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Implications of a freshwater radiocarbon reservoir correction for the timing of late Holocene settlement of the Elk Hills, Kern County, California

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Abstract

Uncertainties regarding the magnitude of freshwater radiocarbon reservoir effects can introduce random errors into dates on archaeological freshwater carbonates. As a result, many archaeologists avoid dating freshwater shells unless no other datable materials are available. The chronology of prehistoric occupation of the former Naval Petroleum Reserve No. 1 (NPR-1) at Elk Hills, Kern County, has been established with 50 radiocarbon dates on freshwater mussels (*Gonidea* and *Anodonta* sp.). Characterization of any freshwater radiocarbon reservoir effect is crucial for the accurate interpretation of inferred settlement and subsistence changes on the Elk Hills. Paired charcoal and freshwater mussels sampled from closely associated contexts were dated to identify a freshwater reservoir effect. Paired *Anodonta* and *Gonidea* sp. shells were dated to investigate interspecific differences in fractionation. Results indicate that a 340 ± 20 ^{14}C yr correction should be applied to conventional ^{14}C dates on freshwater carbonates in the Buena Vista Basin before calendar calibration. Evidence of interspecific differences is inconclusive. Dates recalibrated with the reservoir correction indicate that widespread occupation of the Elk Hills is correlated with increasing precipitation towards the end of the Medieval Climatic Anomaly and during the Little Ice Age, suggesting that slough resource exploitation may have been driven by regional population pressure rather than drought-related declines in aquatic productivity.

Keywords: Freshwater Radiocarbon Reservoir; *Anodonta* sp.; *Gonidea angulata*; Medieval Climatic Anomaly; Elk Hills; Southern San Joaquin Valley

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1. Introduction

Radiocarbon dating provides archaeologists with absolute temporal controls for developing regional cultural and environmental chronologies. Archaeologists are also well-positioned to address the potential interpretive problems associated with dating various materials from different radiocarbon reservoirs [59]. Terrestrial plant carbon is usually the most reliable material, though the "old wood effect" can introduce errors [40,46], and differences in isotopic fractionation between C3 and C4 plants must be considered [13,53]. Marine radiocarbon reservoirs vary geographically and temporally, potentially introducing random errors that can only be accounted for by direct ^{14}C-dating of pre-bomb shells or comparison of archaeological marine shell and terrestrial charcoal [5,22,31,32,39,60]. Characterization of freshwater reservoir effects has received less attention from archaeologists, and it has been suggested that shells of freshwater organisms should only be dated if no other materials are available, unless a reservoir study has been conducted [59:53]. Such has been the case with archaeological investigations conducted on the former Naval Petroleum Reserve No.1, Elk Hills, in the southern San Joaquin Valley of California, where the shells of two freshwater mussel taxa *Gonidea angulata* and *Anodonta* sp. are the most visible archaeological remains at

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many sites and datable charcoal samples are typically scarce [18,19,33].

Differences in radiocarbon content between terrestrial and freshwater systems was first theorized by Godwin [24], who suggested that bicarbonate dissolved from ancient limestone could introduce random errors in carbonates precipitated in freshwater environments. Spurred by observed age discrepancies between marl and terrestrial plants in New Zealand [8], Deevey et al. [21] demonstrated the effect of ^{14}C-depleted bicarbonate in modern aquatic organisms in soft- and hard-water lakes in Connecticut and New York state. Broecker and Walton [12] presented a formal geochemical model describing the radiocarbon budget of freshwater systems, noting that the factors governing ^{14}C concentrations in lakes are the initial ratio of dissolved carbonate to silicate, and the rate of CO_2 exchange with the atmosphere. Subsequently, Keith and coworkers [35–37] argued for decomposition of old humus in rivers and lakes as a main source of ^{14}C-depleted carbon in freshwater systems, a view rejected by Broecker [9]. Several methodological studies during the 1950s and 1960s dated modern freshwater mussel shells (Family Unionidae) to estimate the magnitude of freshwater reservoirs in the Great Lakes and Great Basin regions, in some cases specifically to address archaeological chronologies [10,11,14–17,28,45]. More recently, Berger and Meek [4] proposed a genus-specific radiocarbon correction (i.e., one due to vital effects) of 450 ^{14}C yr for *Anodonta* in the Mojave River Basin determined from pre-bomb museum specimens. In the region of the present study, Sutton and Orfila [57] have calculated a 300 ^{14}C yr correction for *Anodonta* using co-associated turtle and artiodactyl bone from an archaeological site north of Buena Vista Lake, CA-KER-4220.

The potential for a freshwater reservoir effect in Buena Vista Slough was noted by Jackson et al. [33] during analyses of marine shell beads and freshwater mussels at site CA-KER-5404 on the Elk Hills. Calibrated dates on eight beads manufactured from the marine gastropod genus *Olivella* were consistently ~300 years later than samples of freshwater mussel (*G. angulata*) from a shell dump feature at the site [33:131,134–136]. Jackson et al. [33] assumed that the deposition of the beads and the mussel shells was contemporaneous, and suggested that either old carbon was present in the freshwater mussels, or that an inappropriate local marine reservoir correction (ΔR) had been used to calibrate the *Olivella* beads. Noting that ΔR in the Santa Barbara Channel (the presumed source of the *Olivella* shells) had been shown to fluctuate during the Holocene [39], the authors concluded that the local correction applied (i.e., $\Delta R = 225 \pm 35$ ^{14}C yr; [5]) was incorrect. The issue was raised again by Culleton and Jackson [18] in the interpretation of dates on freshwater mussel shell and *Olivella* beads from two other Elk Hills sites, CA-KER-5376 and CA-KER-5955, where the same pattern was noted.

