Journal of Archaeological Science 37 (2010) 42–51

Contents lists available at ScienceDirect

Journal of Archaeological Science

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

Bighorn hunting, resource depression, and rock art in the Coso Range, eastern California: a computer simulation model

Alan P. Garfinkel [a,*], David A. Young [b,d], Robert M. Yohe II [c,e]

[a] California Department of Transportation, 2015 East Shields Avenue, Suite 100, Fresno, CA 93726-5428, USA
[b] Physical and Life Sciences Directorate, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA
[c] Department of Anthropology and Sociology, California State University, Bakersfield, 9001 Stockdale Highway, Bakersfield, CA 93311, USA

ARTICLE INFO

Article history:
Received 21 April 2009
Received in revised form
31 July 2009
Accepted 31 August 2009

Keywords:
Computer simulation
Rock art
Resource depression
Bighorn
Coso Range
California
Hunting religion
Prehistoric forager ecology

ABSTRACT

The extraordinary record of prehistoric rock art depicting tens of thousands of animal images in the Coso Range of eastern California provides an opportunity to study the relationship between aboriginal hunting, forager ecology, bighorn prey population levels, and the production of rock art. We review archaeofaunal evidence that the Coso desert bighorn sheep population was strongly depleted during the Newberry era after 1500 B.C. We discuss the dating of the rock art and show a correlation between bighorn depletion and increased rock art production. These data are consistent with the arrival of Numic foragers ca. A.D. 600 who competed with the Coso Pre-Numics and eventually terminated the Coso rock art tradition. An ecological predator-prey computer simulation of the human populations (Numic and Pre-Numics), the sheep population, and the rock art "population", demonstrates these proposed interconnections and gives a reasonable fit to the observed rock art production rate.

1. Introduction

The Coso Range of eastern California has been occupied by humans since the Paleoindian period. The early inhabitants of the area left pecked rock images in very large numbers. Beginning roughly 2000/1500 B.C. and ending about A.D. 1300, aboriginal people left an elaborate record of hunting scenes with bighorn sheep (*Ovis canadensis*) as their prey. Over time the images become more naturalistic or realistic, larger in size and the image count increases remarkably during its peak period of production and then inexplicably at its peak after about A.D. 1300 the art ceased being produced. There are at least 100,000 individual rock art images represented in the Coso petroglyph record and it is estimated that about half are depictions of bighorn sheep. The Coso Rock Art Complex is one of the largest concentrations of rock drawings in all of North America.

Such a striking array of naturalistic or realistic images is very unusual for the Desert West and this startling record begs explication. Early researchers posited that the tremendous numbers of bighorn representations were indicative of vast herds of bighorn sheep that occupied the area in the distant past. Prehistorians implied that periods of peak sheep hunting correlated with the greatest abundance of bighorn rock art images. Prehistoric animal images were part of a bighorn sheep cult. These images figured in increase rites designed to ensure the return of game animals, human, plant, and animal fecundity, and the health and well-being of the Coso people and their way of life (Garfinkel, 2006; Grant et al., 1968; Hildebrandt and McGuire, 2002; Heizer and Baumhoff, 1962).

This paper provides a population estimate for the meta-population (a group of spatially separated or isolated animals that occupy a fragmented habitat, have limited exchange of individuals, and consist of a number of animal groups that interact in a restricted geographic area) of Coso bighorn and simulates the population dynamic of the local herds in light of human predation. It evaluates the proposition of whether it is possible that bighorn were overharvested and depleted. Archaeofaunal data are adduced to provide a timeline, trajectory, and independent evaluation of the plausibility for bighorn resource depression. It also posits that the Coso inhabitants were seeing population pressure and conflicting land use issues from the neighboring Numic groups to the north

* Corresponding author. Tel.: +1 (559) 243 8400.
E-mail addresses: alan_gold@dot.ca.gov (A.P. Garfinkel), young5@llnl.gov (D.A. Young), robert_yohe@firstclass1.csubak.edu (R.M. Yohe II).
[d] Tel.: +1 (925) 422 7231.
[e] Tel.: +1 (661) 664 3457.

0305-4403/$ – see front matter
doi:10.1016/j.jas.2009.08.010

moving into their territory from the Owens Valley. Standard ecological competition and predator-prey models are applied to simulate human and sheep populations. The simulation models sheep hunting across time and also models rock art production. We develop a model of the competing Numic and pre-Numic exploitation and land use strategies and close by providing a partial explanation of why the Coso Range was such an extraordinary focus of rock art expression.

2. Aboriginal ecology and resource depression

There is a continuing debate about the capacity of foraging societies to manage their prey species and avoid resource depletion. Some writers assert that Native American population numbers were too low or their technology too simple to have a significant impact (Hunn, 1982; Lyman and Cannon, 2004; Yochim and Michael 2001). Others argue that indigenous Americans were too knowledgeable about prey population dynamics to overexploit them or they managed resources based on a conservation ethic (Bettinger,1976; Bodley, 1990:3; Booth and Jacobs, 1990:31; Nelson, 1983; Repetto and Holmes, 1983:612; Stoffle, 2005).

It is often asserted that Native religious beliefs prevented them from over-exploiting their resources (e.g., Nelson, 1983; Stoffle, 2005). Native peoples do tend to view animals as part of their extended spiritual family. Propitiation ceremonies, post-mortem animal funerals, and ritual atonement for the killing of animals (Harrod, 2000; Hultkrantz, 1981, 1987) often ensured hunting success. Yet many groups had inaccurate ideas about the causes of resource depletion and consequences of their continued procurement (Lee and Daly, 1999; Raven, 1990). If game were scarce, it was not due to overexploitation but a consequence of the displeasure of deities. Events in the natural world such as declining resources or unsuccessful hunts arose from offenses to supernatural animal masters and ritual violations (Garfinkel, 2006, 2007; Harrod, 2000:122).

In addition, there is increasing evidence that aboriginal foraging populations could and did overexploit game (Broughton, 1994, 2002; Grayson, 2001; Hames, 2007; Jones et al., 2008; Kay, 1994; Kay and Simmons, 2002). A rather exhaustive review of anthropological and historical case studies concluded that aboriginal people "made no systematic efforts to conserve game species and historically decimated many of those upon which they depended" (Hames, 2007; *sensu* Krech, 1999, 2005).

Byers and Broughton (2004), commenting on prehistoric hunting practices in the Great Basin and their effect on the distribution and abundance of large game, assert that,

"Despite generally favorable environmental conditions for artiodactyls [during the late prehistoric]… in certain contexts,

