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Landscape ecology, settlement, and land use in the Lower Río Verde Valley, Oaxaca, México: An unusual case for coastal Mesoamerica

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ABSTRACT

This article examines the roles of coastal environments in prehispanic settlement patterns and land use within the lower Río Verde Valley, Oaxaca, México using interdisciplinary methods. We first compare population levels in the coastal zone—including areas by the estuaries and sea—to inland habitats such as the floodplain. Second, we discuss resource extraction and trade associated with the coastal zone. Excavations and a 224 km^2 full-coverage survey indicate that, except during the initial Early Formative period (1600–1350 BC), coastal zone habitats were not a settlement focus. Land use concentrated on the extraction of resources such as fish, salt, and ornamental shell. These goods were consumed locally and exchanged *via* long-distance networks for obsidian, pottery, and during the Postclassic period (AD 800–1522), copper items. Archaeofaunal and isotopic data suggest that aquatic resources from estuarine and marine environments constituted a small proportion of the total caloric input, but may have been important sources of protein. Finally, we compare settlement patterns between the lower Verde and other Mesoamerican coastal regions. Lower Verde population in the coastal zone was low, especially relative to areas which practiced mixed subsistence into the Middle/Late Formative periods (ca. 700–150 BC). This is related to the proximity of arable lands to estuaries.

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Fishing; floodplain farming; salt production; long-distance exchange; demographic change

Introduction

This article examines the interrelationship of landscape ecology, settlement patterns, and human land use in the lower Río Verde Valley of Oaxaca, Mexico (Figure 1), with a focus on coastal environments. The lower Verde region is characterized by a sub-tropical climate with variation among its six physiographic zones: the floodplain, secondary valleys, piedmont, coastal plain, estuaries, and salt flats. Two of these zones contain highly productive resource niches which developed during the Formative period (1600 BC–AD 250). Specifically, previous research has shown that anthropogenic erosion in the Río Verde's upper drainage basin beginning ca. 2000 BC increased the river's sediment load. This resulted in an expansion of the floodplain in the lower valley starting

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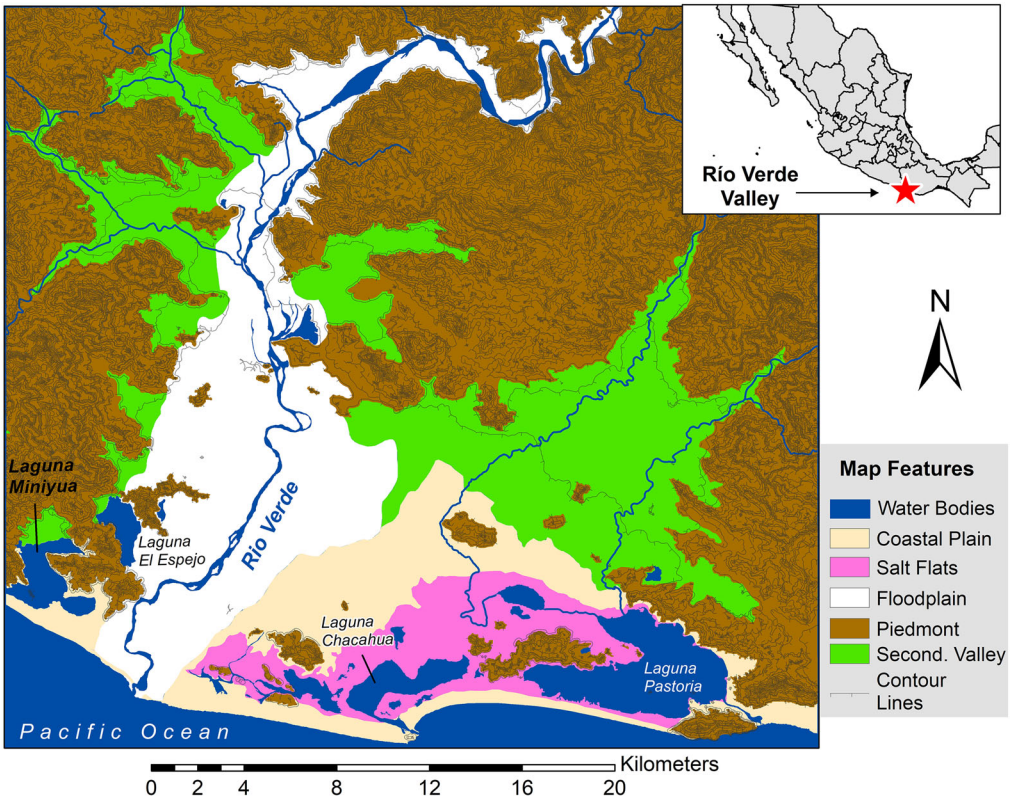


Figure 1. The lower Río Verde Valley, showing location and physiographic zones.

Table 1. Lower Río Verde Valley chronology.[1]

Period	Uncalibrated dates
Late Archaic	4000–1600 BC
Initial Early Formative	1600–1350 BC
Late Middle Formative	700–400 BC
Late Formative	400–150 BC
Early Terminal Formative	150 BC–AD 100
Late Terminal Formative	AD 100–250
Early Classic	AD 250–500
Late Classic	AD 500–800
Early Postclassic	AD 800–1100
Late Postclassic	AD 1100–1522

[1]This sequence is based on data from Hepp (2015, 2019) and Joyce (1991, 2020).

in the initial Early Formative period (ca. 1600–1350 BC) (Table 1), with modern braided-river conditions in place by around 150 BC (Joyce and Goman 2012; Joyce and Mueller 2010; Mueller et al. 2013). Sediments discharged by the Río Verde into the Pacific Ocean were carried east by longshore currents, which accelerated the formation of bay barriers and back-barrier estuaries (ca. 400 BC–AD 250) (Goman, Joyce, and Mueller 2005). These changes likely led to an increase in the availability of subsistence resources, including maize, fish, and shellfish (Joyce et al. 2014; Mueller et al. 2013).

In this paper, we examine how the lower Verde's coastal zone—including the coastal plain, estuaries, and salt flats—was involved in regional human–environment interactions from the initial Early Formative period to the arrival of the Spanish in AD 1522. We draw from a variety of evidence ranging from settlement patterns to findings about resource extraction and trade (e.g., Hedgepeth Balkin 2020; Hepp, Sandberg, and Aguilar 2017; Joyce 1993; Joyce et al. 1995, 1999, 2006; Joyce, Oland, and Kroefges 2009; Levine, Joyce, and Glascock 2011; Williams 2012). In comparison to other Mesoamerican coastal regions, the lower Verde coastal zone had relatively low populations prior to the Late Formative period (400–150 BC). These habitats, however, were valued for the extraction of resources used in subsistence and for long-distance trade. Our data indicate that fish, ornamental shell, and salt were extracted and likely exported, while fish, shellfish, and waterfowl were consumed within the region. Local goods were exchanged *via* long-distance networks for obsidian, copper, and other imports.

