The Fremont Frontier: Living at the Margins of Maize Farming

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Abstract

The Fremont complex provides an important case study to examine the resilience of ancient farmers to climatic downturns. Living at the far northern margin of intensive maize agriculture in the American West, they also provide important insights into border formation processses, both in space and time. Using a tree-ring and simulation-based reconstruction of average annual precipitation and maize growing degree days, along with cost-distance to perennial streams, we model spatial variability in Formative period Fremont site density in the eastern Great Basin. The results have implications for defining the ecological envelope in which farming is a viable strategy across this arid region and can be used to predict where and why maize farming strategies might collapse as climate changes over time.

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1 Introduction

Archaeological populations known collectively as "the Fremont" lived at the far northern periphery of intensive maize farming in western North America, in an area now contained within the modern state of Utah north of the Virgin and Colorado Rivers, from roughly 1600 to 700 years BP (Madsen, 1989; Madsen & Simms, 1998). During this time, they engaged in varying levels of intensification on maize agriculture, along with seasonal investments in hunting, fishing, and gathering (Joel C. Janetski, 1998; Morgan, Fisher, & Pomerleau, 2012; Jerry D. Spangler, Yaworsky, Vernon, & Codding, 2019). Whether these populations represent a distinctive social pattern that sets them apart from Ancestral Puebloan maize farmers to the south remains an open question. Searcy & Talbot (2015), for instance, argue in the affirmative, suggesting that the Fremont worked actively to maintain their borders through intermarriage and regulated trade with their neighbors (Joel C. Janetski, 2002; cf Joel C. Janetski, Jardine, & Watkins, 2011). Whatever the merits of their argument, the emphasis on borderland processes is an intriguing one, with important implications for archaeological research, for everything from specific behavioral strategies, like territoriality and mobility, to key transitions in human evolution, like the transition from foraging to farming or from small scale societies to full-blown states.

For this reason, we seek in this paper to advance the study of Fremont borders, albeit from a socio-ecological perspective, focusing on dynamic interactions between competing individuals on the one hand and individuals and their environment on the other (Bird & O'Connell, 2006; Kennett & Winterhalder, 2006). This dynamic is captured nicely by the Ideal Free Distribution model from Behavioral Ecology, as it represents individual decisions about where to live as attempts to maximize the goodness or suitability of a habitat, where suitability is defined as some function of both the habitat's intrinsic environmental quality and its current population size (Brian F. Codding & Bird, 2015; Fretwell & Lucas, 1969; Winterhalder, Kennett, Grote, & Bartruff, 2010). An important advantage of these conceptual or theoretical models is that they, in their most general form anyway, abstract away from the precise nature of the social interactions involved, thus allowing those interactions to at times provide benefits to individuals and at other times impose costs.

As a test case, we focus on those Fremont living in the eastern Great Basin of western Utah, which we refer to as the western Fremont. The extreme desert conditions that the western Fremont adapted to in the eastern Great Basin provide a useful backdrop for exploring the variable importance of social and ecological factors to borderland processes. For variation in this region, while smooth and continuous, still exhibits abrupt and quite dramatic changes over short distances of space and time, thus heightening the differences between areas that were and were not occupied by the Fremont. Assuming that western Fremont individuals were adept at responding to variation in their local ecology, in particular, that they made decisions about where to live that cohere with the rules of the IFD framework, we can use an empirical or inductive species distribution model of Fremont sites to reconstruct both their ecological and geographic borders (Elith & Leathwick, 2009; Kenneth B. Vernon, Yaworsky, Spangler, Brewer, & Codding, 2021; Yaworsky, Vernon, Spangler, Brewer, & Codding, 2020).

2 Background

2.0.1 The Fremont

Archaeologists have nominated a number of artifact types and artifact properties as candidate traits to distinguish the Fremont from their neighbors in space and time, including metates with secondary grinding surfaces, large semi-subtarranean pithouses, various clay figurines, trapezoidal rock art, one-rod-and-bundle basketry, painted white and corrugated gray ceramics, and elongated corner-notched arrow points (Madsen & Simms, 1998). None of these, however, nor any combination of them, has yet proven up to the task of bringing these diverse people under a single, all-encompassing definition (Madsen & Simms, 1998). Nevertheless, the Fremont do stand out, especially at their population apex roughly 1000 years BP.