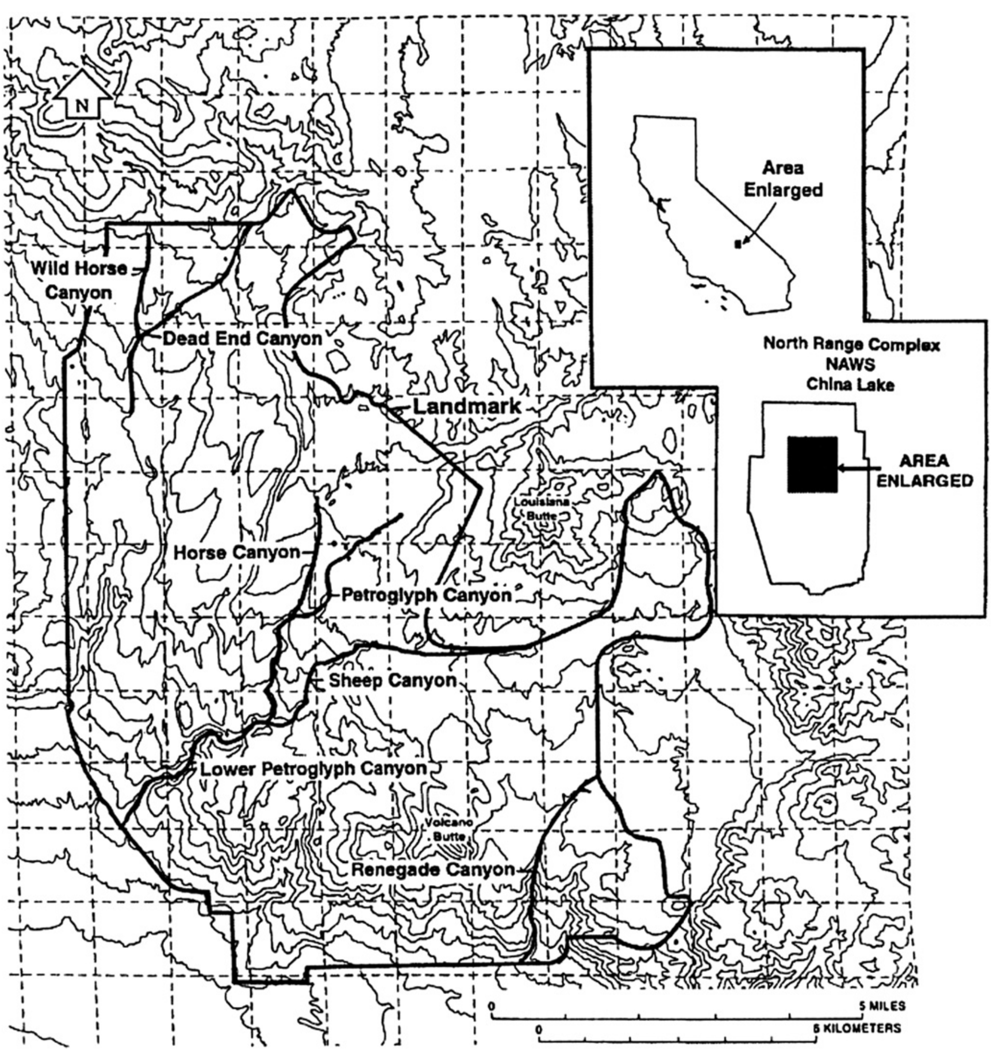

Fig. 1. Location map of Coso Region in California.

human hunting pressure appears to have ultimately overtaken them, *causing substantial population declines* (italics and copy within brackets added)".

Artiodactyl numbers apparently declined substantially due to prehistoric aboriginal predation in the eastern Great Basin during the period from A.D. 450 to 1050 (Janetski, 1997). In California populations of certain high-ranked prey taxa were depressed during the prehistoric era (cf. Broughton, 1994, 2002; Hildebrandt and Jones, 2002). In this paper we accept the depletion hypothesis and develop a model with a strong relationship between bighorn depletion and the production of rock art in the Coso Range.

3. Coso rock art

The Coso Rock Art Complex is located largely within the Coso Range of eastern California and is mostly found within the Naval Air Weapons Station, China Lake (Fig. 1). Impressive numbers of petroglyphs occur on basalt flows, canyon walls, and isolated boulders. The petroglyphs are associated with various archaeological sites: rockshelters, hunting blinds, dummy hunters (stacked stone representations of human hunters), rock rings, milling features, open-air middens, obsidian quarries, and flake scatters. The Naval facility provides restricted access, and petroglyphs are well preserved and largely protected.

Most drawings are in a 90 square-mile area where at least 35,000 elements have been identified. Region-wide surveys provide a conservative estimate of greater than 100,000 images for all periods combined (Hildebrandt and McGuire, 2002; Keyser and Whitley, 2006). The Coso Complex is apparently one of the largest rock art concentrations in the United States and Canada (Grant et al., 1968). One of their more remarkable characteristics is their realism or naturalism (Figs. 2 and 3). Representations of game animals (chiefly bighorn), hunters, weaponry (atlatls, bows, and arrows) and ritual associations (dancers, costumes, bullroarers, etc.) form a significant component of these images. Researchers have labeled this tradition as the Coso Representational Style (Schaafsma, 1986:218). Bighorn drawings are known throughout western North America, and Coso sheep exceed the total for all other regions combined (Grant et al., 1968:34).

3.1. Coso prehistory and rock art dating

The Coso Region has seen decades of intensive study (Garfinkel, 2007; Gilreath and Hildebrandt, 1997, 2008; Grant et al., 1968; Lanning, 1963; and sources within). Coso prehistory has been divided into the Mojave (10,000 B.C.–6500 B.C.), Little Lake (6500 B.C.–1500 B.C.), Newberry (1500 B.C.–A.D. 300), Haiwee (A.D. 300–A.D. 1300), and Marana (A.D. 1300–historic) periods.

In brief, Newberry Period activities emphasized intensive obsidian quarrying and toolstone reduction, ungulate hunting, and rock art production. Several subsistence–settlement shifts, beginning ca. A.D. 600, are coincident with a cultural disjunction in the following Haiwee Period. These changes include a decline in large game hunting, an initial and growing emphasis on dryland hard seeds, the beginning of intensive green-cone pinyon nut use, and the mass harvest of easily procured and abundant small game (Garfinkel, 2007; Gilreath and Hildebrandt, 1997, 2008). The abundance and distribution of obsidian hydration measurements have been used as proxy indicators of the timing and intensity of these shifting patterns (Garfinkel, 2003;[1] Gilreath and Hildebrandt 2008). The changes manifest in the Haiwee era, appear to reflect Numic in-migration and distinctively different adaptations (Bettinger and Baumhoff, 1982; Garfinkel, 2007).[2]

Fig. 2. Coso Representational rock art, Coso Style sheep, bowmen, and more ancient, patinated abstract and geometric petroglyph elements.

The initiation of the Haiwee era is coterminous with the introduction of the bow and arrow. The inception of bow and arrow use has been well established based on dozens of radiocarbon determinations. These age determinations are associated with chronostratigraphic correlations testifying to the advent of small Rose Spring Series arrow points (Yohe, 1992, 1997).

Although proximity is no proof of association, repeated correlations of single-component archaeological sites in direct association with distinctive rock art styles have led to the establishment of plausible and reasonably sound chronological inferences (Robins and Hays-Gilpin, 2000:234). Fortunately, Coso petroglyphs have been the focus of large scale chronometric studies based on decades of intensive scientific research (Gilreath, 1999; Gilreath and Hildebrandt, 1997, 2008; Grant et al., 1968; Hildebrandt and Ruby, 2006; Rogers, in press). These efforts support rock art associations with distinctive time diagnostics (arrow and dart points dating to restricted time spans). They also provide persuasive evidence that petroglyph sites are directly associated with

[1] Evidence has been presented elsewhere to support the notion that a population replacement may have occurred in the Coso Region ca. A.D. 1000–1300 that would have been associated with a series of radical shifts in adaptive strategies, exchange patterns, and ideological systems (Garfinkel 2006, 2007). Alternately, no such ethnolinguistic discontinuity may exist, and changes in subsistence-settlement, socio-political, and ceremonial organization may have been a function of indigenous, autochthonous culture change and loss (cf. Steward 1968). The relationships of rock art abundance, population size, and bighorn sheep ubiquity are not necessarily tied to such a population replacement. The changes identified are more pivotally synchronous with changes in technology (i.e. the introduction of the bow and arrow), the continued over-harvesting of bighorn, and the associated peak production and elaboration of Coso rock art. In short, it is clear that significant cultural changes occurred in this region during this period; whether or not this is the result of population in-migration remains to be more clearly demonstrated.

[2] The relationship and affinity of particular archaeological assemblages with either a Numic or non-Numic (aka pre-Numic) population is subject to considerable controversy (cf. Madsen and Rhode, 1994). Admittedly, it is very difficult to clearly associate archaeological materials with particular ethnolinguistic entities. Some researchers are persuaded and feel that the weight of present evidence supports a distinctive discontinuity and population replacement in the Coso Range most likely signaled by the in-migration of the Numa during the late prehistoric era. Such a cultural manifestation would appear to be marked by Desert Side-notched and Cottonwood points, "Numic Scratched" rock art, and distinctively different adaptive strategies (cf. Bettinger and Baumhoff 1982; Hildebrandt and McGuire 2002; Gilreath 2007; Gilreath and Hildebrandt 2008). Other prehistorians are not so convinced, see continuity in the Coso archaeological record, and insist on the plausibility of an in place, autochthonous cultural devolution perhaps precipitated by cultural instabilities (Pearson 2002; Yohe and Sutton 1999, 2000; Whitley 1998). Nevertheless, an increase in Coso religious display is undoubtedly correlated with a dramatic decline in artiodactyl exploitation.

Fig. 3. Coso Representational rock art, life-sized (7 ft in length from nose to tail) bighorn sheep in Big Petroglyph Canyon.

discrete, single-component prehistoric loci dated by substantial samples of temporally restricted, Coso obsidian hydration measurements, correlated with similarly aged time diagnostic point types and associated with distinctively different depictions of rock art subjects and styles (cf. Gilreath and Hildebrandt, 2008; Grant et al., 1968; Hildebrandt and Ruby, 2006; Rogers, in press).