Cultural responses to environmental change in California and the Great Basin are increasingly a focus of archaeological research (e.g., [1,34,38,41,44,47]), but inferring those responses depends on accurate archaeological and climatic chronologies. Accounting for a freshwater reservoir effect allows for clearer comparison of the Elk Hills archaeology with California's late Holocene environmental records (e.g., [20,25,29,30,42,49,50]). Initial mussel shell dates indicated that the vast majority of sites on the Elk Hills were occupied during the Medieval Climatic Anomaly (MCA; [50]) from 1000 to 600 cal BP; only 3 of 23 dates from 16 sites dated before ca. 1450 cal BP [33:150]. Most of these sites represent short-term camps for processing and consuming foods gathered and hunted from the former Buena Vista Slough [33]. Aside from the mussel shell, bones of fish, turtles, waterfowl, and rabbits – but rarely larger mammal – were recovered. The widespread and sudden appearance of people on the north flank of the Elk Hills at this period was interpreted by Jackson et al. [33:150] as a response to the desiccation of Buena Vista Lake during the prolonged MCA droughts. They hypothesized that the well-established lakeside village sites (cf. [61]) were abandoned as year-round occupation sites as people were forced to move greater distances in search of resources. Declining productivity and availability of terrestrial and aquatic habitats led to the intensive exploitation of lower-ranked slough resources, including freshwater mussels. Characterizing a freshwater reservoir effect in the Buena Vista Basin could alter interpretations of the role of climate change in the timing of settlement shifts in the late Holocene Buena Vista Basin. This paper presents radiocarbon data on paired *Anodonta* and *Gonidea* shells to identify genus-specific reservoir corrections, and paired charcoal and shells of these two genera to characterize the magnitude of the effect in the late Holocene Buena Vista Slough.

2. Methods

Freshwater mussel shell (*Anodonta* sp. and *G. angulata*) is found scattered on the surface or in concentrations representing dumping events, on sites along the north flank of the Elk Hills adjacent to the now-reclaimed Buena Vista Slough (Fig. 1). Samples were selected from two excavated sites, CA-KER-3079/H and CA-KER-5404, to characterize the freshwater reservoir effect (R_f) and to investigate interspecific differences between *Anodonta* and *Gonidea*. To test whether the two genera of freshwater mussels date differently, a pair of individual *Anodonta* sp. and *G. angulata* valves were selected from each of two small, discrete shell lenses at CA-KER-5404 (units SS-14 and SS-18). KER-5404 is located roughly 1.5 km from the former Buena Vista Slough on a small knoll near the transition to the incised interior of the Elk Hills. Each lens measured approximately 30 cm in diameter and contained the valves of 50–60 individual mussels [19]. The small amount of meat provided by each bivalve and the discrete concentration of the shells suggest that these lenses represent single episodes of mussel collection and consumption by individuals, rather than diachronic accumulations of dietary debris by larger groups [19].

To estimate the magnitude of the freshwater reservoir effect in the former Buena Vista Slough, six freshwater mussel/charcoal pairs were recovered from small hearth features and midden excavated at CA-KER-3079/H Locus A. The locus is on a small knoll about 500 m from the old Buena Vista Slough,