Regional setting: Landscape ecology, subsistence, and settlement

The lower Río Verde Valley contains a long history of interdisciplinary investigations that examine the prehispanic human ecology of the region. Research has included archaeological, geomorphological, and paleoecological studies as well as agricultural productivity modeling. Archaeological projects consist of excavations at 19 sites (e.g., Barber 2013; Brzezinski, Joyce, and Barber 2017; Hepp 2015; Joyce 1991, 2010, 2013; Joyce et

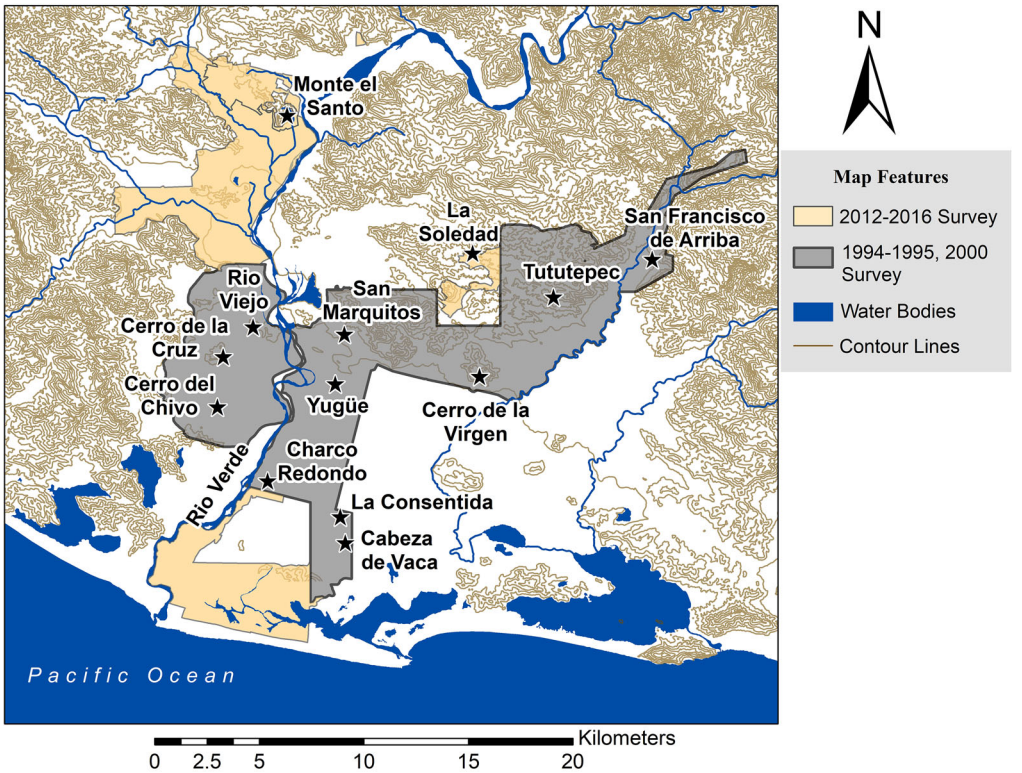


Figure 2. Full-coverage survey in the lower Río Verde Valley: 1994–2016.

al., 1998, 2016; King 2008; Levine 2011; Meehan 2019; Workinger 2013) and a 224 km^2 full-coverage survey (Figure 2) (Hedgepeth Balkin 2020; Joyce, Oland, and Kroefges 2009; Joyce et al. 1999; Workinger 2002). These data provide important information concerning diachronic changes in settlement patterning and land use. Dietary studies have included archaeofaunal and archaeobotanical analysis along with human bone chemistry (Bérubé 2023; Bérubé, Hepp, and Morell-Hart 2020; Fernández 2004; Hepp 2015; Hepp, Sandberg, and Aguilar 2017; Joyce 1991; Morell-Hart 2015; Rancaño Castillo et al. 2023; Rumberger 2016; Woodard 1991). To examine vegetation, land use, and changes in landforms, interdisciplinary teams have conducted geomorphological and paleoecological studies based on a regional coring project (Figure 3) (Goman, Joyce, and Mueller 2005, 2013; Goman et al. 2010, 2014; Joyce and Goman 2012; Joyce and Mueller 1997, 2010; Mueller et al. 2013). Finally, agricultural productivity has been assessed *via* geomorphological investigations (Joyce and Mueller 1997, 2010; Mueller et al. 2013) as well as geospatial (GIS) modeling (Hedgepeth Balkin 2020).

In the semi-tropical lower Río Verde Valley, yearly rainfall ranges from 1000 to 2000 mm with average temperature typically resting between 25 °C and 28 °C (SMN 2011). The availability of freshwater was likely sufficient for prehispanic agricultural production in most of the lower Verde's physiographic zones—with the exception of areas exposed to high amounts of saltwater (the salt flats and beach; see Figure 1).

Over the course of the Formative period, the expansion of the floodplain (ca. 1600–150 BC) and the development of the estuaries (ca. 400 BC–AD 250) would have positively impacted the productivity of subsistence resources—particularly maize, fish, shellfish, and waterfowl (Goman, Joyce, and Mueller 2005; Joyce and Mueller 2010; Mueller et al. 2013). Estuarine environments, including those which developed on the lower Verde coast, are characterized by a higher faunal abundance and species diversity in comparison to other coastal settings such as open bays, continental shelves, or the ocean (Bailey and Milner 2002; Erlandson and Fitzpatrick 2006; Mueller et al. 2013; Perlman 1980; Weckström et al. 2017). Agricultural productivity improved during the Formative period due to increases in the flow rate and sediment load of the Río Verde, which led to floodplain growth, the deposition of a higher volume of organic materials, and an increase in the water table height (Joyce and Mueller 2010, 50; Mueller et al. 2013; see also Hedgepeth Balkin 2020, 584; Joyce and Goman 2012).

The floodplain was the most productive physiographic zone throughout the prehispanic era due to ecological properties such as the fertile alluvium and a relatively high water availability (Hedgepeth Balkin 2020; Joyce and Mueller 1997, 2010; Mueller et al. 2013). The GIS suitability analysis indicates that, in descending order of fertility, the floodplain was followed by the coastal plain, secondary valleys, piedmont, and salt flats. Sampling biases in the soil fertility and water availability components of the GIS model, however, may have inflated the estimated productivity of the coastal plain (Hedgepeth Balkin 2020).

Environmental data suggest that the lower Verde estuarine zone and nearby coastal plain could have been an important locus of settlement and/or subsistence activities, especially after the bay barrier developed by ca. AD 250. Not only were aquatic resources concentrated in the estuarine zone, but moderately productive agricultural lands were located within a short walking distance (2–3 km); the landscape within the estuarine zone itself included salt flats, beaches, and isolated hills with low agricultural potential (see Figure 1).

