, rivers, and streams located less than a quarter mile distance from any given point at tree line. As such, in the Wind River Range water sources are far too abundant and cannot account for the tight location pattern.

4.4. Whitebark Pine proximity

The nuts of the Whitebark Pine (*Pinus albicalus)* provide the most abundant and important food source in the Wind River Range (Adams, 2010), one of the most energy-rich food sources available in prehistoric North America (Surovell, 2000), and offer an extremely high caloric return rate (Rhode, 2010). The exploitation of pine nuts including Limber (*Pinus flexilis*) and Piñon (*Pinus edulis*) has long been considered a component of subsistence paradigms of Numic speaking cultures throughout the Great Basin and the mountains of northwestern Wyoming (Steward, 1938; Adams, 2010).

Healthy Whitebark Pine (albeit recent devastation from Pine Bark Beetle kill) are plentiful throughout the Wind Rive Range and are one of the most common species at tree line according to Fall et al. (1995), modern treeline in the Wind River Range was established around 3000 BP, which is contemporaneous to the earliest dated Wind River Village. As such, a correlation between alpine village location and the nearly blanket distribution of Whitebark pine cannot account for the specific pattern amongst the archaeological sites. However, the healthiest and most abundantly producing Whitebarks grow in moisture rich environments that receive ample year-round sunlight. Two more shapefiles were created using *ArcGIS's* 'solar analyst' and 'hydrology' functions and were cross-referenced with the location of residential structures within village sites. Interestingly, the location of every village coincided with predicted moisture sinks and areas that receive the most yearly sunlight in comparison to the surrounding landscape. It would appear then that late-prehistoric residential structures were located not just within Whitebark Pine forests, but specifically amongst the healthiest and highest producing trees in the stand. The results of this GIS model suggest that the pattern amongst Wind River villages can be best explained by the optimization of pine nut procurement. However, the model alone merely identifies a correlation to potential resource exploitation. Additional corroborating evidence is required to determine if that potential was actually exploited. Furthermore, the location of alpine villages in sunny areas could be interpreted as a preference for sunlight and warmth in a cool environment. But, a model based upon comfort does not translate in the archaeological record and cannot be easily tested.

The occurrence of grounstone cobbles, manos, and/or metates at archaeological sites near to nut producing pine trees has been interpreted as evidence of pine nut harvesting and processing (eg. Adams, 2010; Sheperd, 1992). Groundstone certainly would have been used for other tasks beyond nut processing, however, when found in close proximity to Whitebark Pine, it is likely that a primary function of groundstone was for pine nut preparation. Groundstone from the Lookingbill Site, located 20 miles north of the Wind River Range, validated this assumption as residue analysis detected the processing of pine nuts on the artifacts (see Frison, 1978; Sheperd, 1992).

The sheer amount of groundstone recorded in the Wind River Villages was at first astonishing. High Rise Village alone provided over 85 imported and heavily used *Absarokan Basalt* cobbles, and several *Flathead Sandstone* metates believed by Adams (2010) to have been utilized for processing a number of alpine plants but in particular, Whitebark Pine nuts. Every alpine village recorded in the Wind River Range thus far has presented numerous pieces of groundstone numbering a ratio of nearly two pieces of groundstone for every residential structure recorded. It is without a doubt that extremely large amounts of pine nut processing occurred at the Wind River alpine villages. Given the distribution of village sites specifically located within dense Whitebark Pine stands along with the sheer abundance of groundstone observed within the sites, there is high potential that the settlement pattern of the Wind River villages can best be explained by the procurement and processing of Whitebark Pine nuts. Other variables discussed earlier in this paper likely maintained important roles in the lives of prehistoric Wind River occupants, but, unlike pine nut procurement, these other variables simply cannot account for the specificity of the observed pattern.