Additionally Coso rock art has been evaluated with a host of rigorous temporal controls based on their subject matter (depictions of darts and atlatls versus bows are arrows), style seriations (bighorn form depictions, atlatl styles, and general subject matter – dogs, atlatls and their forms, bow and arrow hunters, medicine bags, Coso style bighorn, patterned body anthropomorphs), superimposition (abstract pecked – the oldest, representational pecked – intermediate, and scratched – recent and late dating), relative revarnishing, and experimental X-ray fluorescence dating. The most recent dating refinements rely on a large scale inventory of 87 sites and an analysis of 19,202 petroglyph elements (Gilreath, 1999; Gilreath and Hildebrandt, 2008).

Based on these studies most prehistorians, now familiar with Coso rock art diachronic production patterning, agree that Coso petroglyphs were sporadically produced during the Mojave and Little Lake periods. More intensive, regular activity and peak production occurs in the Newberry (1500 B.C.–A.D. 300) and early Haiwee eras (A.D. 300–1000). Of the nearly 100 obsidian hydration measurements associated with Coso rock art, more than half are late Newberry and Haiwee period determinations (1000 B.C.–A.D. 1300; 50 hydration measurements with a sample of 96 readings; typically associated with time diagnostic Elko, Humboldt, and Rose Spring point styles). An abrupt cessation of rock art production occurs no later than A.D. 1300 (94% of 505 hydration measurements fall into earlier time periods).

This abrupt cessation of Coso rock art manufacture is signaled by replacement with a simple scratched style believed to be indicative of a disruption by an exotic population (Bettinger and Baumhoff, 1982; Garfinkel, 2007; Gilreath and Hildebrandt, 2008; Hildebrandt and Ruby, 2003; Hildebrandt and McGuire, 2002:245).

We see the Numic in-migration into the Cosos as a distinct expansion emanating from the neighboring Owens Valley. This trajectory is fueled by indigenous population pressure from the adjacent, more well-watered, resource-rich territory bordering the eastern Sierra. Population incursions and in-migration of exotic colonizers into traditional Coso territory naturally spawned conflicting land use patterns, increased tension, and intense competition for limited available subsistence resources. This pattern is an important agent helping to explain the extraordinary fluorescence of rock art production dating to the Haiwee Period (A.D. 300–1300).

Scratched rock art (Fig. 4) is exclusively late and only characteristic of the Marana Period co-occurring with Desert Side-notched and Cottonwood points. Scratched elements have little to no revarnishing and overlie Coso Representational and abstract pecked designs. Older Coso Representation and Great Basin Abstract pecked petroglyph elements never superimpose scratched (Gilreath and Hildebrandt 2008). Scratched rock art elements are presumed to be a cultural marker representing the in-migration of the Numic and are a means of legitimizing their use of an otherwise unfamiliar landscape (Quinlan and Woody 2003; Gilreath and Hildebrandt 2008).

In summary, a wide variety of chronometric analyses confirms that Coso petroglyphs were not made during the last 700 years (*contra* Keyser and Whitley, 2006:18; Whitley, 2005) and were exclusively a pre-Marana Period expression with a distinctive late Newberry and early Haiwee emphasis. Single-component obsidian dates support this chronology and suggest that rock art production began in the Mojave Period by ca. 8000 B.C. (*sensu* Garfinkel, 2007; Gilreath, 1999; Gilreath and Hildebrandt, 2008).

For the purpose of comparison with our simulation model, we need data on the number of rock art images produced over time. From the various sources dating the images, we obtain an estimate of 25% before 1500 B.C., 10% between 1500 B.C. and A.D. 1, 20% between A.D. 1 and A.D. 600, and 45% between A.D. 600 and A.D. 1300. These estimates are based on several criteria: the relative frequency of temporally diagnostic images of atlatls versus bows and arrows, the relative frequency of single-component Coso petroglyphs sites and their associated obsidian hydration measurements (sites, $n = 12$; hydration measurements, $n = 131$), and experimental X-ray fluorescence (XRF) dates of Coso petroglyph elements ($n = 28$). The ages obtained through XRF exhibit a relative distribution that are closely correlated with the dates of

Fig. 4. Numic Scratched and Coso Style bighorn at the mouth of Nine Mile Canyon.

obsidian hydration (Gilreath and Hildebrandt, 2008: Figs. 11 and 12; Lytle, 2008; Lytle et al., 2006; Rogers, in press).

3.2. Hunting magic, hunting technology, increase rites, and the Coso petroglyphs

The prehistoric rock art of the Coso Range provides a valuable record of the Prenumic foraging people who preceded the Numic foragers. By counting and approximately dating the rock images, we can gain a quantitative measure of human activity in the period 1500 B.C.–A.D. 1300. The ubiquity of bighorn images has stimulated the hypothesis that the Prenumic rock image makers were performing "hunting magic" (increase rites) characteristic of forager hunting rituals to increase the sheep that they targeted for food (Garfinkel, 2006, 2007; Garfinkel et al., 2007; Gilreath and Hildebrandt, 2008; Grant et al. 1968; Guenther, 1988:194; Heizer and Baumhoff, 1962; Hildebrandt and McGuire, 2002; McGuire and Hildebrandt, 2005).

Notwithstanding the central importance of hunting magic and increase rites models for explaining Coso rock art, it is acknowledged that sheep imagery became an overarching symbol certainly bordering on an obsession for Coso artisans. This symbology and hallmark animal ceremonialism must have served multiple functions and had a number of meanings. As it developed and morphed through the many centuries and millennia of its exposition, the bighorn came to be associated with other concepts than simply that of a prey species. During its final period of rendition it does appear that the bighorn had significantly more to do with associations of fecundity for plants and smaller game animals, also likely rain, and the general well-being of the Coso world. These changes in the native use of this imagery were correlated with subsistence shifts away from upland large game hunting to a greater (though not exclusive) emphasis on small game and hard seeds (Garfinkel et al., 2009).

It is clear that the atlatl was the primary hunting weapon during the Newberry Period. The bow and arrow made their appearance at the onset of the Haiwee, about A.D. 200/300 (Yohe, 1992, 1994, 1999, 2000). This change may have had dramatic consequences for the depletion of the local bighorn (see Madsen, 1986). The bow and arrow offers longer-range killing power and a number of physical and mechanical advantages over the dart and atlatl. This new technology rapidly replaced the earlier weaponry over nearly all of North America during a period of just a few centuries (Justice, 2002:57; Yohe, 1992).

A more effective hunting technology and a lack of awareness of the optimal harvest rate could have led to a rapid depletion of the sheep. We believe that the introduction of the bow, sheep depletion, and the increased rate of rock art production are closely linked (cf. Grant et al., 1968; Yohe and Sutton, 1999, 2000).

4. Coso Region archaeofauna

A synthesis of regional archaeofaunal data for southeastern California has been formally reported in several publications (Garfinkel, 2006; Gilreath and Hildebrandt, 2008; Hildebrandt and McGuire, 2002; McGuire et al., 2007). These data derive from over 75 prehistoric sites in the general Coso region. Review of these data, comprising nearly 20,000 identifiable faunal elements, indicate a ten-fold higher frequency of artiodactyl exploitation during the Newberry and Haiwee periods than the Marana interval. Artiodactyls by element frequency are estimated at 70% for the Newberry and 53% for the following Haiwee with a minor representation of 5% in the recent Marana (Fig. 5). This is all the more remarkable because of the 50–1 ratio of bighorn to deer that has been identified for Newberry Period components (Gilreath and Hildebrandt, 2008:17, Table 3).

At the perimeter of the Coso Range, faunal data from Portuguese Bench (CA-Iny-2284), further testifies to the importance of sheep during the Late Newberry (A.D. 1–300) and Early Haiwee (A.D. 300–1000) periods (Gilreath 2000). Within the central Coso Range, CA-Iny-2847 and Ray Cave show a similar pattern (Panlaqui 1974; Gilreath 2000).

4.1. Rose spring

Locus 1 of the Rose Spring site, on the western margin of the Coso Range, shows a dramatic decline in vertebrate use at the time of the introduction of the bow and arrow (Yohe, 1992:140, Table 5; Yohe and Sutton, 1999, 2000). Ungulate bones (bighorn or antelope) predominate (in number and weight) in excavation levels dating to the middle and late Newberry Period (500 B.C.–A.D. 300).