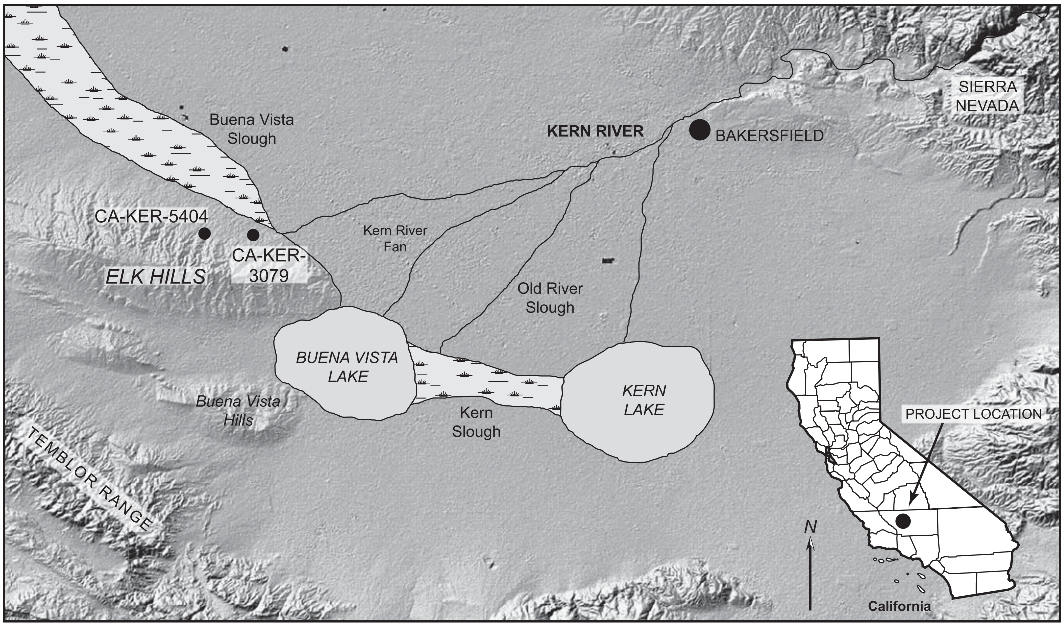

Fig. 1. Location of Elk Hills study sites in relation to major hydrographic features of the Buena Vista Basin, Kern County, California. Basemap Source: USGS Seamless NED Database.

and characterized by dense concentrations of freshwater mussel shell, midden and Late Period *Olivella* beads (e.g., Bennyhoff and Hughes' [3] Classes G, J, H, and K). Individual pieces of freshwater mussel shell were removed from hearth fill for AMS dating. The shell was too fragmented to allow genus-level distinction between *Gonidea* and *Anodonta*. Charcoal samples were chosen from these same contexts. Generally, smaller charred twigs were chosen to avoid the "old wood effect" [40,46], though most of the local plants are relatively short-lived scrub. More pertinent is the ubiquity of *Atriplex* (saltbush) on the Elk Hills. This C4 plant efficiently incorporates heavier carbon isotopes (i.e., ^{13}C and ^{14}C) during photosynthesis, resulting in high δ^{13}C values that can significantly skew radiocarbon calibrations [13]. The problem is obviated by directly measuring rather than estimating δ^{13}C during AMS dating. The measured ratios reveal that five of the six charcoal samples are indeed *Atriplex*, judging by δ^{13}C values ranging from -10.8 to $-12‰$ typical of C4 plants [13,53].

Samples were submitted to Beta Analytic, Inc. for AMS dating, who conducted pretreatment of the specimens (acid etch for carbonates, and acid/alkali/acid baths for charcoal). Measurements of δ^{13}C were made for all samples, and used to correct measured radiocarbon ages [53]. Radiocarbon ages were calibrated with CALIB 4.3 using the INTCAL98 decadal atmospheric curve for all samples [54–56].

3. Results

3.1. Magnitude of the freshwater reservoir

The radiocarbon results for the six shell/charcoal pairs from the hearths at CA-KER-3079/H Locus A are presented in Table 1. The freshwater reservoir correction (R_f) is calculated as the difference between the conventional age of the mussel shell sample and that of its paired charcoal sample.

The conventional ages of the charcoal samples are remarkably consistent with each other, suggesting a relatively short occupation in the late Holocene. The freshwater mussel shells show more variability in their conventional ages, perhaps due to habitat or species effects between *Anodonta* and *Gonidea* at CA-KER-5404. Despite these variations, R_f for each pair is of a similar magnitude and is consistently in the same direction, i.e., all of the shells have greater apparent ages than their paired charcoal sample. These samples indicate that R_f averaged 340 ± 20 ^{14}C yr from 720 to 680 ± 40 ^{14}C yr BP (calculations follow Stuiver et al. [52:983]). This R_f corresponds to a 300-year disparity between calibrated freshwater carbonate and terrestrial charcoal dates during this period. A roughly 50-year disparity remains between these corrected dates and those on marine shell beads at CA-KER-5404, perhaps due to differences between the atmospheric and marine calibration curves, or to late Holocene ΔR fluctuations in the Santa Barbara Channel. Below, fractionation effects between shellfish genera are evaluated with *Anodonta*/*Gonidea* pairs from site CA-KER-5404.

3.2. Interspecific effects

Radiocarbon data for two *Anodonta*/*Gonidea* pairs from CA-KER-5404 are presented in Table 2. Comparison of the δ^{13}C-corrected conventional ages indicates an offset between the two genera, with *Gonidea* dating 70 ^{14}C yr and 100 ^{14}C yr older than *Anodonta* in SS-14 and SS-18, respectively. The 2σ calibrated ages of each pair overlap, but less in the pair from SS-14. The age discrepancies between the taxa are unlikely to be the result of misinterpreted archaeological context, but may be due to variability in atmospheric ^{14}C content

Table 1
^{14}C Data for paired freshwater mussel and charcoal samples from CA-KER-3079/H Locus A