5. Conclusion

The outcome of this project displays that in the Northern Wind River Range, the location of late-prehistoric cut and fill lodge villages can be accurately predicted based upon the occurrence of Whitebark pine stands. Despite the predictive model's success in this specific task, it does posses some analytical shortcomings. The use of remote sensing to identify subsistence opportunities and in turn, site locations, barely touches upon the intricate relationship between prehistoric humans and their environments. By focusing on the task-specific variables associated with the economics of pine nut consumption, this model does not take into consideration other non-quantifiable influencers such as cultural conceptions and causations behind landscape use (see Bender and Wright, 1988; Walsh et al., 2006). In addition, the model highlights the intentionality behind the original placement of sites that were continuously occupied in some cases for thousands of years. It is dangerous to transfix the reasons a particular group first inhabited a site onto those who later resided in the same location.

Despite its shortcomings, this project can be considered successful in that it identified a relationship between alpine villages and optimal locations for pine nut procurement. Furthermore, this model confirms the power of the polythetic approach by showing that several noncultural and topographic variables can be combined to predict the location of archaeological sites and consequently, identify cultural factors underlying their pattern. The results were not intended to be comprehensive but rather heuristic as they generate more questions than they answer. To paraphrase a section of Halstead (1998), optimizing models can only be used securely as heuristic measures of resource potential, and independent evidence should be sought that this potential was actually exploited. The positive identification of a subsistence oriented settlement pattern generates a platform to launch more specific scientifically oriented or theoretical research questions.

The link between village site location and pine nuts in the Wind River Range raises many queries in the interpretation of hunter-gatherers at altitude in North America. Was hunting as important to prehistoric alpine subsistence models such as Bettinger (1994) and Benedict (1992) suggest? If pine nuts were intensively harvested as early as 3,000 BP, as radiocarbon results from High Rise Village imply (Adams, 2010), what role did this particular resource play in shaping communal social structures? If alpine villages were initially located and utilized primarily for pine nut consumption, how does this weight the typically used *push vs. pull* models to explain mountain inhabitation (Adams, 2010; Aldenderfer, 2006; Bettinger, 1991; Morgan et al., 2012)? Exploring the above questions would greatly advance our understanding of both the seemingly sudden occurrence of late-prehistoric alpine villages, and, the more general exploitations of high altitudes by hunter-gatherers. The high likelihood that alpine villages were initially constructed to take advantage of a specific plant resource suggests that the sites' occupants possessed an intimate familiarity with their environment which would not be expected if the population was suddenly 'pushed' into the mountains by an event such as population pressure. Rather, a deep knowledge of Whitebark Pine ecology (eg. understanding where specifically the healthiest and most abundantly producing trees grow within a stand) would be more characteristic of a population that were not strangers to the mountains and had routinely frequented the alpine ecotone.

Despite supporting such a paradigm, this predictive model cannot by itself prove the reasons underlying the construction of alpine villages. It can, however, provide a direction for more specific research and analyses. Residue analysis of groundstone tools collected from alpine villages would greatly aid our understanding of their association to pine nut processing. Furthermore, an increased resolution of alpine human palaeoecology before villages is of utmost priority. If we are to argue that alpine villages represent either a sudden intensification of alpine resources, or, a changed expression of a long established mountain tradition, it is absolutely necessary that we understand what came before.

The above questions represent few of many that must be answered in order to more fully understand the intricate relationship between prehistoric humans and high altitude environments. The development and utilization of the Wind River village predictive model marks a step in that direction. The success of this project is a catalyst that provides a solid foundation for more specific questions to be generated, researched, and hopefully answered.

Acknowledgments

First and foremost, a big thank you to Richard Adams for introducing me to archaeology as a young teenager and providing never-ending guidance ever since. Many thanks to Rebecca Sgouros, Orrin Koenig, Robert Kelly, and David Hurst Thomas for comments, edits, and advice. Additional thanks to Orrin for planting this idea in my head during a campfire poster session at 11,500 ft., Bryon Schroeder for advice, planning, and guidance, to Bill Ringle for helping me work through GIS problems, to those who have worked with us on many occasions: Orrin Koenig, Tory and Meredith Taylor, John Lund, and Carolyn Gillette. And those who lent their help on a few expeditions: Sarah Kennedy, Kelly Stirn, Will Stirn, Rebecca Sgouros, and the many number of Dubois locals who have spent time with us in the hills and taken care of us in their community. Immeasurable thanks to Heath and Sarah Woltman for helping us with logistics and transporting our team and gear deep into the mountains. Additional thanks to the Dubois Museum and to the funding agencies who have made these trips feasible: the George C. Frison Institute, the Abernethey Research Foundation, the Explorers Club, and everyone who has been kind enough to donate to our work, thank you.