The total metric volume of animal bone peaks at just under 60 g and the number of individual artiodactyl identifications is highest ($n = 39$) in the most fauna-rich late Newberry excavation levels. The faunal remains volume drops to between 8 and 28 g and remains at these greatly reduced levels throughout the Haiwee era. Large mammal remains (as a percentage of bone weight) peaks at 60 percent of total bone weight in the Newberry and sees a dramatic reduction to between 5 and 25 percent of the total faunal inventory during the Haiwee. The number of artiodactyl bones in the most heavily represented excavation contexts also drops to less than 25% of the former values ($n =$ less than or equal to 9 specimens). Large mammal exploitation, in general, also drops to the lowest levels during the Haiwee Period (A.D. 300–1300) and Marana (A.D. 1300 – Historic) intervals.

As a percentage of the total faunal assemblage, hare (*Lepus californicus*) and small mammal contribute significantly larger portions to the faunal record after A.D. 1000 than at any time before. Thus over-harvesting of artiodactyls likely occurred during the Newberry and Haiwee periods such that the number of large game animals was significantly reduced and perhaps depleted. Such a shift occurred over time and indicates a reorientation from artiodactyl exploitation to an emphasis on small game.

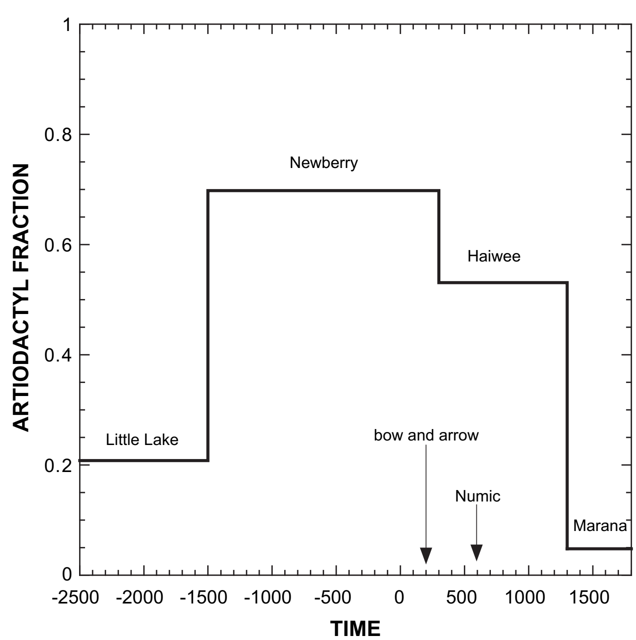

Fig. 5. Fraction of artiodactyl bones from terrestrial archaeofaunal remains in southeastern California plotted as a function of time.

4.2. White Mountains

Twelve village sites and hunting camps were discovered at high elevations (3150–3850 m) in the alpine tundra east of the Owens Valley and north of the Coso Region (Bettinger, 1991). Grayson (1991, 2001) posited that overexploitation of bighorn in the White Mountains during the Newberry and Haiwee periods caused their numbers to drop precipitously. Radiocarbon dates ($n = 33$) and projectile points ($n = 2{,}339$) provided the chronology and allowed reconstruction of changing land use. It is apparent that early components were principally hunting camps and later seasonal villages. Occupation began ca. 1500 B.C. and continued into the historic. The earliest sites were the foci of hunting parties and after A.D. 600 seasonal camps were established. Throughout two mammals were the predominant game – bighorn and marmots (*Marmota flaviventris*). The relative dietary contributions of these animals varied. The earliest sites had significant contributions of bighorn. By the very late prehistoric, dietary fauna were almost exclusively marmots.

Grayson (2001:15, Fig. 6) indicates that almost 25 percent of the faunal assemblage during the Newberry Period were artiodactyls. That contribution drops to 20 percent during the early Haiwee era (A.D. 250–600). The large mammal contribution is drastically reduced after that time to less than 10 percent, concurrent with a shift to seasonal villages in the late Haiwee Period (A.D. 600–1250). By Marana little more than one percent of the fauna is large mammal and the remainder is almost exclusively marmot.

Grayson argues and provides strong support for a pattern of sporadic hunting over several thousand years leading to a substantial reduction of bighorn beginning with the first hunts and culminating in the last millennium. Although such shifts are sometimes correlated with changes in climate, in the White Mountains case, there were no such unilinear changes in paleoclimate. However, the archaeofaunal record exhibits a remarkably unilinear and systematic decline in large game abundance over time and exhibits no relationship to any reconstructed course of climatic variability thus providing largely irrefutable evidence of excessive aboriginal predation (*sensu* Grayson 1991, 2001).

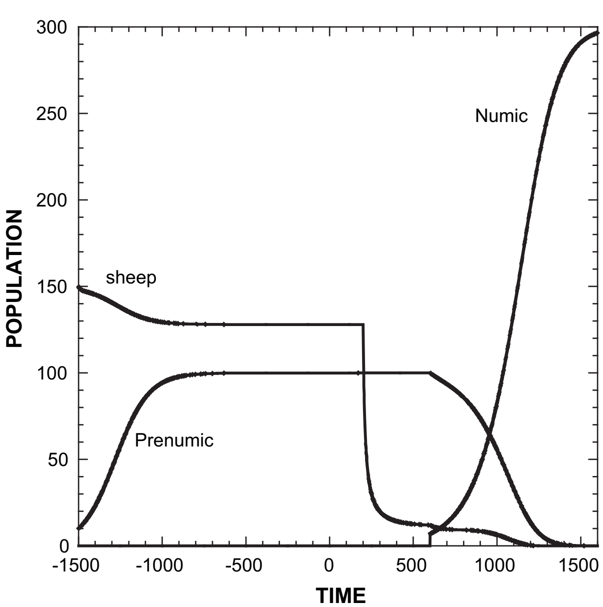

Fig. 6. The Prenumic, Numic, and bighorn sheep populations predicted by computer simulation for the years 1500 B.C.–A.D. 1600.

5. Quantitative models in archaeology

Quantitative models of cultural phenomena are useful when observational data are available for direct comparison with the model. Inexpensive desktop computers and software have made computer simulation accessible to archaeologists who wish to explore the quantitative aspects of their field. Quantitative modeling in archaeology has added useful depth to our understanding of prehistoric human behavior (Gilbert and Doran, 1994; Kohler and Gumerman, 2000; Renfrew and Cooke, 1979; Sabloff, 1981; Winterhalder et al., 1988)

Models of human population dynamics are typically borrowed from mathematical ecology. Different populations can interact by such processes as competition, predation, and symbiosis (Murray, 1989; Ricklefs, 1973). Human foragers may compete by collecting the same food, and humans will obtain food by predation. Dynamic models may include the related elements of space and time or apply only time as an independent variable.

Quantitative simulation begins with an idea that several archaeologically significant variables are causally linked. The modeler proceeds to estimate the nature of the relations and to write these in mathematical form. If time is a variable of interest, the mathematics typically takes the form of differential equations. If both space and time are variables, then partial differential equations are used.

Constant parameters in the equations must be estimated based on reasoned arguments. Then a computer program is written to solve the equations and graphically represent the solutions. An iterative process of changing parameters, running the program, and comparing with observed data is then carried out. When agreement is obtained without too many adjustable parameters, we can say that the simulation was successful. The results should yield new insights into the relationship between the variables of interest. Quantitative simulations add precision to debates and frequently reveal unanticipated variable interconnections. This paper presents a simple example of this process.

6. The simulation model

In order to explore the relationship of aboriginal populations, bighorn hunting, and rock art production we have developed a simulation model that quantitatively monitors changes in the size of these populations over time. Young and Bettinger (1992) previously published a population model for the spread of the Numic across the Great Basin. This model was based on the Lotka–Volterra differential equations used in theoretical ecology (Ricklefs, 1973) describing competing biological populations. By adding a spatial diffusion term to the equations, they created a simulation of the Numic spread which demonstrated how the Numic population, by more intensively exploiting the environment, could spread at the expense of the Prenumic population, and eventually drive them to extinction.