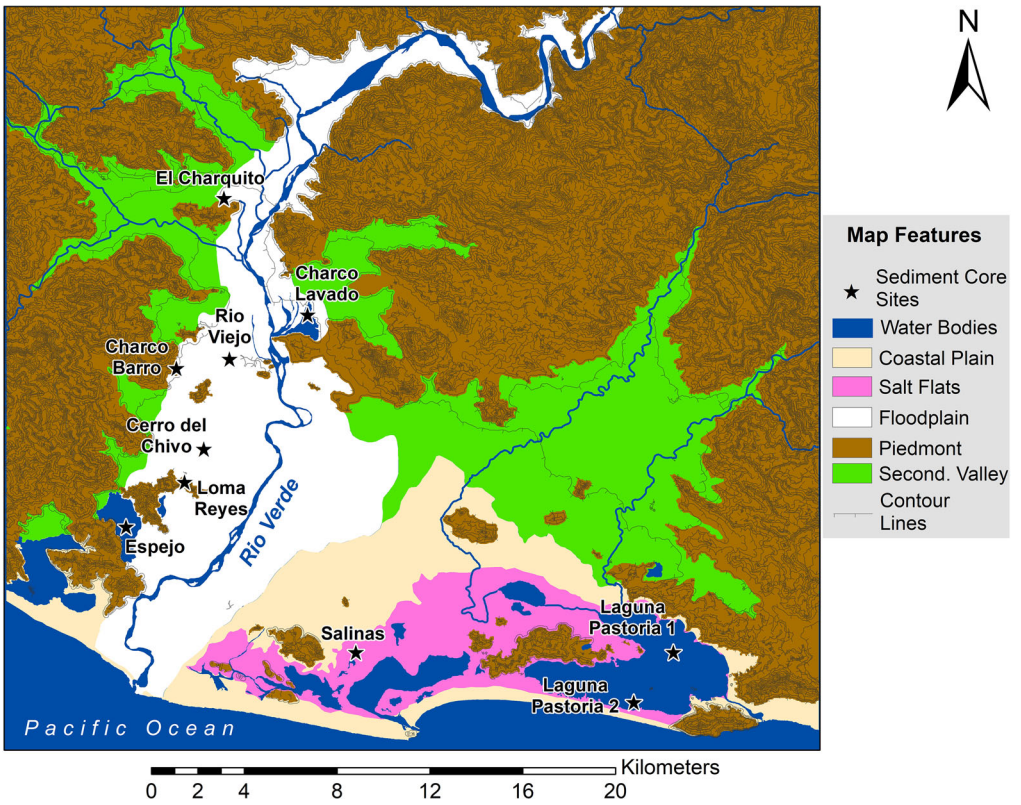


Figure 3. Sediment cores extracted for paleoecological study in the lower Río Verde Valley. Credit: Paleoecological data derive from Goman and colleagues (Goman, Joyce, and Mueller 2005, 2013; Goman et al. 2010, 2014; see also Joyce and Goman 2012).

Paleoecological, dietary, and settlement pattern data, however, suggest that the estuaries and coast played a relatively small role in lower Verde settlement and subsistence. Of the region's six physiographic zones, the floodplain has the strongest paleoecological evidence for anthropogenic land clearance and maize cultivation in prehispanic times—particularly for the Late Formative onward—although sampling issues may have biased the results somewhat (see Goman, Joyce, and Mueller 2005, 2013; Goman et al. 2010, 2014; see also Joyce and Goman 2012). The majority of the sediment cores for paleoecological sampling were extracted from ponds and lakes (extant and relict) within the floodplain, thereby providing a localized land use signal within this zone (see Figure 3). A smaller proportion of samples have been collected from within the estuarine zone at Laguna Pastoría and the Salinas site (Goman, Joyce, and Mueller 2005, 2013; Lock et al. 2014). The estuary data are more indicative of regional land use due to the fact that in large water bodies, local pollen is swamped by the regional pollen signal. Charcoal collected from these cores, however, can provide a more local signal of land clearance because it does not travel far from its point of origin when transported by wind or water. Charcoal data from the Salinas site and Laguna Pastoría indicate land clearance by burning close to the estuaries at ca. 2830 cal BC, corresponding to the Late Archaic period (4000–1600 BC) (Table 1). While paleoecological evidence for land clearance is

Table 2. Residential occupation by physiographic zone (% of total regional hectares by phase).[1]

	Total regional occupation	Piedmont zone		Floodplain zone		Secondary valley zone		Coastal plain zone	
Period	ha	ha	%	ha	%	ha	%	ha	%
Initial Early Formative	6.6	2	30.3	0.1	1.5	0.0	0.0	4.5	68.2
Late Middle Formative	65.6	0.5	0.8	63.7	97.1	1.4	2.1	0.0	0.0
Late Formative	374.5	137.5	36.7	117.2	31.3	119.7	31.9	0.2	0.1
Early Terminal Formative	556.0	144.2	25.9	326.5	58.7	85.2	15.3	0.1	0.0
Late Terminal Formative	1072.5	416.7	38.9	373.2	34.8	275.9	25.7	6.7	0.6
Early Classic	1231.2	594.4	48.3	241.5	19.6	388.0	31.5	7.3	0.6
Late Classic	1054.4	242.7	23.0	393.4	37.3	402.0	38.1	16.4	1.6
Early Postclassic	627.7	295.0	47.0	261.4	41.6	69.0	11.0	2.4	0.4
Late Postclassic	2424.3	1723.5	71.1	114.4	4.7	585.9	24.2	0.6	0.02

[1]The salt flat zone is not included in this table due to the lack of residential occupation in this zone.

absent between the Late Archaic and Middle Formative (ca. 1350–700 BC), excavations at the coastal plain site of La Consentida demonstrate maize cultivation during the initial Early Formative (1600–1350 BCE; see Hepp 2019). Beginning in the late Middle Formative period (700–400 BC), agricultural land use signals are strongest in the floodplain zone (Goman et al. 2010). Current dietary data indicate that maize was an important component of the diet in the lower Verde region throughout the prehispanic sequence (Bérubé 2023; Hepp 2019; Hepp, Sandberg, and Aguilar 2017; Joyce 1991; Morell-Hart 2015; Woodard 1991), although a variety of fauna from both aquatic and terrestrial environments were also consumed (Fernández 2004; Hepp 2019; Rancaño Castillo et al. 2023).

In regard to settlement patterning, the lower Verde coastal plain was only sparsely occupied during most of the prehispanic era (Tables 1 and 2; Figures 4–8). No Late Archaic sites have been detected which corroborate paleoecological indications of land clearance, but a relative lack of direct, archaeological evidence for human activity during this period is not unusual in Mesoamerica, particularly in lowland regions (Borejsza 2021). During the initial Early Formative (Figure 4), the majority of lower Verde settlement was located in the coastal plain (68.2%), although this was largely a function of low regional population, as indicated by only 6.6 ha of total occupation in the valley. Beginning in the late Middle Formative, regional population increased, while coastal plain settlement dropped considerably, remaining below 2% of the total regional occupation for the remainder of the prehispanic era (Table 2). Instead, settlement concentrated in physiographic zones that extended farther inland—the floodplain, piedmont, and secondary valleys—with the primary focus of settlement shifting over time (Figures 5–8). What is more, little occupation took place within easy access to marine and estuarine resources; the proportion of regional occupation at a 1 km radius from these water bodies never exceeded 1%. After the initial Early Formative, settlement on the coastal plain and/or near the estuaries peaked during the Late Classic period (AD 500–800; see Table 2 and Figure 7). The largest sites in the coastal plain and estuarine zones—including Cabeza de Vaca and Barra Quebrada—reached their greatest occupation at this time (15 and 10 hectares, respectively). Occupation at smaller residential sites (0.2–4.5 ha) in