Around this time, the Fremont likely reached their greatest geographic extent, inhabiting an area that encompassed most of the modern state of Utah (Joel C. Janetski et al., 2011), with varying levels of support for occupations in Idaho (Dean, 1992), Nevada (Hockett, 1998), Colorado (Baker, 1999), and Wyoming (Hakiel, Hakiel, Mackey, Reust, & Laurent, 1987; Smith, 1992). These modern political boundaries roughly overlap with the eastern Great Basin and Colorado Plateau physiographic provinces.

A basin and range topography dominates the landscape of the Great Basin, with large, dry valleys and endorheic basins punctuated by north-south trending mountain ranges. Changes in elevation in this setting are quite dramatic, on the order of several thousand meters over a short east-west transect. As elevation drives virtually every climatological process in the region, the local ecology is characterized by equally dramatic extremes. In a given year, the average rainfall is less than 30 cm (Grayson, 2011), with roughly 90% of that falling as winter snow-pack in the mountains (Grayson, 2011). On the valley floor, temperatures are much warmer, decreasing at a rate of just over 2 °C for every 300 m gained in elevation (Grayson, 2011). An important trade-off thus exists between temperature and precipitation, with warmer and drier conditions at lower elevations and cooler and wetter conditions at higher elevations.

The Fremont first emerged within these areas as local Archaic populations transitioned away from mobile foraging, adopting semi-sedentary agricultural practices from the southwest in a piecemeal fashion over several hundred years (Patterson, 2015; Simms, 1986; Jerry D. Spangler, 1993, 2000, 2013). Accumulating evidence suggests this transition to agriculture accompanied periods of depressed resource availability (K. R. Barlow, 2002; Joel C. Janetski, 1997; Simms, 1986) and sustained population growth (K. Renee Barlow, Towner, & Salzer, 2008; Brian F. Codding et al., 2021; Jerry D. Spangler, 2013). During this transition, the Fremont also began concentrating in larger, more complex villages like Five Finger Ridge (Joel C. Janetski & Talbot, 1997) and Nawthis Village (Metcalfe, 1984), where they built ceremonial structures and shared communal storage. Single and multi-family hamlets also persisted through this time, though there is some evidence to suggest that they tended to cluster around larger villages (Joel C. Janetski & Talbot, 1997).

The Fremont developed several agricultural adaptations for coping with the marginal and stochastic conditions in the eastern Great Basin and the Colorado Plateau, the two most important perhaps being settlement and irrigation. On the Colorado Plateau, the eastern Fremont settled deep within the steep canyons and washes that flanked the tributaries of major rivers like the Green and Yampa. In the Great Basin, the western Fremont chose to settle on open, alluvial fans and stream terraces along the lower slopes of most ranges. In either case, it appears that they chose locations at elevations around 1800 m that optimized the trade-offs between precipitation, water runoff, high temperatures, and frost-free days (Lindsay, 1986). For similar reasons, they used canals and check dams to irrigate their plots (Boomgarden, Metcalfe, & Simons, 2019; Matson, Lipe, & Haase, 1990; Jerry D. Spangler, Yentsch, & Green, 2010). While these adaptations facilitate farming in the arid west, they are still susceptible to extended drought, and a single short growing season makes agricultural returns highly variable. To cope with these uncertainties, Fremont farmers may have adopted additional risk-mitigation strategies like spreading farm plots among different micro-environments, a technique otherwise known as plot diversification (Patterson, 2015; Jerry D. Spangler, 1993, 2013). The Fremont also relied heavily on intra- and inter-annual crop storage both to provide a surplus during the winter season and to make-up for poor yields (Jerry D. Spangler et al., 2019).