We propose to apply this population model to the prehistoric human ecology of the Coso Range. Here it is assumed that the Numic replaced the Prenumic and that bighorn were depleted during the Haiwee Period. We wanted to build a model of Prenumic – Numic – bighorn sheep populations in a fairly small geographic area around the Coso Range. The Prenumic and Numic occupations must have overlapped in time and both preyed upon the sheep, and the two populations competed for resources. In addition, we want to couple this population model to a model of rock art production that generates a prediction of the quantity of rock art in the Coso Range.

Our model consists of four differential equations for the Numic, Prenumic, bighorn sheep, and rock art populations in the Coso

Range area. Because the area is small (less than 100 square miles), we omit the spatial dimension and focus only on the time-dependence of the populations. By adjusting parameters in the equations, we can make predictions of the rock art production that can be compared with and fitted to the observed data.

For the Numic population P_1:

$$\frac{dP_1}{dt} = b_1P_1 - d_1P_1 - g_1P_1^2 - c_{12}P_1P_2 \tag{1}$$

For the Prenumic population P_2:

$$\frac{dP_2}{dt} = b_2P_2 - d_2P_2 - g_2P_2^2 - c_{21}P_2P_1 \tag{2}$$

For the bighorn sheep population P_3:

$$\frac{dP_3}{dt} = b_3P_3 - d_3P_3 - g_3P_3^2 - c_{31}P_3P_1 - c_{32}P_3P_2 \tag{3}$$

For the rock art "population" P_4:

$$\frac{dP_4}{dt} = b_4P_2\left(\frac{P_2}{P_3}\right) \tag{4}$$

Equation (1) expresses the population growth rate for the Numic population. The parameters are set to $b_1 = 0.02$, $d_1 = 0.01$, $g_1 = 3.333 \times 10^{-5}$, and $c_{12} = 3.333 \times 10^{-5}$. These parameters are all annual rates, in units of population change per year. These numbers are the birth rate, the death rate due to natural causes, the logistic death rate due to resource limitation, and the competition death rate due to the presence of the Prenumic population. The first three terms are set to give an equilibrium Numic population of 300 in the Coso area consistent with ethnohistoric estimates by Steward (1938) of Coso Range aboriginal demographics.

The last term in Eq. (1) acts on the Numic growth rate only as long as the Prenumic population P_2 coexists with the Numic. The Numic population is set to zero until A.D. 600, at that time 7 Numic people are introduced into the area. The date of A.D. 600 was selected since much evidence has been mustered indicating a cultural and adaptive discontinuity occurring at this time that appears to be synchronous with the in-migration of a Numic population into the Cosos at about this date (Bettinger 1976; Garfinkel 2007).

Equation (2) expresses the population growth rate for the Prenumic population. The parameters are set to $b_2 = 0.02$, $d_2 = 0.01$, $g_2 = 1.000 \times 10^{-4}$, and $c_{21} = 1.000 \times 10^{-4}$. These numbers are the birth rate, the death rate due to natural causes, the logistic death rate due to resource limitation, and the competition death rate due to the presence of the Numic population. The first three terms are set to give an equilibrium Prenumic population of 100 in the Coso area. Ten Prenumic individuals are introduced into the area at 1500 B.C. and the Prenumic population begins to grow until it reaches 100.

The parameters for the prehistoric human populations are of course unknown, but reasonable assumptions for the *b*, *d*, and *g* numbers can be estimated from ethnographic data and general observations about forager populations (cf. Alroy, 2001:1893).

The competition parameter *c* represents a hypothesis about how two human populations might interact by analogy with competing animal populations. The competition is nonviolent and reflects different efficiencies for gathering the same food. It is likely that the Prenumic depended on the sheep much more than the Numic did (Bettinger and Baumhoff, 1982).

The Numic populations specialized in pinyon nut and other seed collecting and could thereby extract more food calories from the environment than the Prenumic (Gilreath and Hildebrandt, 2008:12–14). The Numic would have included all the resources of the Prenumic, including bighorn sheep, and hence their impact on the bighorn population would have been additive (Bettinger and Baumhoff, 1982:488). This broader spectrum resource use allowed the Numic to attain a larger population density, and even though the Numic may have been less efficient in sheep predation, their larger numbers would have further depleted the sheep enough to put the Prenumic at a severe disadvantage. This in turn could have led to higher Prenumic death rates and their eventual disappearance (cf. Garfinkel, 2007; Young and Bettinger, 1992).

Equation (3) expresses the population growth rate for the bighorn sheep population. The sheep population parameters are not easy to determine, but extensive observation of wild herds by game specialists have been published and allow the estimates for b_3, d_3, and g_3 to be made (Epps et al., 2004; Wehausen, 1983, 1999).[3] The first four parameters are set to $b_3 = 0.25$, $d_3 = 0.15$, $g_3 = 6.667 \times 10^{-4}$, and $c_{31} = 5.934 \times 10^{-4}$. These numbers are the birth rate, the death rate from natural causes, the logistic death rate from food limitation and carnivore predation, and the predation rate from Numic hunters. In order to fit the sharp increase in rock art production after A.D. 1, we postulate a corresponding sharp decrease in the sheep population due to Prenumic predation. It is possible that the introduction of the bow and arrow and the use of hunting dogs at this time greatly increased the predation rate and reduced the sheep population accordingly. Evidence for the introduction of hunting dogs during this time and their association with the introduction of the bow and arrow is found in frequent depictions and associations in the Coso Representational rock art panels. Rock drawings of hunting dogs with bow and arrow hunters are an exclusively late prehistoric, Haiwee era, manifestation and are amply documented in over 200 instances in Coso iconography (Grant et al. 1968:24, 120).

To model this, we set $c_{32} = 1.467 \times 10^{-4}$ before A.D. 200 and $c_{32} = 9.234 \times 10^{-4}$ after A.D. 200. The first three terms in Equation (3) are set to give an equilibrium sheep population in the Coso area of 150, which is assumed to be the situation at 1500 B.C., when the Prenumic population responsible for the greatest number of sheep images arrives.

Two bighorn per square mile is considered a generous upper limit for an area such as the Cosos (Epps et al., 2003, 2004; Wehausen, 1983, 1999; Wehausen et al., 1987). If such a density of bighorn were correlated with the greatest concentration of rock art then sheep herds occupied a small area of 90–100 square miles. Therefore, based on current population estimates, and detailed assessments of the Cosos, we would project that only about 150–200 bighorn ever populated the area. This is all the more remarkable when one considers that there are no less than 50,000 individual drawings of bighorn in the Coso rock art complex!

Equation (4) expresses the growth in number of rock art images created by the Prenumic population. We assume that the images are attempts to use supernatural power to replenish the sheep

[3] A recent in-depth study of California desert bighorn sheep population dynamics evaluated their current status (local extinction versus extant) and found a strong correlation of elevation and precipitation with population persistence into the twentieth century (Epps et al. 2004). These researchers learned that extinction of desert bighorn herds (metapopulations) were most likely in areas with <1500-m elevation and <200-mm annual precipitation. Most of the Coso Range is in that lower minimum elevation and the majority of the Coso rock drawings are located in areas below that elevation. Additionally, the Coso Range has an annual precipitation of 100–140 mm – one of the driest areas in the region. Taller mountain ranges have more and better forage than lower elevation ranges and often better "escape terrain" – the latter a critical factor for bighorn survival. Arid regions with lesser moisture content and increased evapotranspiration drastically affect bighorn diet quality and demography. Precipitation is a factor even more limiting than temperature. Lower and drier mountain habitats, like the Coso Range, provide the highest risks of bighorn extinction.

population, which is an important part of the Prenumic diet. The parameter b_4, the "birth" rate of petroglyph images, is multiplied by P_2, which is proportional to the number of Prenumic artists, and by the intensity of rock art production, given by the ratio of the Prenumic population to the sheep population. We assume that the Prenumic noticed the decline in sheep numbers and actively generate rock art at a rate inversely proportional to the per capita availability of the sheep (P_3/P_2). Hence the total rate is given by $b_4P_2(P_2/P_3)$. This model is merely one of many possible models relating rock art production to the sheep population. The essential element is the inverse relation between the two variables P_3 and P_4. As sheep are depleted, by the bow and arrow after A.D. 200 and by increasing human population after A.D. 600, the per capita availability of sheep decreases and the production of rock art increases.

There is only minimal depletion of the rock art images because most of these rock art elements endure almost indefinitely. Arguably, through a variety of taphonomic considerations, some rock art images would be impossible to discern due to repatination of their desert varnish. Other rock art elements would have been destroyed or are not discernible due to natural environmental processes that have buried them in alluvium or eroded and spalled them off the rock faces upon which they rest.