Provenience	Sample number (Beta-#)	Material	Measured ^{14}C age BP	δ^{13}C (‰ PDB)	Conventional ^{14}C age BP	R_f
S3.2/W1.3 Feature 1	180840	Charcoal	630 ± 40	−20.4	710 ± 40	430 ± 50
	180839	Freshwater Mussel	830 ± 50	−6.4	1140 ± 50	
S3.195/W1.305 Feature 1	180842	Charcoal	480 ± 40	−10.8	710 ± 40	340 ± 60
	180841	Freshwater Mussel	720 ± 60	−4.9	1050 ± 60	
S2.78/W1.65 Feature 1	180843	Charcoal	480 ± 40	−12.0	690 ± 40	340 ± 40
	180844	Freshwater mussel	760 ± 40	−8.5	1030 ± 40	
S2.8/W1.65 Feature C	180846	Charcoal	490 ± 40	−11.0	720 ± 40	280 ± 40
	180845	Freshwater mussel	680 ± 40	−5.5	1000 ± 40	
S2.41/W1.53 Point	180847	Charcoal	450 ± 40	−10.8	680 ± 40	350 ± 40
Provenience 4	180848	Freshwater mussel	740 ± 40	−7.3	1030 ± 40	
S2.41/W1.53 Point	180849	Charcoal	470 ± 40	−11.4	690 ± 40	320 ± 40
Provenience 2	180850	Freshwater mussel	710 ± 40	−6.9	1010 ± 40	
Weighted mean R_f						340 ± 20

Conventional radiocarbon ages are δ^{13}C-corrected with measured values [53]. R_f is calculated as a weighted mean with unequal uncertainties following Stuiver et al. [52:983]. Uncertainty in R_f is taken as the maximum of the "scatter" sigma in unweighted mean (i.e., $s/\sqrt{n} = 20.1$ ^{14}C yr) and the weighted mean sigma (i.e., $1/\left(\sqrt{\sum 1/\varepsilon^2}\right) = 17.7$ ^{14}C yr, where ϵ is the measurement error) after Stuiver et al. [52:983].

from ca. 1000 to 550 cal BP, species-specific carbonate metabolism, habitat differences between *Anodonta* and *Gonidea*, or some combination of these factors. As to habitat, *Anodonta* prefers slow-moving waters with muddy substrates such as lakes, whereas *Gonidea* is more commonly found in faster waters with sandier substrates such as streams and rivers [58]. The observation that the fluvial *Gonidea* is more depleted in ^{14}C than is the lacustrine *Anodonta* is consistent with the findings of Keith and coworkers [35–37], who identified a similar trend between lake and river pelecypods in their data and that of Broecker and Olson [10,11].

The variation in the apparent ages of *Anodonta* and *Gonidea* may partly result from variations in the atmospheric calibration curve during the last ca. 1000 ^{14}C yr BP. Applying the 340 ± 20 ^{14}C yr correction to the four dates from CA-KER-5404 renders the 2σ calibrated ranges for each pair statistically indistinguishable, despite the differences in conventional ^{14}C ages (Table 3). In sum, the question of genus-specific ^{14}C corrections for these two species (i.e., differences arising from metabolic fractionation rather than habitat differences or variable atmospheric ^{14}C content) remains open. *Anodonta*/*Gonidea* pairs from periods of more stable ^{14}C production are required to definitively resolve the issue.

4. Discussion

The estimated value $R_f = 340 \pm 20$ ^{14}C yr between ca. 720 and 680 ^{14}C yr BP is comparable to offsets reported for *Anodonta* by Sutton and Orfila [57] of 300 ^{14}C yr north of Buena Vista Lake, and Joan Scheinder (written communication 1989, cited in Berger and Meek [4]) of 350 ^{14}C yr in the Lake Manix Basin. Berger and Meek [4:581] report a R_f of 450 ^{14}C yr derived from pre-bomb *Anodonta* specimens collected from Los Angeles and Yermo, California, with measured ^{14}C age of 480 ± 60 ^{14}C yr, and a known age of ca. 30 ^{14}C yr (i.e., collection in AD 1920). This value did not account for the proportions of the three specimens that the sample comprises, or the apparent age of the atmosphere in AD 1920. Using the reported sample weights and assuming complete homogenization of all the shells, the average age is closer to 20 ^{14}C yr, or collection in AD 1930, making the offset 460 ± 60 ^{14}C yr. The apparent age of the atmosphere in AD 1930 was approximately 150 ^{14}C yr [56]. Deducting this value from the measured age gives $R_f = 310 \pm 60$ ^{14}C yr, which is similar to the range of values cited above. The general consistency of these offsets may indicate a genus- or family-level (Unionidae) ^{14}C fractionation effect, as proposed by Berger and Meek [4], though the presence of a geologic source of ^{14}C cannot be ruled out in any of these settings.

4.1. The source of depleted radiocarbon in the Buena Vista Basin

The classical explanations for the presence of ^{14}C-depleted carbon in freshwater mussels include dissolution

Table 2
^{14}C Data for *Anodonta*/*Gonidea* shell pairs, CA-KER-5404

Sample number (Beta-#)	Provenience	Material	Conventional ^{14}C age BP	δ^{13}C (‰ PDB)	2σ Calibrated age range (cal BP)
180855	SS-14 Shell lens/20–30 cm	Single *Anodonta* valve	680 ± 40	−6.1	680–560
180856	SS-14 Shell lens/20–30 cm	Single *Gonidea* valve	750 ± 40	−4.0	740–650
180853	SS-18 Shell lens/25–35 cm	Single *Anodonta* valve	890 ± 40	−5.8	920–700
180857	SS-18 Shell lens/25–35 cm	Single *Gonidea* valve	990 ± 40	−6.0	970–790

Conventional radiocarbon ages are δ^{13}C-corrected with measured values [53]. Dates were calibrated with Calib 4.3 using the Intcal98 curve [54–56].