2.0.2 The Ideal Free Distribution

In population ecology, settlement decisions are represented as a choice between habitats, where each habitat has some net biological value or benefit, known as its suitability (S). Typically, though not always, this value exhibits negative density dependence, declining as a function of population size (N), perhaps owing to increased competition or resource depression. When N is very small, the suitability of a habitat approaches its pristine or intrinsic quality (Q), or its gross value independent of all settlement costs (Greene & Stamps, 2001). Together, these parameters suggest a very simple model of habitat suitability:

$$S = Q - f(N)$$

This is known as the Ideal Free Distribution (IFD) model (Fretwell & Lucas, 1969). The IFD model assumes that individuals will choose habitats that maximize S, settling the most suitable habitat first then shifting to the next most suitable habitat when those become equal, and thereafter infilling each at an equal rate. The aggregate effect is a population distributed at equilibrium, meaning suitability is equal for all habitats. When conditions are ideal (individuals have perfect knowledge) and free (individuals face no additional costs to settlement), this distribution will also satisfy the “input matching” rule, with populations occurring at larger numbers in habitats with greater intrinsic value (Parker, 1978).

Two circumstances provide important exceptions to this simple model. The first concerns economies of scale, or situations in which S exhibits positive density dependence. In ecology, these are known as Allee effects, and they are assumed to occur at low density (Allee, Park, Emerson, Park, & Schmidt, 1949; Fretwell & Lucas, 1969). The second concerns additional settlement costs (C), or costs associated with moving from one habitat to another. This is a violation of the free element of the IFD. When it occurs, the result is an ideal despotic distribution (IDD) (Fretwell & Lucas, 1969). This has the consequence of reducing the total population in the more suitable habitat at equilibrium (Fig. 1-B).

Many social and ecological variables may be relevant to defining a general measure of Q, but here we are focusing on ecological determinants of habitat quality specific to maize farmers. The intuition behind this is simple enough. Maize farmers are expected to settle areas where maize farming is most productive, that is, in areas with higher levels of maize suitability. If we assume that the distribution of maize-farming sites represents the distribution of populations across habitats at equilibrium, we can combine this concept of maize-specific suitability with the input matching rule to reconstruct the ranking of habitats on the basis of ecologically-relevant parameters. In effect, we model the distribution of sites (N) as a function of those ecological covariates, then use that model to estimate the maize niche in ecological and geographic space.

3 Materials and Methods

3.0.1 The Project Area

Because we are focusing on the western Fremont, we constrain the current project area to western Utah, as shown in Fig. 1. On the far eastern edge of this region, the Wasatch Range and the Tushar Mountains together stand as the primary physiographic boundaries separating the Great Basin from the Colorado Plateau. On its far western edge, a series of north-south ranges straddle the Nevada state line or lie just inside it, including the Snake Range where Great Basin National Park is located. Its northern periphery is the Great Salt Lake and the West Desert, its southern boundary the Pine Valley Mountains that separate the Great Basin from the Virgin River watershed. This is a region approximately 107,000 km^2 in area, encompassing virtually all of the Bonneville Basin in western Utah.

These boundaries also serve as geographic borders between the western Fremont and other contemporaneous populations. Around the Great Salt Lake and the Utah-Nevada border, Fremont farming gives way to intensive foraging modes of subsistence. The Wasatch Range and Tushar Mountains separate the western from the eastern Fremont on the Colorado Plateau, and the Pine Valley Mountains serves as a border between the Fremont and the Virgin Ancestral Puebloan to the south.

3.0.2 The Unit of Analysis

The unit of analysis for this research is the HUC10 watershed (n = 183), as defined by the Watershed Boundary Dataset (WBD) developed by the US Geological Survey and the Natural Resources Conservation Service within the US Department of Agriculture (USGS & USDA NRCS, 2013). These provide a spatially-explicit proxy for specifically human habitats in the proposed study