Nevertheless we believe that given the remarkable ubiquity of Coso rock art imagery and the unusual security measures associated with the China Lake Naval Weapons facility, this study area provides a surprisingly intact rock art record where most rock art images are preserved and only a very small percent of the glyphs have been destroyed or are occluded through natural geological and geomorphic processes.

We would estimate that less than 10% of all rock art images would be so disturbed as to be difficult to impossible to view. Therefore we do not include a "death" rate term for the rock art. The parameter b_4 is set to 0.10. The number of images begins at 25,000 (from earlier Paleoindian and Archaic sources) at 1500 B.C. and grows to an estimated 100,000 by A.D. 1300 as the rock art production rate increases. The Coso rock art production ceases as the Prenumic population dies out.

Having formulated these equations, we then employed a computer to solve them using a simple finite difference method. The time is measured in steps of $\Delta t = 0.1$ year, and the totals for each population are computed as the values at the last time step plus the computed rate of change dP/dt times the time step Δt:

$$P(t+\Delta t) \cong P(t) + \frac{\mathrm{d}P(t)}{\mathrm{d}t}\Delta t \qquad (5)$$

A large number of simulations were done in order to obtain an optimum parameter set. The results are shown in Figs. 6 and 7.

7. Results and analysis

Fig. 6 overlays the simulated Numic, Prenumic, and sheep populations. The sheep start with a population of 150 at 1500 B.C. An initial Prenumic population of 10 is introduced at 1500 B.C. and the sheep population declines slightly under predation. At A.D. 200 the bow and arrow is introduced. It is generally accepted by most prehistorian that the use of the bow and arrow may have facilitated a much higher predation rate. Such overharvests would result in a sheep population that drops precipitously and then stabilizes at a low value. The discontinuity introduced by the bow and arrow appears as a sharp drop in the sheep population and a corresponding sharp rise in the rock art production. The Numic are introduced as a population of 7 at A.D. 600. The Numic population grows and competes with the Prenumic. They also hunt sheep, although less efficiently than the Prenumic. The sheep largely

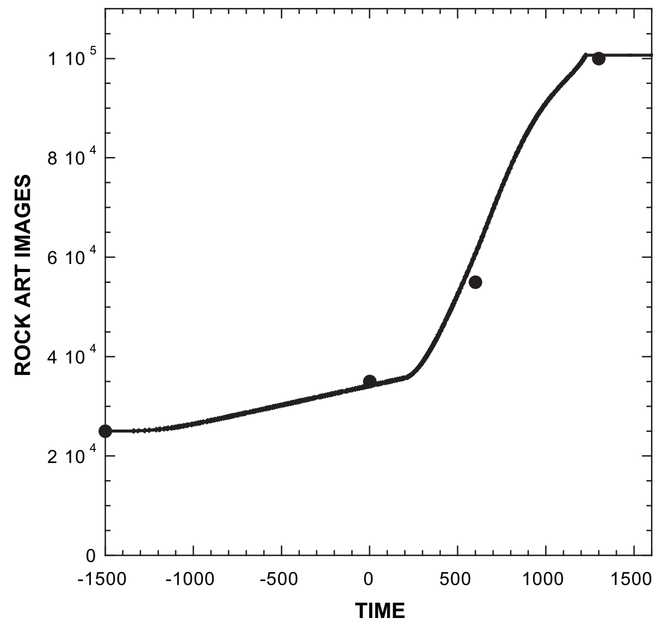

Fig. 7. Estimated numbers of total rock art images created for the years 1500 B.C.–A.D. 1600.

disappear by A.D. 1200, the Prenumic population disappears by A.D. 1300, and the Numic population approaches its equilibrium value of 300 by A.D. 1600.

Fig. 7 compares the prediction of Equation (4) with the approximate data on the dates of the rock art. The estimated cumulative rock art counts are shown as points in Fig. 7. The model parameters c_{31} and c_{32} are adjusted to optimize the fit of the predicted curve to the points. The model correctly shows a steep increase in rock art production following the decrease in the sheep population. The agreement is imperfect, but it is satisfactory, given the imprecision of the estimates and the extreme simplicity of the model.

Even though more efficient weapons were able to achieve a higher kill rate of bighorn sheep, the resulting smaller size of the sheep population leads to a smaller overall catch than that represented in the preceding Newberry Period. The sheep do not reach a new equilibrium in the Haiwee era because the intrusive Numic population also prey on the sheep and appear to eventually drive both the sheep and the pre-Numics into local extinction. The archaeofaunal record represented in the Marana Period supports this conclusion, and suggests that the simulation has captured realistically an important aspect of Coso cultural evolution.

It is possible that although sheep were depleted by A.D. 1300 they were not driven to local extinction. By adjusting the birth rate from 0.25 to 0.20 and increasing the rock art production rate, we can generate a simulation that allows the sheep to survive (Fig. 8). We have adjusted the parameters in this simulation to also obtain an approximate fit to the rock art numbers.

We emphasize that this model is a highly simplified picture of human behavior. Our purpose is not to "retrodict" prehistoric events but to offer a possible framework for explaining archaeological data from the Coso Range. Quantitative data allow the refinement of interpretation and modeling that mere verbal theorizing cannot provide. Further improvements in dating rock art would be useful in developing quantitative models of the type described here. We believe that the dating of the rock art will be an excellent diagnostic tool for deciphering the human population dynamics and cultural evolution in prehistoric eastern California.

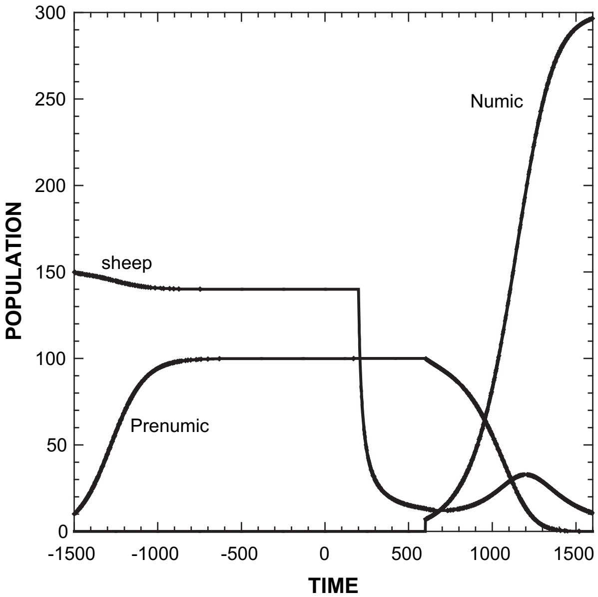

Fig. 8. The Prenumic, Numic, and bighorn sheep populations predicted by the computer simulation for the years 1500 B.C.–A.D. 1600. The bighorn birth rate and rock art production rate have been modified to yield surviving sheep at A.D. 1600.

8. Summary and conclusions

In this paper we have examined the archaeological evidence for the dating of Coso rock art, the dating of Coso archaeofaunal remains, and the evidence for an intrusive population that brought the Coso culture to an end. The computer simulation ties these elements together and demonstrates that the explosion of rock art can be explained by assuming that the Coso Prenumic artists increased their activities as the sheep population decreased from overharvesting.

What might have been the motivation for such a counterproductive behavior pattern? Prestige given to the successful hunter of scarce game might be the answer. As large game hunting increased in importance the depictions altered; bighorn images became more frequent and larger in size. When the bighorn became less plentiful and more difficult to kill a successful hunter would have been provided with greater prestige. Hildebrandt and McGuire (2002:250) point out that the taking and sharing of large game conferred individual fitness benefits for males signaling their authority and achievement. This intensification pattern was a distinctive "currency" correlating with a spike in animal ceremonialism, ritual activity, and the production of symbolic behavior associated with a social system driven by high prestige hunting. McGuire et al. (2007:363–364) emphasize the important role that prestige hunting plays in local extirpations. They recognize that non-optimal foraging behavior in overkill situations are fueled by the escalating importance of prestige as key prey animals diminish and their consequent rarity heightens the leadership roles of successful hunters and provides greater power and influence mitigating any tendency to prey switch.