Table 3
R_f-corrected ^{14}C data for *Anodonta*/*Gonidea* shell pairs, CA-KER-5404

Sample number (Beta-#)	Provenience	Material	R_f-corrected conventional ^{14}C age BP	δ^{13}C (‰ PDB)	R_f-Corrected 2σ Calibrated age range (cal BP)
180855	SS-14 Shell lens/20–30 cm	Single *Anodonta* valve	340 ± 40	−6.1	490–310
180856	SS-14 Shell lens/20–30 cm	Single *Gonidea* valve	410 ± 40	−4.0	520–320
180853	SS-18 Shell lens/25–35 cm	Single *Anodonta* Valve	550 ± 40	−5.8	650–510
180857	SS-18 Shell lens/25–35 cm	Single *Gonidea* valve	650 ± 40	−6.0	670–550

Conventional radiocarbon ages are δ^{13}C-corrected with measured values, and reservoir-corrected by subtracting 340 ^{14}C yr from the conventional age [53]. Dates were calibrated with Calib 4.3 using the Intcal98 curve [54–56].

of geologic carbonates [8,9,12,21,23,24,45]; inputs of old soil humus [35–37]; residence time [12,23]; and vital effects [4,37]. Some or all of the old carbon in the Buena Vista Basin is likely derived from geologic sources in the Kern River watershed, and is then stored and concentrated in the groundwater aquifer. Stretches of the Kern River flow over pre-Cretaceous limestones in the Sierra Nevada, and through Miocene marine sediments in the Sierra foothills before settling into the Buena Vista Lake and Slough system [43,48]. In general, the present groundwater chemistry of dissolved solids in California's Central Valley grades from bicarbonate anions on the east side to chloride and sulfate anions on the west side, reflecting mineral inputs from the Sierra Nevada and the Coast ranges, respectively [6]. In the Buena Vista Basin itself, surface waters of Buena Vista and Kern lakes, and Buena Vista Slough, were likely to have been dominated by $NaHCO_3$, as well as lesser amounts of $CaCO_3$ and $Mg(HCO_3)_2$, as the groundwater underlying those now-relict lake beds show [6:A38]. Water samples from the Kern River and Kern Lake analyzed by the pioneering agronomist E. W. Hilgard in 1880 demonstrated that compared to rivers to the north, such as the Kings and San Joaquin, the Kern River contained dangerously high concentrations of $NaHCO_3$ that threatened to destroy the agricultural productivity of the southern San Joaquin Valley [27]. The extreme concentrations of $NaHCO_3$ in Kern Lake in 1880, about 18 months after it had nearly dried out and caused a mass die-off of fish and turtles, suggest that bicarbonate was probably also periodically concentrated in the lakes by evaporation, perhaps contributing to a type of carbon reservoir described by Geyh et al. [23] in Laguna Lejía (Chile's Atacama Desert). This also suggests that the concentration of ^{14}C-free carbon in the lakes of the Buena Vista Basin probably varied through time in response to fluctuating surface area to volume ratios, which reflect time-dependent hydrologic, climatic and geologic factors [12,21,23].

4.2. Archaeological implications for the late Holocene Buena Vista Basin

Recalibrated freshwater mussel shell dates from Elk Hills sites are presented in Table 4 with $R_f = 340 \pm 20$ ^{14}C yr subtracted from the conventional ^{14}C age. Procurement of freshwater mussels appears to be most intense after ca. 700 cal BP, and the few dates earlier than 1200 cal BP (i.e., only 5 of 50 dates) may indicate that slough resources were not a subsistence focus on Elk Hills during earlier periods. Fig. 2 depicts the R_f-corrected 2σ calibrated ranges of the 45 post-1500 cal BP dates on freshwater mussel from 17 Elk Hills sites, plotted against inferred climate from the drowned stumps in the Mono Basin [50], and tree-rings from the southern Sierra Nevada [25] and the White Mountains [29,30,42]. Comparison with the regional climate records indicates a general correlation of mussel procurement on the Elk Hills with cooler, wetter conditions towards the end of the Medieval Climatic Anomaly and during the Little Ice Age. The parallel between the termination of drought in the Mono Basin and cluster of freshwater mussel 2σ-ages ca. 700–550 cal BP appears to be the strongest relationship, though the dates also show good agreement with LaMarche's [42] data, and the broader trend of increasing precipitation after ca. 700 cal BP in all the records. It has been argued that the differences in timing and severity of droughts revealed in these proxies – specifically, apparent contradictions between the tree-ring records and the drowned stumps in the Mono Basin – undermine hypotheses of widespread social reorganization in response to climate change in the late Holocene of western North America (e.g., comments on Jones et al. [34]: [2,7,26]). Bearing those criticisms in mind, appearance of abundant freshwater mussel shell across the Elk Hills at the termination of MCA droughts in the Mono Basin [50] is compelling because both indicate the state of the hydrologic system directly. Unlike dendroclimatic records, the Mono Basin stumps show the end result of extended temperature and precipitation anomalies on the hydrologic landscape from which prehistoric peoples made their living [51:627].