References

Adams, R., 2006. The Greater Yellowstone ecosystem, Soapstone Bowls, and the Mountain Shoshone. World Archaeol. 38, 528–546.

Adams, R., 2010. Archaeology with Altitude: Late Prehistoric Settlement and Subsistence in the Northern Wind River Range, Wyoming (Unpublished PhD dissertation). Department of Anthropology, University of Wyoming, Laramie.

Adams, R., Schroeder, B., Koenig, O., 2009. Prehistoric alpine villages in the Wind River Range, Wyoming. In: Paper Presented at the Ninth Biennial Rocky Mountain Anthropological Conference, Gunnison, Colorado.

Aldenderfer, M., 2006. Modeling plateau peoples: the early human use of the world's high Pleateaux. World Archaeol. 38, 357–370.

Bender, S., 1980. High country adaptations. Plains Anthropol. 89, 181–197.

Bender, S., Wright, G., 1988. High-altitude occupations, cultural process, and high plains prehistory: retrospect and prospect. Am. Anthropol. 90, 619–639.

Benedict, J., 1974. Early occupations of the Caribou lake site, Colorado Front Range. Plains Anthropol. 19, 1–4.

Benedict, J., 1992. Footprints in the snow: high altitude cultural ecology of the Colorado Front Range, USA. Arct. Alp. Res. 24, 1–16.

Benedict, J., 1996. The Game Drives of Rocky Mountain National Park (Research Report No. 7). Center for Mountain Archaeology, Ward, Colorado.

Bettinger, R., 1991. Aboriginal occupation at high altitude: alpine villages in the White Mountains of Eastern California. Am. Anthropol. 93, 656–679.

Bettinger, R., 1994. How, when, and why Numic spread. In: Madsen, D., Rhode, D. (Eds.), Across the West: Human Population Movement and the Expansion of the Numa. University of Utah Press, Salt Lake City, pp. 44–55.

Brandt, R., Groenewoudt, B., Kvamme, K., 1992. An experiment in archaeological site location: modeling in the Netherlands using GIS techniques. World Archaeol. 24, 268–282.

Fall, P., Davis, P., Zielinski, G., 1995. Late Quaternary Vegetation and Climate of the Wind River Range, Wyoming. Quat. Res. 43, 393–404.

Frison, G., 1978. Prehistoric Hunters of the High Plains. Academic Press, New York, NY.

Halstead, P., 1998. Mortality models and milking: problems of Uniformatarianism. Anthropozoologica 27, 3–20.

Husted, W., 1965. Early occupation of the Colorado Front Range. Am. Antiq. 30, 494–498.

Kershaw, L., MacKinnon, A., Pojar, J., 1998. Plants of the Rocky Mountains. Lone Pine, Edmonton.

Koenig, O., 2010. Does This Hearth Have a Home? A Hearth Centered Spatial Analysis (Unpublished Masters thesis). Department of Anthropology, University of Wyoming, Laramie.

Larson, M.L., Kornfield, M., 1994. Betwixt and between the Basin and the Plains: the limits of Numic expansion. In: Madsen, D., Rhode, D. (Eds.), Across the West: Human Population Movement and the Expansion of the Numa. University of Utah Press, Salt Lake City, pp. 200–210.

Llobera, M., 2012. Life on a pixel: challenges in the development of digital methods within an "Interpretive" landscape archaeology framework. J. Archaeol. Method Theory 19, 495–509.

Losey, A., 2012. Risk and climate at high altitude, a Z-score model case study from Wyoming's Wind River Range. In: Paper Presented at the 33rd Great Basin Anthropological Conference, Stateline, Nevada.

Madsen, D., Rhode, D. (Eds.), 1994. Across the West: Human Population Movement and the Expansion of the Numa. University of Utah Press, Salt Lake City.

Morgan, C., Losey, A., Adams, R., 2012. High-altitude hunter-gatherer residential occupations in Wyoming's Wind River Range. North Am. Archaeol. 33, 35–79.