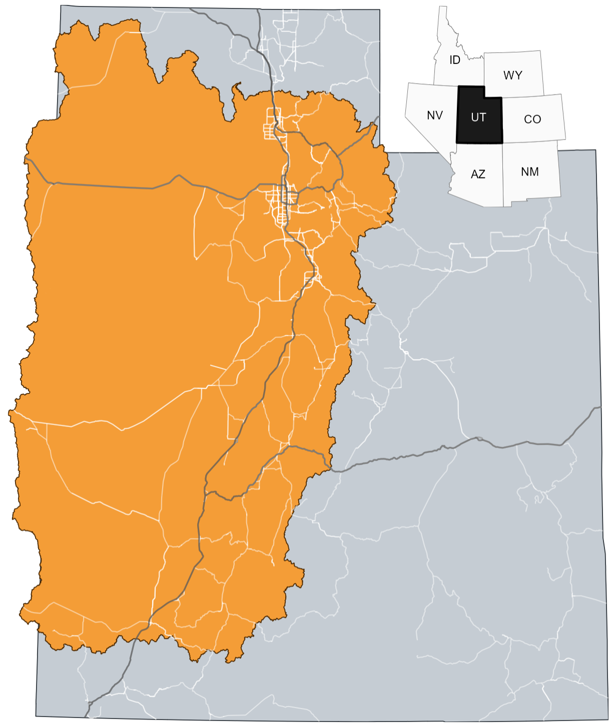

Figure 1: Overview map showing the project area in orange. Dark gray lines represent major interstate highways, white lines state highways and local roads.

area. There are two reasons for this. First, the topography of the region is such that the cost of travel between watersheds is often quite significant. All else being equal, individuals should, therefore, spend more time traveling within watersheds than between them. Second, watersheds are by definition water sinks, funneling all available run-off into their respective stream networks. Given the extreme aridity of the proposed project area, this also makes them critical resource sinks, especially for maize farmers.

Aggregating to the level of the watershed also reduces the computational burdens of this modeling exercise. In particular, it makes paleoclimate reconstructions more tractable, as we are only estimating the means within each watershed through time. See below for details.

3.0.3 Site Data

To identify Fremont sites in the project area, we rely on site records and cultural resource reports hosted by the cultural resource information systems in Nevada (NVCRIS) and Utah (Sego) with permission from the respective State Historic Preservation Offices. The Sego system also includes an attribute table with affiliation data for each site that we use to filter Fremont sites where possible. For a previous project, we also performed a stratified random sample of all archaelogical sites by county in western Utah and recorded affiliation and other attribute data from their site forms. For this analysis, we compare the results of that previous effort with the sites identified by filtering the Sego system as a form of quality control. The resulting dataset contains 2,248 individual Fremont

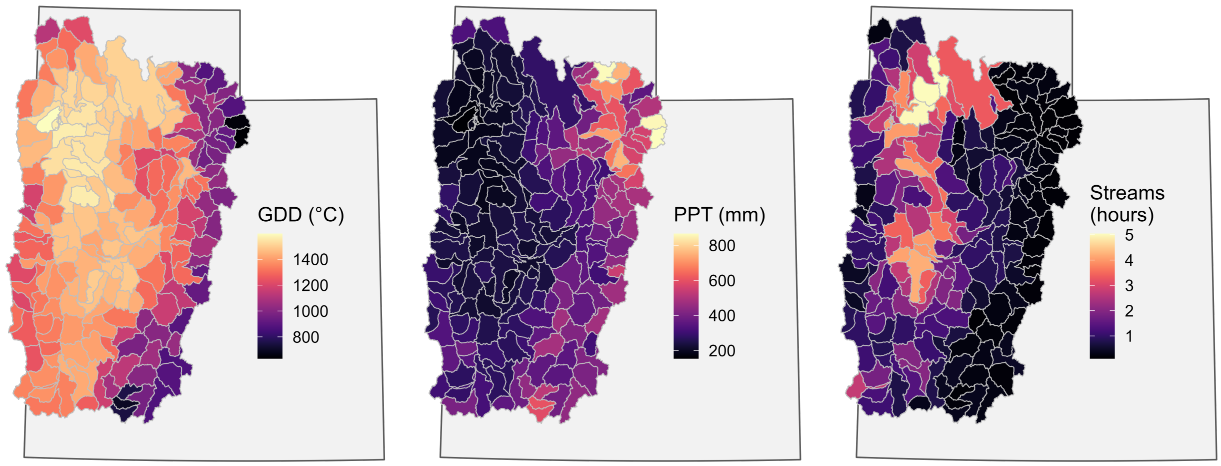

Figure 2: Distribution of covariates across watersheds. These include maize growing degree days (GDD), summer precipitation (PPT), and cost-distance to streams (Streams).

sites.