Intensive procurement of freshwater mussels (and other slough resources) appears to have begun at the termination of the MCA and during the Little Ice Age (post-ca. 700 cal BP) as aquatic habitats were expanding and renewing in the Buena Vista Basin, rather than shrinking and declining in productivity during the MCA, as proposed by Jackson et al. [33]. In light of this new chronology, the forces that drove the intensive gathering of mussels and other slough foods may need to be reconsidered. For example, greater productivity of post-MCA aquatic habitats may have allowed regional population to increase, necessitating increased diet breadth or a larger foraging range that included the Elk Hills to support the permanent village sites at Buena Vista Lake [61].

Table 4
R_f-corrected freshwater mussel ^{14}C dates from Elk Hills Sites

Sample (Beta-#)	Site number	Provenience	Material	Conventional ^{14}C age BP[a]	δ^{13}C[b]	2σ calibrated age range (BP)	Reference
111362	CA-KER-5397	SCA-1/surface	Bulk mussel	50 ± 80	−6.9	280−0	Jackson et al. [33]
112706	CA-KER-5367	SP-3/0−50 cm bs	Bulk mussel	140 ± 60	−7.8	280−0	Jackson et al. [33]
108269	CA-KER-5401	STP-26/20−40 cm bs	Bulk mussel	190 ± 60	nr	310−0	Jackson et al. [33]
190870	CA-KER-3080 Locus A	Unit SW1/0−20 cm bs	Single *Gonidea*	290 ± 40	−6.1	460−290	Culleton et al. [19]
180851	CA-KER-3082	Unit 277920E/3911460N Feature 1/19−30 cm bs	Single mussel	350 ± 40	−4.5	490−310	Culleton et al. [19]
180855	CA-KER-5404	SS-14/20−30 cm bs	Single *Anodonta*	340 ± 40	−6.1	490−310	Culleton et al. [19]
190868	CA-KER-3080 Locus A	Unit 104.03/0−20 cm bs	Single *Gonidea*	340 ± 40	−3.9	490−310	Culleton et al. [19]
111364	CA-KER-5398/H	SP-24/0-50 cm bs	Bulk mussel	400 ± 60	−5.3	520−310	Jackson et al. [33]
180856	CA-KER-5404	SS-14/20−30 cm bs	Single *Gonidea*	410 ± 40	−4.0	520−320	Culleton et al. [19]
112711	CA-KER-3082	RRU-21/0-40 cm bs	Bulk mussel	400 ± 70	−5.6	530−310	Jackson et al. [33]
190869	CA-KER-3080 Locus A	Unit 105.03/0−20 cm bs	Single *Gonidea*	430 ± 40	−3.9	540−330	Culleton et al. [19]
116688	CA-KER-3077 Locus A	EU-3/0-20 cm bs	Bulk mussel	440 ± 60	−4.6	550−320	Jackson et al. [33]
116689	CA-KER-3077 Locus A	EU-6 Feature 1	Bulk *Anodonta*	460 ± 70	−5.1	630−310	Jackson et al. [33]
111363	CA-KER-5396	SP-4/0−50 cm bs	Bulk mussel	470 ± 60	−5.5	630−320	Jackson et al. [33]
168084	CA-KER-3397	CU-2/0−10 cm bs	Single mussel	520 ± 40	−5.0	640−500	Culleton and Jackson [18]
108268	CA-KER-5401	STP-3/20−40 cm bs	Bulk mussel	510 ± 70	nr	650−340	Jackson et al. [33]
180853	CA-KER-5404	SS-18 Shell lens/25−35 cm bs	Single *Anodonta*	550 ± 40	−5.8	650−510	Culleton et al. [19]
180854	CA-KER-5404	SS-18 Feature 18−C/26 cm bs	Single *Anodonta*	550 ± 40	−4.4	650−510	Culleton et al. [19]
168090	CA-KER-5955	STU-1/0−20 cm bs	Single mussel	560 ± 40	−3.3	650−520	Culleton and Jackson [18]
168087	CA-KER-5955	CU-1/0−30 cm bs	Single mussel	600 ± 40	−3.1	650−540	Culleton and Jackson [18]
106600	CA-KER-5404	TU-3/20−30 cm bs	Bulk *Gonidea*	600 ± 60	−6.3	660−530	Jackson et al. [33]