Rhode, D., 2010. Food values and return rates for Limber Pine (*Pinus flexilis*). In: Poster Presented at the 32nd Annual Great Basin Anthropological Conference, Layton, Utah.

Russel, O., 1955. Journals of a Trapper. In: Hains, A. (Ed.). University of Nebraska Press, Lincoln.

Schroeder, B., 2010a. Plan of Attack, the Alcova Redoubt: a Protohistoric Fortification in Central Wyoming (Unpublished Masters thesis). Department of Anthropology, University of Wyoming, Laramie.

Schroeder, B., 2010b. If it walks like a duck and quacks like a duck… fortification use by the Eastern Shoshone. In: Paper Presented at the 32nd Annual Great Basin Anthropological Conference, Layton, Utah.

Schroeder, B., 2013. Test Excavation Results and Residential Feature Evaluation for 48AB301: the Shirley Basin Lodge Site (A report prepared for and archived at the Rawlins BLM Field District Office, Rawlins, Wyoming).

Sheperd, R., 1992. A Cultural Model for Groundstone Use in the Middle Rocky Mountains: the Helen Lookingbill Site (Unpublished Masters thesis). Department of Anthropology, University of Wyoming, Laramie.

Steward, J., 1938. Basin-plateau Aboriginal Sociopolitical Groups. In: Bureau of Ethnology Bulletin 120. Smithsonian Institution.

Surovell, T., 2000. Early Paleoindian women, children, mobility and fertility. Am. Antiq. 65, 493–508.

Stirn, M., Adams, R., 2012. The Inkwells 2010 Archaeological Project, Shoshone National Forest, Fremont County, Wyoming (Report prepared for and archived at the Wyoming State Historical Preservation Office, Laramie, Wyoming).

Stirn, M., Schroeder, B., Adams, R. Mountain Misconceptions: Why Wyoming's Prehistoric High-altitude Occupations Are Important (unpublished manuscript).

Thomas, D.H., 2013a. Alta Toquima: why did foraging families spend summers at 11,000 feet? In: Janetski, J., Parezo, N. (Eds.), Archaeology for All Times: Papers in Honor of Don D. Fowler. University of Utah Press, Salt Lake City.

Thomas, D.H., 1982. The 1981 Alta Toquima Village Project: a Preliminary Report. Desert Research Institute, Social Sciences Center (Technical Report Series, no. 27).

Thomas, D.H., 1994. Chronology and the Numic expansion. In: Madsen, D., Rhode, D. (Eds.), Across the West: Human Population Movement and the Expansion of the Numa. University of Utah Press, Salt Lake City, pp. 56–58.

Thomas, D.H., 2011. Personal Communication.

Thomas, D.H., 2012. The chert core and the obsidian rim: some long-term implications for the Central Great Basin. In: Rhode, D. (Ed.), Meetings at the Margins: Prehistoric Cultural Interactions in the Intermountain West. University of Utah Press, Salt Lake City, pp. 254–270.

Thomas, D.H., 2013b. Engineering Alta Toquima: social investments and dividends at 11,000 feet. In: Zedeño, M., Scheiber, L. (Eds.), Engineering Mountain Landscapes. University of Utah Press, Salt Lake City.

Thomas, D.H., Bettinger, R., 1976. Prehistoric Piñon ecotone settlements of the Upper Reese River Valley, Central Nevada. Anthropol. Pap. Am. Mus. Nat. Hist. 53, 263–366.
Verhagen, P., Whitley, T., 2012. Integrating archaeological theory and predictive modeling: a live report from the scene. J. Archaeol. Method Theory 19, 49–100.
Walsh, K., Richer, S., Beauliau, J.L.D., 2006. Attitudes to altitude: changing meanings and perceptions within a 'marginal' alpine landscape- the integration of paleoecological and archaeological data in a high-altitude landscape in the French Alps. World Archaeol. 38, 436–454.
Wheatley, D., Gillings, M., 2002. Spatial Technology and Archaeology: the Archaeological Applications of GIS. Taylor & Francis, London.
Zeimans, G., 1975. 48AB301: a Late Prehistoric Site in the Shirley Basin of Wyoming (Unpublished Masters thesis). Department of Anthropology, University of Wyoming.