These site data include everything from small ceramic scatters to massive Fremont villages like Five Finger Ridge. For this analysis, we assume that these reflect different levels of population size and settlement intensity. All else being equal, scatters should follow from shorter stays by fewer people, villages from longer stays by more people. This is important because population size contributes to a habitat's total suitability according to the IFD model, and our attempts to reconstruct the ecological and geographic borders of the Fremont rely heavily on the input-matching rule, or the idea that habitats with greater intrinsic quality will have larger populations at equilibrium. We, therefore, weight the count of sites in each watershed by the total number of residential features that they contain (+1 for sites with no features). So, a site with no residential features counts as one site, a site consisting of, say, four pithouses counts as four unique sites, and a site containing a roomblock with seven rooms counts as seven sites. This brings the total weighted site count to 2,447, with minimum and maximum values of 0 and 119, respectively. The geographic distribution of observed sites over watersheds is shown in Fig. 4.

3.0.4 Environmental Covariates

For this analysis, we use both topographic and climatological covariates. The topographic covariate is cost-distance to perennial streams (measured in hours). This provides a coarse grained estimate of water availability, as well as the potential costs of irrigation. To calculate this, we apply Campbell's hiking function (Campbell, Dennison, Butler, & Page, 2019) to slope estimates derived from a digital elevation model (DEM) using the R package hiker (Kenneth Blake Vernon, 2021). This allows us to generate estimates of travel time between grid cells in the DEM and then calculate the accumulated cost of travel from each perennial stream to any grid cell within each watershed. We then aggregate these values to the watershed level by taking their mean. We use the R package FedData (R. Kyle

Bocinsky, 2020) to download perennial stream features from the US National Hydrography Dataset (USGS, 2022b) and a DEM from the US National Elevation Dataset (USGS, 2022a).

Climate covariates include net water-year precipitation (PPT) and maize growing degree days (GDD), as these have a large effect on maize productivity, thus providing important constraints on the patterns of settlement for those who relied on maize for subsistence. We hindcast these for each watershed and year over the Fremont sequence from 1550 to 550 years BP (400 to 1400 CE) using the Correlation Adjusted corRelation (CAR) method implemented in the R package paleocar (R. Kyle Bocinsky, 2019). This method, in effect, regresses modern climate data against the width of younger tree rings, then uses older rings to predict past climate trends (K. R. Bocinsky, Rush, Kintigh, & Kohler, 2016; for further details, see R. Kyle Bocinsky & Kohler, 2014). In this case, we use interpolated precipitation and temperature estimates from the ~800 m resolution PRISM dataset (PRISM Climate Group, 2014) and all tree-ring samples in North America, which were obtained from the International Tree Ring Database using FedData. For each watershed, we took the median values of PPT and GDD over the Fremont sequence.

The geographic distributions of these covariates over watersheds are shown in Fig. 2. As these are all in one way or another driven by elevation, it is reasonable to expect that they will correlate, and indeed a correlation test does show that to be the case. That said, the modeling technique we use (described below) applies basis expansions to these predictors, so it matters more whether they are co-linear in their basis expansions. This is known as concurvity, which we test for after fitting an initial exploratory model. We then drop cost-distance to springs from the final model.

3.0.5 Statistical Modeling and Model Evaluation

The response variable is a count of sites per watershed, so it should arise as the result of a Poisson process. We also expect it to exhibit a non-linear response to PPT, GDD, and cost-distance to streams, so we fit a generalized additive model (GAM) to the data using the R package mgcv (Wood, 2004). For this modeling effort, however, we use a negative binomial rather than a Poisson distribution, as it can account for potential dispersion without giving up the inferential benefits of maximum likelihood. We also include a selection penalty that can penalize coefficients within the basis expansion to zero.