112707	CA-KER-3079 Locus C	TEU-1 Feature 1	Bulk *Anodonta*	620 ± 70	−8.0	670−540	Jackson et al. [33]
112708	CA-KER-3080 Locus C	EU-7/0−20 cm bs	Single *Gonidea*	640 ± 50	−6.6	670−550	Jackson et al. [33]
180836	CA-KER-5373/H Locus C	Unit 30 Feature 1/5−25 cm bs	Single mussel	660 ± 40	−6.0	670−550	Culleton et al. [19]
180838	CA-KER-5373/H Locus C	Unit 103 Feature 2/13−28 cm bs	Single mussel	650 ± 40	−6.8	670−550	Culleton et al. [19]
180845	CA-KER-3079 Locus A	Unit S 2.8/W 1.65 Feature C/12−22 cm bs	Single mussel	660 ± 40	−5.5	670−550	Culleton et al. [19]
180850	CA-KER-3079 Locus A	Unit S 2.41/W 1.53 Point Provenience 2; 10−20 cm bs	Single mussel	670 ± 40	−6.9	670−550	Culleton et al. [19]
180857	CA-KER-5404	SS-18 Shell lens/25−35 cm bs	Single *Gonidea*	650 ± 40	−6.0	670−550	Culleton et al. [19]
108266	CA-KER-3167	TU-1/0−10 cm bs	Bulk mussel	630 ± 70	nr	680−520	Jackson et al. [33]
180844	CA-KER-3079 Locus A	Unit S 2.78/W1.65/0−10 cm bs	Single mussel	690 ± 40	−8.5	690−560	Culleton et al. [19]
180848	CA-KER-3079 Locus A	Unit S 2.41/W 1.53 Point Provenience 4; 10−20 cm bs	Single mussel	690 ± 40	−7.3	690−560	Culleton et al. [19]
112709	CA-KER-3080 Locus C	EU-7/0−20 cm bs	Bulk mussel	680 ± 60	−4.5	710−550	Jackson et al. [33]
116691	CA-KER-5373/ H Locus C	CU-1/30−40 cm bs	Bulk mussel	690 ± 70	−5.0	730−540	Jackson et al. [33]
116690	CA-KER-5404	RRU-25/0−40 cm bs	Bulk mussel	700 ± 60	−6.0	730−550	Jackson et al. [33]
188992	CA-KER-3085	Unit 45.03/15−20 cm bs	Single *Anodonta*	720 ± 50	−6.6	730−560	Culleton et al. [19]
180841	CA-KER-3079 Locus A	Unit S 3.195/W 1.305 Feature 1/10−20 cm bs	Single mussel	710 ± 60	−4.9	740−550	Culleton et al. [19]
168088	CA-KER-5955	RRU-2 0−40 cm bs	Single mussel	780 ± 40	−6.5	760−660	Culleton and Jackson [18]
107055	CA-KER-3168	TU-2/0−20 cm bs	Bulk mussel	760 ± 60	−7.1	790−560	Jackson et al. [33]
106601	CA-KER-5404	TU-3/20−30 cm bs	Single *Gonidea*	760 ± 50	−6.6	790−570	Jackson et al. [33]
180839	CA-KER-3079 Locus A	Unit S 3.2/W 1.3 Feature 1/17 cm bs	Single mussel	800 ± 50	−6.4	880−660	Culleton et al. [19]
112710	CA-KER-3080 Locus C	EU-6/20−40 cm bs	Bulk mussel	770 ± 60	−6.3	890−560	Jackson et al. [33]
107056	CA-KER-3168	TU-2/40−60 cm bs	Bulk mussel	790 ± 70	−6.4	910−570	Jackson et al. [33]
111365	CA-KER-5392 Locus A	SP-37/0−50 cm bs	Bulk mussel	810 ± 60	−10.7	910−660	Jackson et al. [33]
108270	CA-KER-3080 Locus D	STP-2/0−20 cm bs	Bulk mussel	1120 ± 60	nr	1170−930	Jackson et al. [33]
168085	CA-KER-3397	CU-2/10−20 cm bs	Single mussel	1160 ± 40	−6.2	1170−970	Culleton and Jackson [18]
168086	CA-KER-3397	RRU-2	Single mussel	1920 ± 40	−9.2	1950−1740	Culleton and Jackson [18]
188993	CA-KER-3085	Unit 83.03/120−125 cm bs	Single *Anodonta*	2050 ± 40	−6.7	2120−1900	Culleton et al. [19]
116692	CA-KER-5392 Locus B	CU-1/30−40 cm bs	Bulk mussel	2740 ± 50	−6.0	2950−2760	Jackson et al. [33]
116693	CA-KER-3166/H	CU-1/50−60 cm bs	Bulk mussel	4500 ± 100	−5.8	5450−4860	Jackson et al. [33]
108267	CA-KER-3166/H	TU-2/40−50 cm bs	Bulk mussel	4400 ± 60	nr	5280−4845	Jackson et al. [33]