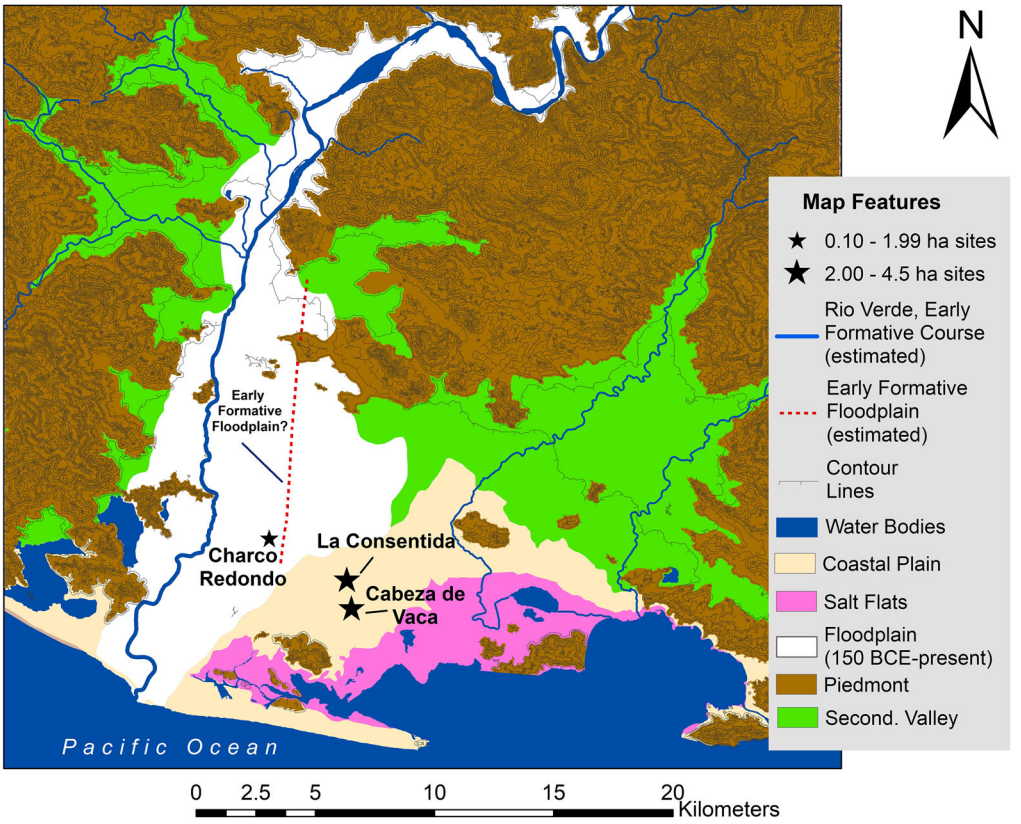


Figure 4. Initial Early Formative settlement in the Lower Río Verde Valley.

these zones also typically dates to the Classic period or later. Overall, the coastal plain and estuarine zones drew limited populations overall (see Table 2), but the formation of the bay barrier (ca. 400 BC–AD 250) may nevertheless be linked with a modest residential expansion near these water bodies.

The role of the lower Verde estuaries and coast in resource extraction and trade

Ethnohistoric and archaeological evidence suggests that while the lower Verde estuaries, salt flats, and coastal plain played a comparatively small role in regional settlement, sites in these zones were actively involved in resource extraction for both local consumption and trade. The coastal zone of the lower Verde is an ideal source for a variety of resources widely valued in Mesoamerica such as fish, salt, ornamental shell, palm oil, and feathers (e.g., Grove 1988; Joyce 1991, 1993; Levine 2011). These materials were likely exported to interior regions and may have attracted outside merchants bearing luxury items such as copper as well as obsidian and other goods.

Documentary evidence for coastal resource extraction and the export of coastal goods from the lower Verde derives from ethnohistoric sources such as the Mixtec codices as well as early colonial accounts, including the *Relaciónes Geográficas* (e.g.,

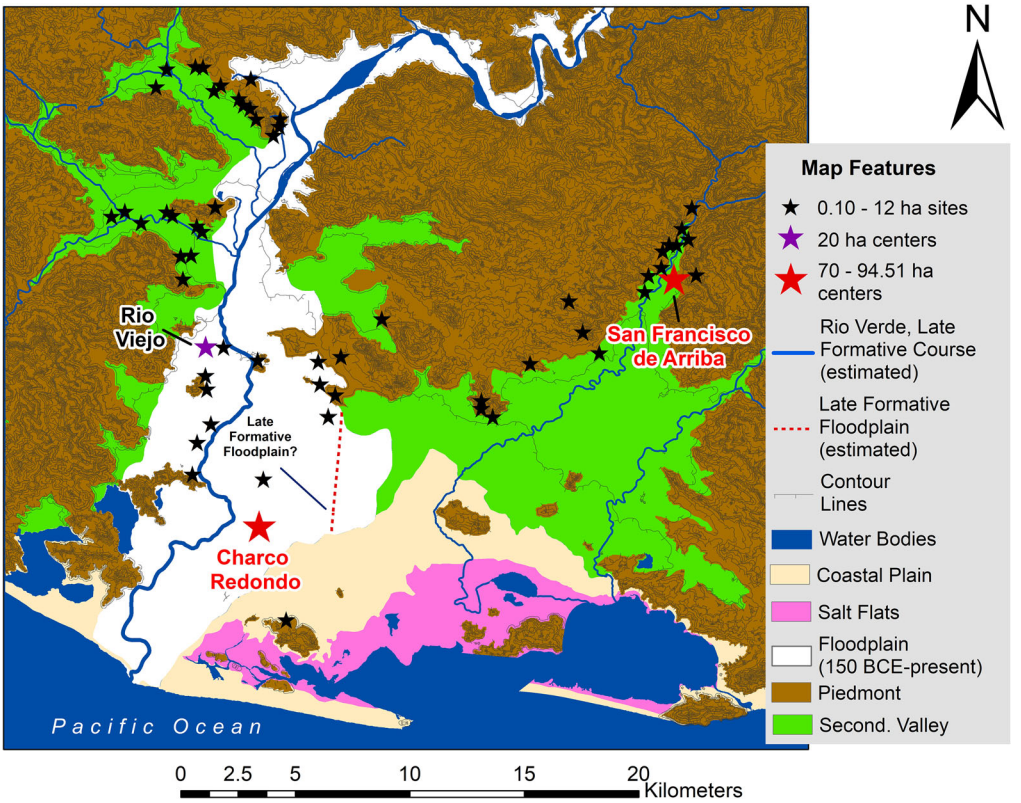


Figure 5. Late Formative settlement patterning in the Lower Río Verde Valley.

Acuña 1984; Díaz del Castillo 1996; see also Joyce 1993; Joyce et al. 2004; Levine 2011; Spores 1993). These sources provide data on the economic activities of the people of Tututepec (see Figure 8)—the capital of an expansive Late Postclassic (AD 1100–1522) empire and an important early Colonial period town. Early Colonial accounts record that *Ixtac Quiautzin*, Tututepec's second Colonial-period ruler, claimed ownership of 15 fishponds and 10 saltworks (Berlin 1947). Although the locations of the fishponds were not specified, it is likely that they included the coastal estuaries. The *Relaciónes Geográficas* in particular describe a vibrant economy for Tututepec including the trade of local goods along with tribute items extracted from subject communities (Levine 2011, 27–9). The *Relaciónes* confirm that salt from the lower Verde region was exported to highland communities in both the Valley of Oaxaca and Mixteca Alta. Tututepec was also a regional market center that drew people, including merchants, from surrounding regions and beyond (Levine 2011; Levine, Joyce, and Glascock 2011).