Importantly, we add to the model specification a constant offset for the log of the area of each watershed, in effect making this a model of population *density*. This is meant to address the idea that larger watersheds will have more sites just as a matter of chance. We also include a linear term for the proportion of each watershed classified as federally protected land. This is meant to address potential sampling biases owing to taphonomic processes operating on the archaeological record. Notably, for these data, those are almost entirely the result of Euro-American colonization of the area, in particular, the impacts of modern farming techniques and the development of the Wasatch Front as the urban center of the state of Utah. This is a coarse metric, but our expectation is that the greater the share of a watershed with federal protections, the smaller the effect of these anthropogenic impacts, the more sites we should observe.

Table 1: Parametric coefficients

	estimate	std.error	statistic	p.value
(Intercept)	0.0069	0.3041	-16.364	0e+00
protected	4.1873	0.4321	3.314	9e-04

Table 2: Approximate significance of smooth terms

	edf	ref.df	statistic	p.value
s(precipitation)	3.2084	4	52.93	0.000
s(gdd)	0.9513	4	18.67	0.000
s(streams)	1.8385	4	11.31	0.001

After fitting the final model, we compare the full model to an intercept-only null model using a Likelihood Ratio Test to ensure that the increased fit of the final model makes up for its increased complexity. We also test for spatial autocorrelation in the untransformed residuals using Monte Carlo simulations of Moran's I.

All analyses are conducted in the R programming language and environment (R Core Team, 2021).

4 Results

All linear (or parametric) coefficients are significant in the final model. The intercept (β = -4.977, p $<$ 0.0001) is close to zero when transformed back onto the response scale, likely reflecting the large number of watersheds with zero Fremont sites. The proportion of watersheds falling under federal protections (β = 1.432, p = 0.001) has a positive effect on site counts, thus confirming our expectation that more sites occur in watersheds with a larger proportion of federal land. All smooth terms are also significant in the final model. The effective degrees of freedom (EDF) for PPT (EDF = 3.208, p $<$ 0.0001) suggests a strong non-linear effect of that covariate on site counts. The EDF for GDD (EDF = 0.951, p $<$ 0.0001), being less than one, indicates that parts of the smooth term were penalized to zero. In this case, that led GDD to have an entirely linear effect on site counts. The relationship also appears to be mostly linear. The EDF for cost-distance to streams (EDF = 1.839, p = 0.001) suggests a weak non-linear effect on site counts.

Results of the ANOVA Likelihood Ratio Test ($\chi^2(9.15) = 72$, p $<$ 0.0001) show significant increase in model fit for the increased model complexity. Concurvity values for the covariates are large, but not much larger than 0.8, a common threshold for determining how much is too much concurvity. The Moran's I test shows significant autocorrelation (I = 0.05, p = 0.001) in the untransformed residuals.