[a] Conventional (^{13}C-corrected) ^{14}C ages reported with 340 ± 20 ^{14}C yr reservoir correction subtracted, and calibrated with Calib 4.3 using the Intcal98 atmospheric curve [53−56].

[b] nr = not reported by Jackson et al. [33].

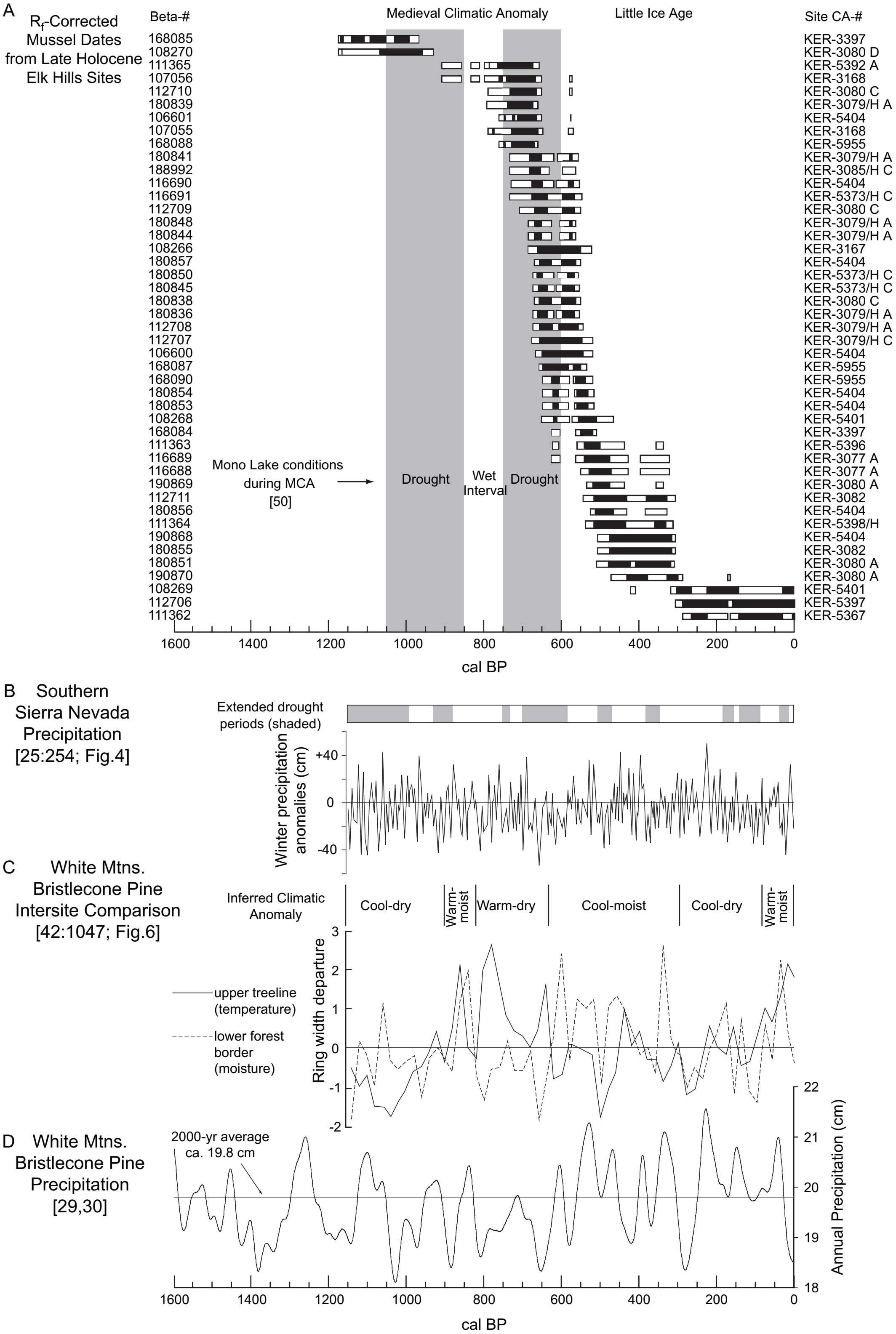

Fig. 2. Reservoir-corrected 1σ (closed) and 2σ (open) calibrated dates on freshwater mussel shell from Elk Hills archaeological sites post-1500 cal BP compared with: A. Mono Basin drought [50]; B. Southern Sierra Nevada precipitation anomalies (redrawn from Graumlich [25: Fig. 4]); C. White Mountains intersite bristlecone pine comparison (redrawn from LaMarche [42: Fig. 6]; D. White Mountains bristlecone pine precipitation record (data from Hughes and Graumlich [29,30]. The intensive exploitation of freshwater mussels coincides with generally cooler, wetter conditions at the end of the Medieval Climatic Anomaly [50] and during the Little Ice Age.

5. Conclusions

Paired radiocarbon dates on charcoal and freshwater mussel shell (*Anodonta* and *Gonidea* sp.) samples from archaeological sites on the Elk Hills in the Buena Vista Basin of the southern San Joaquin Valley indicate a freshwater reservoir effect (R_f) of 340 ± 20 ^{14}C yr between 720 and 680 ^{14}C yr BP. A R_f of this magnitude is consistent with values reported for *Anodonta* by other researchers. Paired dates on *Anodonta* and *Gonidea* sp. shells from discrete lenses may indicate genus-specific offsets from metabolic or habitat difference, but further work is required to resolve the issue. The source of ^{14}C-depleted carbon Buena Vista Basin may be bicarbonate dissolved from pre-Cretaceous limestone in the Kern River watershed, which is then concentrated and stored in groundwater aquifers. Recalibration of R_f-corrected mussel shell dates from the Elk Hills shows a correlation of intensive use of the Buena Vista Slough resources with periods of increased precipitation toward the end of the Medieval Climatic Anomaly and during the Little Ice Age. Slough resource exploitation on the Elk Hills may have resulted from growing regional population pressure as aquatic habitats became more expansive and productive, rather than from declining resource availability as previously supposed. Characterizing the freshwater radiocarbon reservoir in the Buena Vista Basin allows for better articulation of the regional cultural chronology with California's climate record.

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