Significantly, we see this pattern in the rock art record as Coso hunters are frequently adorned with horned headdresses ($n = 200$). Hence Coso rock art, in its period of peak production, is not so much a proxy measure of economic abundance and success of bighorn hunts but was, quite the contrary, a manifestation of ritual intensification designed to affect supernatural agents to increase animals, plants, and the availability of water (Garfinkel et al., 2009). The culmination of this tradition is manifested in the life-size depiction of bighorn sheep – a labor intensive effort driven by the desire to appease the deities and revitalize a culture in chaos.

Acknowledgements

This research was in part supported by funds from a California State University, Bakersfield faculty research grant. Many people helped in allowing us to conduct these investigations. Alexander (Sandy) Rogers, Curator of Prehistory, Maturango Museum, Ridgecrest, California, aided our work through his critical eye, thoughtful review of our research, and wide-ranging insights on the character of Coso prehistory. Michael Baskerville, Base Archaeologist, Naval Air Weapons Station, China Lake, facilitated our access to the extraordinary resources of the Coso Range. We greatly appreciate his continued stewardship of this outdoor laboratory and archaeological treasure. William Wight was of great help to us by providing site location information and in acting as our on-base guide to various rock art loci. Donald Austin, Sand Carved Designs, continues to provide insights into rock art research method and theory throughout the Western United States. Ken and Anna Lu Pringle, close friends, aid in our research by providing their home as a satellite research station and continue to serve with unending hospitality and comic relief. Ken Pringle's decades of experience in the study of the Coso petroglyphs are a continued source of wisdom and much needed perspective on such scientific pursuits. Richard Gaskin is a new partner in prehistory and we appreciate his support. John Wehausen and Clinton Epps brought a novel perspective to our interdisciplinary study by providing a source of expertise bringing their extensive backgrounds in wildlife biology and the study of desert bighorn. Former China Lake base archaeologist, Russ Kaldenberg, has continued to support our efforts and we appreciate his collaboration.

References

Alroy, J., 2001. A multispecies overkill simulation of the end-Pleistocene mass extinction. Science 292, 1893–1896.
Bettinger, R.L., 1976. The development of pinyon exploitation in central eastern California. Journal of California Anthropology 3, 81–95.
Bettinger, R.L., 1991. Aboriginal occupation at high altitudes: alpine villages in the White Mountains of eastern California. American Anthropologist 93, 656–679.
Bettinger, R.L., Baumhoff, M.A., 1982. The Numic spread: great Basin cultures in competition. American Antiquity 47, 485–503.
Bodley, J.H., 1990. Victims of Progress. Mayfield, Mountain View, California.
Booth, A.L., Jacobs, H.M., 1990. Ties that bind: Native American beliefs as a foundation for environmental consciousness. Environmental Ethics 12, 27–44.
Broughton, J.M., 1994. Declines in mammalian foraging efficiency during the Late Holocene, San Francisco Bay, California. Journal of Anthropological Archaeology 13, 371–401.
Broughton, J.M., 2002. Pre-Columbian human impact on California vertebrates: evidence from old bones and implications for wilderness policy. In: Kay, C.E., Simmons, R.T. (Eds.), Wilderness and Political Ecology: Aboriginal Influences and the Original State of Nature. University of Utah, Salt Lake City, Utah.
Byers, D.A., Broughton, J.M., 2004. Holocene environmental change, artiodactyl abundances, and human strategies in the Great Basin. American Antiquity 69, 235–255.
Epps, C.W., Bleich, V.C., Wehausen, J.D., Torres, S.G., 2003. Status of bighorn sheep in California. Desert Bighorn Council Transactions 47, 20–35.
Epps, C.W., McCullough, D.R., Wehausen, J.D., Bleich, V.C., Rechel, J.L., 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18, 102–113.
Garfinkel, A.P., 2003. Dating "Classic" Coso style sheep petroglyphs in the Coso Range and El Paso Mountains: implications for regional prehistory. Society for California Archaeology Newsletter 37, 34–37.
Garfinkel, A.P., 2006. Paradigm shifts, rock art theory, and the Coso sheep cult of eastern California. North American Archaeologist 27, 203–244.
Garfinkel, A.P., 2007. Archaeology and rock art of the eastern Sierra and Great Basin frontier. Maturango Museum Publication Number 22. Maturango Museum Press, Ridgecrest, California.
Garfinkel, A.P., Austin, D., Earle, D., Williams, H., 2009. Myth, ritual, and rock art: Coso decorated animal humans and the animal master. Rock Art Research 26(2). The Journal of the Australian Rock Art Research Association (AURA) and of the International Federation of Rock Art Organizations (IFRAO), Rock Art Research 26 (2), 179–197.