A minimum of six archaeological sites located in the coastal zone during survey may be linked to resource extraction, with at least four additional possible examples (see Table 3). Most of these sites were undatable using surface ceramics, which typically consisted of highly eroded sherds and/or chronologically non-diagnostic coarse brownwares ideal for boiling brine in the salt extraction process (Andrews 1983; Kepecs 2003; McKillop 2019). Indeed, survey data provide the strongest evidence for salt production

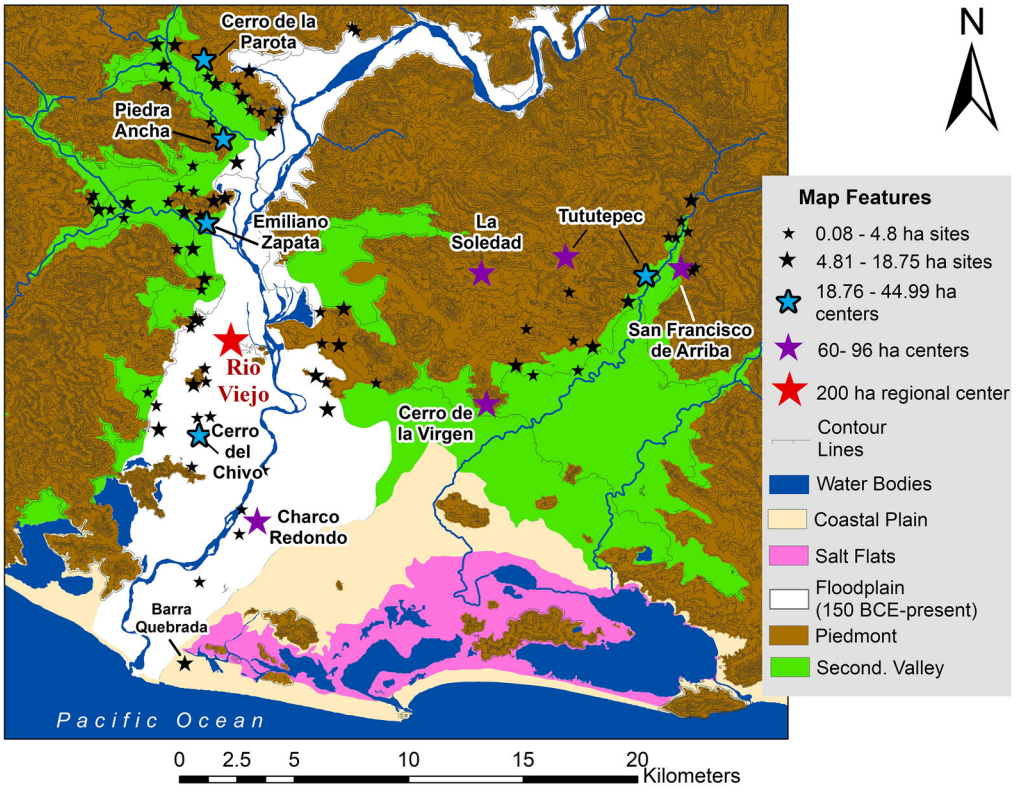


Figure 6. Late Terminal Formative settlement patterning in the Lower Río Verde Valley.

in comparison to other possible resource acquisition activities at coastal zone sites including agricultural production, stone quarrying, and fishing (Table 3).

Archaeological survey (Hedgepeth Balkin 2020) and excavation data (Grove 1988) confirm the presence of salt extraction sites north of the coastal estuaries. These sites have a high surface visibility due to the extensive processing by-products left behind (e.g., mounds containing sediments discarded after extracting salts), as well as other features linked with the salt extraction process such as pits (Figure 9) and sherds from large, coarse brownware vessels. The predominant salt production procedure at these sites was likely the *sal cocida* method, which involves boiling filtered salt water or brine in ceramic cooking wares in order to separate and extract the salts (Andrews 1983, 16–8; Kepecs 2003, 127; McKillop 2019, 28–31). This method has been identified and studied extensively in coastal Mesoamerica as well as inland areas such as saline lakes and springs (e.g., Andrews 1983; Lesure 2009; McKillop 2019, 2023, this section; Pye, Hodgson, and Clark 2011; Valdez and Mock 1991). Here, we draw on studies conducted in relative geographic proximity to the lower Verde region. Limited archaeological evidence suggests that *sal cocida* production occurred as early as the Early Formative on the Pacific coast of Guatemala, Chiapas, and the Isthmus of Tehuantepec (Andrews 1983, 110–1, 119–23; Lesure 2009; Pye, Hodgson, and Clark 2011). It is therefore likely that this method would have also been used in prehispanic times within the lower Verde region, which is located approximately 250 km west of the Isthmus of

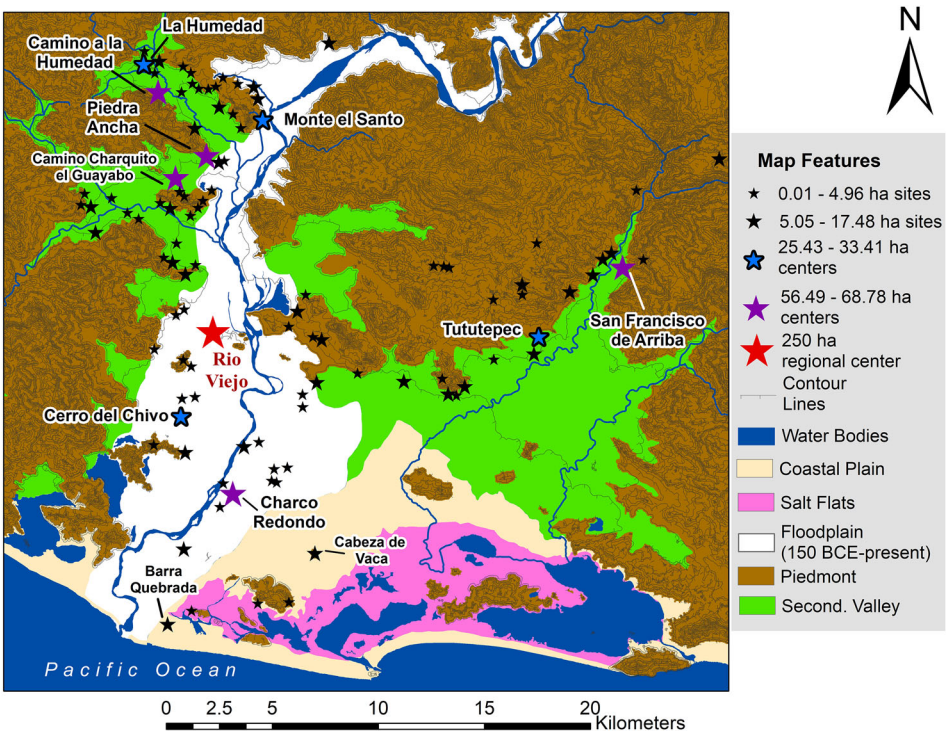


Figure 7. Late Classic settlement patterning in the Lower Río Verde Valley.

Tehuantepec (see also Grove 1988). Some of the lower Verde coastal plain sites also exhibited evidence for *sal solar*, a method whereby salts are extracted from salt water or brine *via* solar evaporation (Andrews 1983, 16–8, 62–3; Kepecs 2003, 127; McKillop 2019, 28–30). In the lower Verde region, *sal solar* techniques appear to be associated with post-conquest times, in contrast to other areas of Mesoamerica, such as the Northern Yucatán and Belize (Kepecs 2003; McKillop 2019).