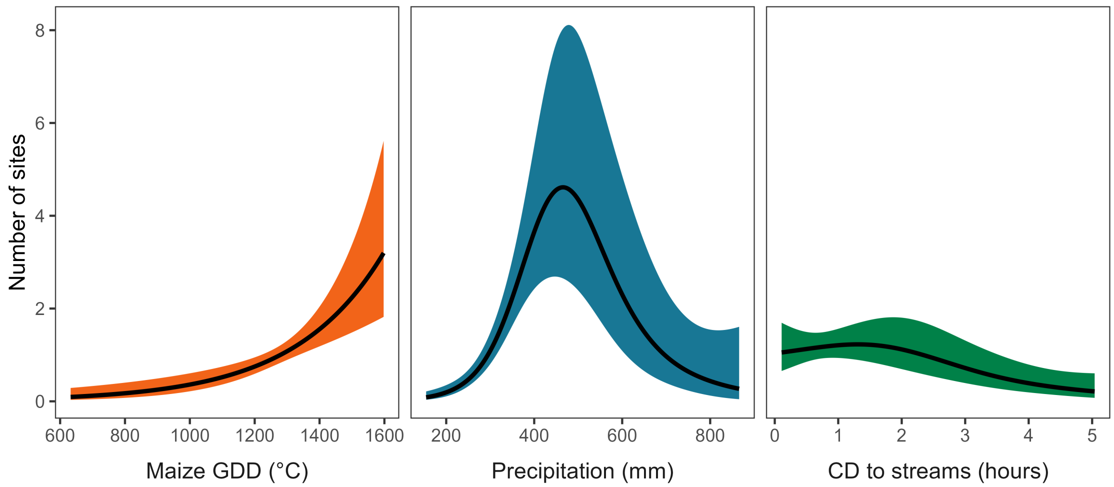

Figure 3: Marginal response plots. Each plot shows the response of site counts to changes in a target covariate while holding all other variables at their mean.

5 Discussion

Our results indicate that Fremont maize farmers generally preferred warmer watersheds with longer growing seasons, moderate levels of PPT (in the range of 400-600 mm), and greater access to perennial streams, as shown by the marginal response plots in Fig. 3. A curious result of our analysis is that site counts do not increase linearly as a function of PPT, but instead decline after 500 mm. We believe this is likely an artifact of elevation and the trade-off with GDD. At high elevations where precipitation levels are maximized, temperature and the length of the growing season are also minimized. It is likely that these elevations also maximized effective soil moisture and the moisture index (defined as the ratio of available water to plant water demand), both of which are a function of temperature and PPT, and are known to be predictive of agriculture development (Brian F. Codding et al., 2021; Ramankutty, Foley, Norman, & McSweeney, 2002; Yaworsky & Codding, 2017). The western Fremont, therefore, chose site locations at elevations that maximized agricultural suitability, where that is some function of both GDD and PPT. This is suggested by the geographic distribution of sites across watersheds estimated by our model (see Fig. 4), though we note that watersheds are too coarse grained to get a good sense of the true distribution. Nevertheless, these findings have important implications for the regional prehistory of the eastern Great Basin, particularly for the spread and eventual collapse of maize agriculture.

5.1 The Spread of Maize Agriculture

Our results suggest that maize farmers in the Great Basin preferentially targeted a certain elevation band that coincides with alluvial fans, forming a rim around the lower slopes of mountains and ridges. The extreme ruggedness and aridity of this region led to extreme circumscription, with the costs of intensive farming outside these areas being so severe as to render that alternative virtually

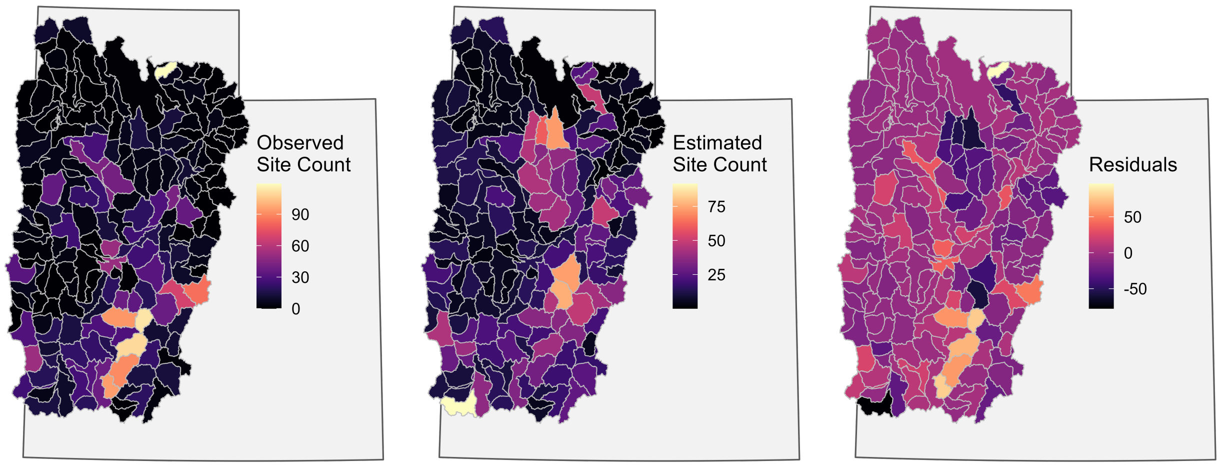

Figure 4: Geographic distribution of Fremont sites across watersheds. The left panel shows the observed distribution, the middle panel the estimated distribution, and the right panel the residual distribution. These are the transformed residuals, so they represent the difference between the observed and estimated counts. Visual inspection of the residuals suggests fairly serious spatial autocorrelation.