Garfinkel, A.P., Marcom, G., Schiffman, R.A., 2007. Culture crisis and rock art intensification: Numic ghost dance paintings and Coso representational petroglyphs. In: Christensen, D., Whitehead, P. (Eds.), American Indian Rock Art, vol. 33. American Rock Art Research Association, Tucson, Arizona, pp. 83–103.
Gilbert, N., Doran, J. (Eds.), 1994. Simulating Societies. The Computer Simulation of Social Phenomena. University College London Press, London, England.
Gilreath, A.J., 1999. Chronological assessment of the Coso rock art landmark – an obsidian hydration analysis. On file Naval Air Weapons Station, China Lake, California.
Gilreath, A.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.
Gilreath, A.J., 2007. Rock art in the golden state: pictographs and petroglyphs, portable and panoramic. In: Jones, T.L., Klar, K.A. (Eds.), California prehistory: colonization, culture and complexity. Alta Mira, New York, pp. 273–290.
Gilreath, A.J., Hildebrandt, W.R., 1997. Prehistoric use of the Coso Volcanic Field. Contributions of the University of California Archaeological Research Facility No. 56. University of California, Berkeley, California.
Gilreath, A.J., Hildebrandt, W.R., 2008. Coso rock art within its archaeological context. Journal of California and Great Basin Anthropology 28 (1), 1–22.
Grant, C., Baird, J.W., Pringle, J.K., 1968. Rock drawings of the Coso Range, Inyo County, California: an ancient sheep-hunting cult pictured in desert rock carvings. Maturango Museum Publication Number 4. Maturango Museum Press, Ridgecrest, California.
Grayson, D.K., 1991. Alpine fauna from the White Mountains, California: adaptive change in the late prehistoric Great Basin? Journal of Archaeological Science 18, 483–506.
Grayson, D.K., 2001. The archaeological record of human impacts on animal populations. Journal of World Prehistory 15, 1–68.
Guenther, M., 1988. Animals in Bushman thought, myth, and art. In: Ingold, T., Riches, D., Woodburn, J. (Eds.), Hunters and Gatherers 2: Property, Power and Ideology. Berg, Oxford, England, pp. 192–202.
Hames, R., 2007. The ecologically noble savage debate. Annual Review of Anthropology 36, 177–190.
Harrod, H.I., 2000. The Animals Came Dancing: Native American Sacred Ecology and Animal Kinship. University of Arizona Press, Tucson, Arizona.
Heizer, R.F., Baumhoff, M.A., 1962. Prehistoric Rock Art of Nevada and Eastern California. University of California Press, Berkeley, California.
Hildebrandt, W.R., Jones, T.L., 2002. Depletion of Prehistoric Pinniped Populations along the California and Oregon coasts: were humans the cause? In: Kay, C.E., Simmons, R.T. (Eds.), Wilderness and Political Ecology: Aboriginal Influences and the Original State of Nature. University of Utah, Salt Lake City, Utah, pp. 72–110.
Hildebrandt, W.R., McGuire, K.R., 2002. The ascendance of hunting during the California Middle Archaic: an evolutionary perspective. American Antiquity 67 (2), 231–256.
Hildebrandt, W.R., Ruby, A., 2006. Prehistoric pinyon exploitation in the southwestern Great Basin: a view from the Coso Range. Journal of California and Great Basin Anthropology 26, 11–31.
Hultkrantz, A., 1981. Belief and Worship in Native America. Syracuse University, Syracuse, New York.
Hultkrantz, A., 1987. Native Religions of North America. Harper and Row, San Francisco, California.
Hunn, E.S., 1982. Mobility as a factor limiting resource use in the Columbian Plateau of North American. In: Williams, N.M., Hunn, E.S. (Eds.), Resource Managers: North American and Australian Foragers. Westview, Denver, Colorado, pp. 17–43.
Janetski, J.C., 1997. Fremont hunting and resource intensification in the eastern Great Basin. Journal of Archaeological Science 24, 1075–1088.
Jones, T.L., Porcasi, J.F., Gaeta, J.W., Codding, B.F., 2008. The Diablo Canyon fauna: a coarse-grained record of trans-Holocene foraging from the central California mainland coast. American Antiquity 73, 289–316.
Justice, N.D., 2002. Stone Age Spear and Arrow Points of California and the Great Basin. Indiana University Press, Bloomington, Indiana.
Kay, C.E., 1994. Aboriginal overkill: the role of Native Americans in structuring western ecosystems. Human Nature 5, 359–398.
Kay, C.E., Simmons, R.T. (Eds.), 2002. Wilderness and Political Ecology: Aboriginal Influences and the Original State of Nature. University of Utah, Salt Lake City, Utah.
Keyser, J.D., Whitley, D.S., 2006. Sympathetic magic, hunting magic, and rock art in far western North America. American Antiquity 71, 3–26.
Kohler, T.A., Gumerman, G.J. (Eds.), 2000. Dynamics of Human and Primate Societies. Agent-Based Modeling of Social and Spatial Processes. Oxford University, New York.
Krech III, S., 1999. The Ecological Indian: Myth and History. Norton, New York.
Krech III, S., 2005. Reflections on conservation, sustainability, and environmentalism in indigenous North America. American Anthropologist 107, 78–86.
Lanning, E.P., 1963. Archaeology of the Rose Spring Site (INY-372), vol. 49. University of California Publications in American Archaeology and Ethnology, Berkeley. 3, 237–336.
Lee, R.B., Daly, R., 1999. The Cambridge Encyclopedia of Hunters and Gatherers. Cambridge University, Cambridge.
Lyman, R.L., Cannon, K.P. (Eds.), 2004. Adding Prehistory to Conservation Biology: Zooarchaeological Studies from North America. University of Utah, Salt Lake City, Utah.
Lytle, F., 2008. Rapid dating of desert varnish by XRF chemical analysis. On file Maturango Museum, Ridgecrest, California.
Lytle, F., Lytle, M., Garfinkel, A.P., Rogers, A.K., Pringle, J.K., Wight, W., Kaldenberg, R., 2006. Initial Results of experimental X-ray fluorescence dating of the Coso Range petroglyphs of eastern California. On file at the Maturango Museum, Ridgecrest, California.
McGuire, K.R., Hildebrandt, W.R., 2005. Re-thinking Great Basin foragers: prestige hunting and costly signaling during the Middle Archaic Period. American Antiquity 70 (4), 693–710.
McGuire, K.R., Hildebrandt, W.R., Carpenter, K., 2007. Costly signaling and the ascendance of no- can-do archaeology: a reply to Codding and Jones. American Antiquity 72 (2), 358–365.
Madsen, D.B., 1986. Great Basin nuts: A short treatise on the distribution, productivity and prehistoric use of pinyon. Anthropological Papers Number 110. In: Condie, C.J., Fowler, D.D. (Eds.), Anthropology of the Desert West: Essays in Honor of Jesse D. Jennings. University of Utah Press, Salt Lake City, pp. 21–42.
Madsen, David. B., Rhode, D. (Eds.), 1994. Across the West: Human Population Movement and the Expansion of the Numa. University of Utah, Salt Lake City, Utah.
Murray, J.D., 1989. Mathematical Biology. Springer–Verlag, Berlin, Germany.
Nelson, R.K., 1983. Make Prayers to the Raven. University of Chicago, Chicago, Illinois.
Panlaqui, C., 1974. The Ray Cave Site. In: C. Panlaqui, K. Berry. T. Hillebrand (Eds.), Excavation of two sites in the Coso Mountains of Inyo County, California. Maturango Museum Monograph Number 1. Maturango Museum, Ridgecrest, California.
Quinlan, A.R., Woody, A., 2003. Marks of distinction: rock art and ethnic identification in the Great Basin. American Antiquity 68, 372–390.
Raven, M.M., 1990. The Point of no diminishing returns: Hunting and resource decline on Boigu Island, Torres Strait. Ph.D. dissertation, Department of Anthropology, University of California, Davis.
Renfrew, C., Cooke, K.L. (Eds.), 1979. Transformations. Mathematical Approaches to Culture Change. Academic, New York.
Repetto, R., Holmes, T., 1983. The role of population in resource depletion in developing countries. Population and Development Review 9, 609–632.
Ricklefs, R.E., 1973. Ecology. Chiron Press, Salt Lake City, Utah.
Robins, M.R., Hays-Gilpin, K.A., 2000. The bird in the basket: gender and social change in Basketmaker iconography. In: Reed, P.F., Morris, E. (Eds.), Foundations of Anasazi Culture: The Basketmaker-Pueblo Transition. University of Utah, Salt Lake City, Utah, pp. 231–247.
Rogers, A.K. A chronology of six Coso rock art motifs in the Coso Range, eastern California. American Indian Rock Art Volume 35, American Rock Art Research Association, Tucson, Arizona, in press.
Sabloff, J.A. (Ed.), 1981. Simulations in Archaeology. University of New Mexico, Albuquerque, New Mexico.
Schaafsma, P., 1986. Rock Art. In: d'Azevedo, W.L. (Ed.), Handbook of North American Indians, vol. 11, Great Basin. Smithsonian Institution, Washington, D.C, pp. 215–226.
Steward, J.H., 1938. Basin-Plateau Aboriginal Sociopolitical Groups. Bureau of American Ethnology Bulletin 120. Government Printing Office, Washington, D.C.
Stoffle, R., 2005. Places that count: traditional cultural properties in cultural resource management; tribal cultural resource management: full circle to stewardship. American Anthropologist 107, 138–140.
Wehausen, J.D., 1983. White Mountains Bighorn Sheep: An Analysis of Current Knowledge and Management Alternatives. Inyo National Forest Administrative Report (Contract 53-9JC9-0-32), Bishop, California.
Wehausen, J.D., 1999. Rapid extinction of mountain sheep populations revisited. Conservation Biology 13, 378–384.
Wehausen, J.D., Bleich, V.C., Weaver, R.A., 1987. Mountain sheep in California: a historical perspective on 108 years of full protection. Transactions Western Section The Wildlife Society 23, 65–74.
Whitley, D.S., 2005. The Iconography of Bighorn Sheep Petroglyphs in the Western Great Basin. In: Johnson, Keith L. (Ed.), Onward and Upward!, Papers in Honor of Clement W. Meighan. Chico: Stansbury Publishing, pp. 191–203.
Winterhalder, Bruce, Baillargeon, William, Cappelletto, F., Daniel Jr., I.R.F., Prescott, C., 1988. The Population Ecology of Hunter-Gatherers and their Prey. Journal of Anthropological Archaeology 7, 289–328.
Yochim, Michael, J., 2001. Aboriginal overkill overstated: errors in Charles Kay's hypothesis. Human Nature 12, 141–167.
Yohe, Robert M., II 1992 A reevaluation of western great basin cultural chronology and evidence for he timing of the introduction of the bow and arrow to Eastern California based on new excavations at the Rose Spring Site (CA-Iny-372). Unpublished Ph.D. Dissertation, Anthropology Department, University of California, Riverside.
Yohe, Robert M., II 1997. The Introduction of the Bow and Arrow and Lithic Resource Use at Rose Spring (CA-INY-372). Journal of California and Great Basin Anthropology 20, 26–52.
Yohe, Robert M., II 2000. "Rosegate" Revisited: Rose Spring Point Temporal Range in the Southwestern Great Basin. In: JoanSchneider, S., RobertYohe II, M., Gardner, Jill K. (Eds.), Archaeological Passages: A Volume in Honor of Claude Nelson Warren. Western Center for Archaeology and Paleontology, Hemet, California, pp. 213–224.
Yohe, Robert M., II and Mark Q. Sutton 1999 Settlement, Subsistence, Technology, Environmental Change, and the Rose Spring Period in the Western Mojave Desert. Paper presented at the 1999 Kelso Conference on California Desert Prehistory, Panamint Springs, California.
Yohe, Robert M., II Mark Q. Sutton., 2000. Implications of Technological and Environmental Change in the Rose Spring Period in the Western Mojave Desert. Paper presented at the 2000 Annual Meetings of the Society for California Archaeology, Riverside, California.
Young, David A., Bettinger, Robert L., 1992. The Numic spread: a computer simulation. American Antiquity 57 (1), 85–99.