The majority of salt processing sites in the lower Verde survey zone were non-habitational, as suggested by a lack or very low density of domestic remains, including ceramics (apart from coarse brownwares; see above), stone alignments, and groundstone. At least one of the prehispanic salt production sites (RV193), however, may have contained adjoining residences, as indicated by fragmentary alignments and groundstone. One historic salt production site with residential remains was also identified (RV191). Finally, Los Tamarindos (RV195)—a site occupied during the Late Classic, Late Postclassic, and post-contact times—contained residential terraces and house platforms, which were located near historic and modern salt production features. It is possible that salt processing at this site extended into prehispanic times.

Indirect evidence suggests that some of the salt processing sites without diagnostic ceramics were used in the Late Postclassic period. This is corroborated by ethnohistoric accounts (Acuña 1984; see above). In addition, the site of Salinas Quemada (RV13) contains Late Postclassic as well as Colonial period pottery (Grove 1988; Hedgepeth Balkin 2020, 469–75), indicating that salt production occurred at the site during either or both periods.

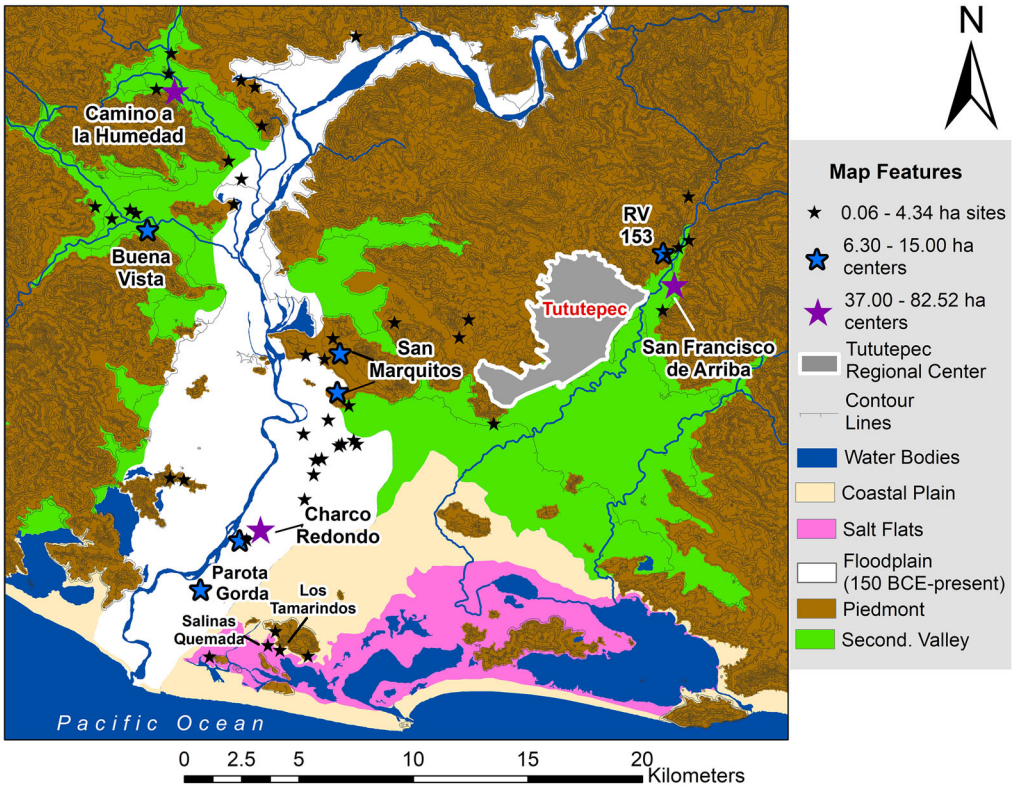


Figure 8. Late Postclassic settlement patterning in the Lower Río Verde Valley, showing the Tututepec capital.

Table 3. Resource extraction sites recorded during survey on the Lower Verde coast.

Site	Resource extraction: Confirmed/Possible	Resource	Residential (Yes/No)	Dates
RV13: Salinas Quemada	Confirmed	Salt	No	Late Postclassic, Colonial
RV14: Laguna Salinas	Confirmed	Salt	No	Unavailable
RV188: Cerro del Diablo	Confirmed	Salt	No	Unavailable
RV191	Confirmed	Salt	Yes	Historic
RV193: Las Plazuelas	Confirmed	Salt	Possibly	Unavailable
RV200: La Colita de Barra Quebrada	Confirmed	Salt	No	Unavailable
RV189: El Cañon de Toño León	Possible	Salt	Temporary camp?	Unavailable
RV195: Los Tamarindos	Possible	Salt	Possibly	Late Classic, Late Postclassic, Post-contact
RV197: Cerro de las Salinas	Possible	Building Stone	No	Unavailable
RV199: Cerro Tamarindos	Possible	Agricultural goods (terrace)	No	Unavailable

Sites near estuarine and marine settings in the lower Río Verde Valley may have also been associated with the acquisition of aquatic fauna (Fernández 2004; Joyce 1991; Pérez Herández and Hepp 2015). Data indicate that lower Verde residents acquired fish,



Figure 9. Abandoned pit feature used in salt production on the Lower Verde coastal plain.

shellfish, and waterfowl from the coastal zone, in addition to the river and freshwater ponds in the region. According to ethnohistoric sources (Paso y Troncoso 1981; Spores 1993; Whitecotton 1992), salted fish were traded to the Oaxaca highlands. Shell for use in the manufacture of ornaments was also distributed to the interior perhaps as early as the Early Formative period (Feinman and Nicholas 1993; Joyce 1993; Winter 1984).

People in the lower Río Verde Valley traded coastal goods like salt and ornamental shell along with other resources like cotton and cacao for a variety of goods from other regions (Joyce 1993; Joyce et al. 2014; King 2008). Highland regions had complimentary resources attractive for trade. Evidence from the lower Verde indicates that beginning in the Formative period, people imported highland goods such as obsidian from Central Mexico, West Mexico, and Veracruz along with ceramics from the Valley of Oaxaca and the Mixteca Alta (Joyce 1991, 1993; Joyce et al. 1995, 2006; Levine, Joyce, and Glascock 2011; Williams 2012; Workinger 2002). By the Early Postclassic period (AD 800–1100), copper artifacts were imported from sources in the mountains of West Mexico (Hosler 1994, 2003; Hosler, Lechtman, and Holm 1990; Levine 2011; Meehan 2019; Vidal-Guzmán 2015); archaeological evidence for copper mining has not been found in Oaxaca (Kroefges 2004, 101). The trade routes through which copper items moved from West Mexico to the lower Verde were probably overland at least until the Postclassic period (White and Barber 2012) due to factors such as the difficulty of navigating the high-energy coastal environment.

In the lower Verde region, Early and Late Postclassic copper artifacts have been found at ceremonial, residential, and salt processing contexts at inland and coastal plain sites (Hedgepeth Balkin 2020; Levine 2007, 2011; Meehan 2019; Vidal-Guzmán 2015). The regional survey recently recovered copper artifacts from two sites near the estuaries: Salinas Quemada (RV13) and Salinas Manantial (RV16). Heavy copper axes were found at Salinas Quemada (Figure 10a), including three fragments and two complete



Figure 10. Copper axes found on the Lower Verde coast. (a) Heavy axe from Salinas Quemada (RV13); (b) axe money from Salinas Manantial (RV16).

Table 4. Measurements of heavy copper axes from Salinas Quemada (RV13).