unsustainable. For maize farmers, the Great Basin should, thus, have the look and feel of an island biogeography, with mountains rising up like islands out of an ocean of desert sand and sagebrush.

To account for the timing and tempo of island colonization among food producers in Oceania, Kennett, Anderson, & Winterhalder (2006) offer an extension of the IFD framework that might actually apply to the Great Basin. Their model depends crucially on the potential for farming populations to introduce economies of scale or Allee effects, with suitability increasing with increasing population at low densities. They also assume that individuals will prefer nearer habitats to those that are farther away, under the assumption that greater distances impose greater settlement costs, all else being equal. Together, these assumptions suggest a pulsating pattern of maize spread into the North American Southwest, with maize agriculture growing, then spreading, growing, then spreading, as appears to have happened in Oceania.

This need not be a wholesale movement or adoption of agricultural practices, either. Madsen & Simms (1998) argue that Fremont subsistence largely varies along two dimensions: levels of residential mobility and levels of cultigen adoption. While some were more mobile, moving from isolated patch to isolated patch, others were more sedentary, typically tethered to a productive wetland or riparian area. As local populations increase, the benefits of increased sedentism and cultigen adoption would slowly begin to outweigh the benefits of a more mobile and foraging-centered diet. According to our model, individuals moving in this direction would tend to concentrate more of their time and energy in the maize farming niche. This would then have the effect of increasing population size within a smaller area, possibly leading to Allee effects, which would invite further sedentism from those in the surrounding area. Following this logic, the patchy adoption of agriculture makes more sense. The degree and speed with which it occurs is simply a function of how fast habitat quality declines and how quickly populations grow.

5.2 The Collapse of Maize Agriculture

After farming these regions successfully for almost a thousand years, the Fremont began an abrupt process of abandonment starting around 700 years BP. The cause of this event is still a matter of some dispute, though a growing consensus appears to be coalescing around climatic changes driving severe reductions in agricultural productivity (Benson, Petersen, & Stein, 2007; Finley, Robinson, DeRose, & Hora, 2020; Jerry D. Spangler et al., 2019; Marcus J. Thomson, Balkovič, Krisztin, & MacDonald, 2019; Marcus J. Thomson & MacDonald, 2020). We follow Lindsay (1986) in thinking this was likely owing to climatic events that decoupled temperature and precipitation optima within the range of elevation where maize farming was possible. Lindsay suggests that the end of the Medieval Warm Period may have been responsible for this decoupling, as it involved higher temperatures and more growing-season precipitation owing to the northward intrusion of summer monsoons. This period lasted from roughly 1,000 to 600 years BP (Graumlich, 1993; Grayson, 2011), so it does coincide with the height of the Fremont complex.

Given the logic of IFD, this likely led to increased populations with concomitant spillovers into less suitable habitats (Brian F. Codding et al., 2021). However, given the extreme circumscription we have highlighted in the Great Basin, the available alternatives would have been limited, potentially leading to increasing population packing across all habitats during this time, thus making the Fremont especially sensitive to climatic downturns.

6 Conclusion

In this paper, we sought to reconstruct Fremont borders using the distribution of known Fremont sites across watersheds. On the assumption that those distributions represent past Fremont populations at equilibrium, we use the input-matching rule derived from the IFD model to infer the intrinsic quality of each watershed, where those serve as spatially-explicit maize farming habitats. This then allows us to define borders not as strict boundaries, but as gradients along which Fremont are more or less likely to settle. Of course, given the environmental extremes characteristic of the Great Basin, those gradients were quite abrupt, suggesting that ecological factors might be more relevant to border formation processes in the region.

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