Specimen #	Complete?	Length (cm)	Thickness (cm)	Weight (g)
RV13-A-1	Complete	9.65	0.9	152
RV13-A-2	Fragment		1.1	
RV13-A-3	Fragment		1.05	
RV13-A-4	Complete	11	1.0	341
RV13-A-5	Fragment		0.8	

specimens (Table 4). This is a salt processing site (see above) with occupations dating to the Late Postclassic and Colonial periods. Copper axes of a similar size and weight have been identified in West Mexico (Hosler 1994; Hosler, Lechtman, and Holm 1990). Salinas Manantial is a residential site with a small (0.31 ha) Early Classic (AD 250–500) occupation and a larger (4.34 ha) Late Postclassic one. Two complete copper axes were recovered near one of the site's residential platforms (Figure 10b). In contrast to those from Salinas Quemada, the Salinas Manantial axes were relatively lightweight, long, and extremely thin (Table 5), matching Hosler and colleagues' description of Type 3a axe monies (Hosler, Lechtman, and Holm 1990, 14, Table 3). Similar to the heavy axes from RV13, the RV16 axe monies were made in West Mexico during the Late Postclassic (Hosler's "period 2") (Hosler 1994, 2003; Hosler, Lechtman, and Holm 1990). Ethnohistoric sources such as the *Relaciónes Geográficas* evince the circulation of these items shortly before and after the Spanish conquest (Acuña 1984; Rojas, 1998; see

Table 5. Measurements of copper axe monies from Salinas Manantial (RV16).[1]

Specimen #	Length (cm)	Thickness (cm)	Weight (g)
RV16-A-1	14.7	0.1	38
RV16-A-2	14.5	0.1	31

[1]Both axe monies from RV16 were complete specimens.

Berdan et al. 2003, 102; Levine 2011, 27). Postclassic scholars agree that axe monies served as a medium of exchange (Berdan et al. 2003, 101–2; Hosler 1994; Hosler, Lechtman, and Holm 1990; see also Levine 2011, 21). The evidence from RV13 and RV16 suggests that small Late Postclassic communities around the estuaries may have been directly involved in the importation of goods. If inlets to the ocean were open in the Late Postclassic as they are periodically in the present day, then maritime traders could have traveled by watercraft to within a few hundred meters of these sites.

In summary, evidence suggests that lower Verde sites in the coastal zone participated in far-reaching exchange relationships. Ethnohistoric sources such as the *Relaciónes Geográficas* indicate that a variety of tropical goods were exported from the coast during the Late Postclassic and Early Colonial periods (see Levine 2011, Table 1). The strongest direct archaeological evidence for coastal resource extraction derives from salt production sites near the estuaries, many of which probably had Late Postclassic occupations. Lower Verde peoples likely exchanged salt, fish, and ornamental shell as well as other goods which were not preserved in archaeological contexts, such as feathers, and cacao. In return, people acquired items such as obsidian and copper. Revealingly, lower Verde sites with copper axes in near-marine/estuarine settings either contained evidence for salt production (RV13) or were located directly adjacent to the salt flats (RV16).

Comparative analysis of the settlement history of the Lower Verde coast

This section examines the degree to which the settlement, population density, and utilization of coastal aquatic habitats in the lower Río Verde Valley compares to other coastal regions of Mesoamerica. Generally, coastal peoples settled near wetlands and/or directly on the coast prior to the Late Formative, when they focused on aquatic fauna with maize as a secondary resource. Populations often shifted inland during the Middle–Late Formative as maize agriculture became an increasingly important part of Mesoamerican lifeways (e.g., Arnold 2009; Blake et al. 1992; Clark 2004; Clark and Hodgson 2021; Killion 2013, 590; Lesure and Wake 2011; Rosenswig 2010; Rosenswig et al. 2015; Smalley and Blake 2003; Smith, Ebert, and Kennett 2014; Valdez et al. 2021; VanDerwarker 2006; Voorhies 2004; Webster 2011; although see Lesure et al. 2014, 657; 2021).

Settlement and subsistence in the lower Río Verde Valley differs somewhat from patterns seen elsewhere in coastal Mesoamerica. Population densities in the lower Verde coastal zone appear comparatively low, especially before the Late Formative (Tables 1 and 2). This generalization may not apply to the Late Archaic, which is associated only with paleoecological evidence for anthropogenic land clearance in the lower Verde. Low Archaic period site densities, in other words, may reflect factors such as preservation conditions rather than actual population size (*sensu* Borejsza 2021).

The lower Verde region's earliest archaeological sites date to the initial Early Formative period, when settlement concentrated on the coastal plain (Table 1 and Figure 4). Subsistence data for this period are available only from Hepp's (2019) excavations at the coastal plain site of La Consentida. Based on stable isotope data from human burials, maize was a significant part of the diet (estimated 40–50% of the caloric intake) during the initial Early Formative (Bérubé, Hepp, and Morell-Hart 2020). The people of La Consentida also exploited other plant foods, including beans and root crops, along with terrestrial mammals such as deer, and fish and shellfish from aquatic environments ranging from freshwater to marine (Bérubé, Hepp, and Morell-Hart 2020; Pérez Hernández and Hepp 2015). The diets of La Consentida residents therefore focused more on maize agriculture, as compared to the mixed subsistence pattern found in other coastal regions which emphasized aquatic resources (e.g., Arnold 2009; Blake et al. 1992; Clark and Hodgson 2021; Kennett et al. 2010; Killion 2013; Pool et al. 2023, this section; Rosenswig 2010, 2021; Rosenswig et al. 2015; Smalley and Blake 2003; VanDerwarker 2006; Webster 2011; see also Lesure, Sinensky, and Wake 2021).

No sites have been identified in the region for the latter half of the Early Formative and the beginning of the Middle Formative (ca. 1350–700 BC; see Tables 1 and 2), suggesting that there was a settlement hiatus. People appear to have returned to the region during the late Middle Formative (700–400 BC), initially concentrating on the floodplain. Beginning in the Late Formative period (400–150 BC), significant populations also occupied piedmont and secondary valley zones, albeit to varying degrees over time (Table 2 and Figures 5–8). Habitats in the coastal zone were never again a significant focus of settlement.

Bone chemistry and archaeological data such as midden contexts suggest that coastal fauna did not represent a major proportion of the overall caloric intake in the lower Verde region (Fernández 2004; Hepp 2019; Joyce 1991; Rancaño Castillo et al. 2023). These resources, however, may have served as significant protein sources. Inhabitants of sites in the coastal plain, floodplain, and piedmont consumed marine/estuarine species such as catfish and mussels. Other fauna exploited include freshwater fish (e.g., sleeperfish); terrestrial mammals such as deer or coyote; and reptiles. The dietary emphasis on marine/estuarine fauna, however, varied across time and space, as indicated by archaeofaunal data (Fernández 2004; see also Hepp 2015; Hepp, Sandberg, and Aguilar 2017; Rancaño Castillo et al. 2023). Overall, the exploitation of fauna from the estuaries and ocean surpassed that of riverine habitats. Furthermore, people living closer to the coast were more likely to consume marine/estuarine fauna (Joyce 1991; see also Hepp 2015, 227). Nevertheless, factors such as resource overexploitation or general availability may have led sites to diversify resources at various points during the prehispanic era to include more terrestrial fauna or to consume fish/shellfish at locations far from the coast (Fernández 2004, 131–40). In summary, the precise degree to which lower Verde peoples relied on coastal fauna for protein is unclear. Current evidence, however, supports a more traditional model of maize agriculture development earlier in the Formative, rather than a prolonged mixed subsistence pattern.

In comparison to other coastal regions of Mesoamerica, why did lower Verde settlement focus so little on the coastal zone, with an emphasis on agricultural resources early on? We propose that the resource potential of the coastal zone was likely

insufficient to draw significant populations during the Formative period. Major factors which may account for this phenomenon are the timing and impact of ecological changes in the region. The growth of the bay barrier along the coast would have led to an increase in faunal diversity and abundance due to the development of low-energy, brackish water niches which harbored nutrients (Goman, Joyce, and Mueller 2005; Hepp 2015; see also Perlman 1980). The developing estuaries, however, were probably not fully enclosed until the end of the Formative (ca. AD 100–250; Winter and Joyce 1987). By this time, floodplain productivity had improved due to the expansion of this zone (ca. 1600–150 BC), an increase in the water table, and the heightened deposition of organic matter (Joyce and Mueller 2010; Mueller et al. 2013). Because this was likely an incremental process, the agricultural productivity of the floodplain began to exceed that of other physiographic zones well before the Late Formative. Regional population was steadily increasing beginning in the late Middle Formative (Table 2), and these groups would likely have been in search of farmlands to ensure a dependable source of calorie-dense foods, in addition to protein-yielding faunal resources. Such factors may be behind the establishment of lower Verde populations in the floodplain and other nearby areas outside the coastal zone before the estuaries had fully developed.

In terms of farming, evidence suggests that areas in close proximity to marine/estuarine resources—including the coastal beach and salt flats—would not have provided a suitable alternative to the floodplain. The agricultural productivity of coastal beach and salt flats was low due to highly sandy and saline soils. To reach arable lands, it would thus have been necessary to walk to the coastal plain, which was typically 2–3 km from the estuaries. While the coastal plain may have also been fertile (Hedgepeth Balkin 2020), the gulf in productivity between this zone and the floodplain may have been large enough to deter significant settlement due to factors such as relatively sandy soils. In summary, although the coastal zone was an important source of protein-bearing resources, it was not the preferred choice for sustained settlement.

What conditions could have resulted in more continuous settlement near marine/estuarine habitats in the lower Verde region, and coastal Mesoamerica more generally? In the lower Río Verde Valley, the estuaries are surrounded by broad salt flats as well as sandy plains and beaches (see Figure 1) which are not suitable for agriculture. We therefore expect that areas with relatively productive farmlands (especially, but not limited to, alluvial plains) in close proximity to estuarine environments were more likely to sustain populations during the Formative period and beyond. Such habitats would allow for agricultural production as well as the collection of protein-yielding fauna within the same general vicinity.

The Western and Eastern Lower Papaloapan Basin regions (WLPB and ELPB, respectively) on the Gulf Coast appear to support this prediction (Mullen 2022; Pool et al. 2023, this section; Stark and Ossa 2007). The WLPB environment consists of a wide river delta that intersects with coastal estuaries, resulting in fertile, alluvial farmlands in direct proximity to abundant, aquatic fauna. Farmers could focus on seasonally flooded low areas in the dry season and higher areas which evade floods (e.g., low hills) in the wet season. Stark and Ossa (2007, 391) note that WLPB populations were more attracted to the delta lowlands than the uplands throughout the prehispanic era, beginning around 600 BC (see also Stark and Curet 1994).

The environmental conditions of the ELPB overlap with those of the WLPB, but notable differences may have resulted in somewhat divergent settlement trajectories. The ELPB also contains a river delta and an associated alluvial plain (Pool et al. 2023, this section), but these features do not extend to the coastal lagoons in the north. Instead, the northern reaches of the ELPB contain paleodunes along the coastline, with lagoons slightly to the south of them. While the paleodune soils are low in agricultural productivity, their elevated positioning would have been ideal for rainy season agriculture. Much more fertile soils, however, exist between the paleodunes and the lagoons (Mullen 2022). Regional survey data indicate that populations settled in both the southern end of the study area—which included the major Olmec center of Tres Zapotes—and the estuarine zone from the Early Formative through the Classic periods. The density of architectural features was higher in the estuarine zone than the overall study region during the Late Formative (Mullen 2022; see also Pool et al. 2023, this section).

The Soconusco region provides an interesting contrast with the Papaloapan Basin examples. Relatively arable lands are located in parts of the region's coastal plain, with the most productive area consisting of alluvium between two swamps—known as the Cuauhtemoc and Mazatan zones (Rosenswig 2008, Figure 1, 390; see also Lesure, Sinensky, and Wake 2021, 482–3). The agricultural productivity of the Soconusco coastal plain, however, is compromised by a relative preponderance of salty soils in the immediate vicinity of the estuaries, among other factors (Lesure, Sinensky, and Wake 2021, 482). Revealingly, settlement on the Soconusco coastal plain was not continuous during the Formative period and beyond (Lesure, Sinensky, and Wake 2021; Rosenswig 2008; Rosenswig et al. 2015). Nonetheless, populations remained on the coastal plain through the early Middle Formative—far longer than in the lower Verde region, perhaps due to the fertile alluvium between the swamps.

In summary, the Gulf coast and Soconousco case studies discussed above suggest that arable farmlands in the vicinity of estuaries are important for sustaining populations. Environmental characteristics which satisfy these needs can vary extensively. The most arable lands in a particular region, for instance, are not necessarily confined to alluvial zones, as we have seen in the ELPB (see Pool et al. 2023, this section).

Conclusions

Survey data from the lower Río Verde Valley indicate that, with the exception of the initial Early Formative period, settlement did not concentrate on the coastal zone. Archaeofaunal and isotopic data suggest that marine/estuarine fauna likely served as important protein resources, but lower Verde residents also turned to terrestrial and riverine fauna to varying degrees across the prehispanic era. Furthermore, maize agriculture was emphasized early in the Formative, rather than a mixed subsistence pattern as in many Mesoamerican coastal regions. Land use in the lower Verde coastal zone focused on the extraction of coastal resources such as salt, ornamental shell, and fish which were consumed locally and exchanged *via* long-distance networks for goods, including obsidian, copper, and pottery.

Prehispanic settlement in the lower Río Verde Valley varies noticeably in comparison to other Mesoamerican coastal regions—especially those which pursued mixed subsistence

regimes into the Middle/Late Formative periods. Although initial Early Formative settlement in the lower Verde focused on the coastal plain, population appears low compared to areas such as the Soconusco and Gulf coast, and there are no sites yet recorded for the period from ca. 1200 to 700 BC. A probable explanation for the lower Verde's divergence from these coastal Mesoamerican trends is ecological. The resource availability in the coastal zone was likely relatively low prior to the formation of the estuaries. By that time, the agricultural productivity of the floodplain had surpassed other physiographic zones to the extent that floodplain farming would have been far more appealing than within 2–3 km of the estuarine zone. Case studies from the Gulf coast and the Soconusco regions support our expectation that settlement was more likely to be sustained in marine/estuarine settings if they also contained arable lands. Although the Soconusco environment was dominated by salty soils, arable lands near the swamps may be responsible for the higher and longer-lasting populations in this region than in the lower Verde. Continued evaluation of these expectations is needed in other coastal regions of Mesoamerica. To our knowledge, continued settlement in proximity to coastal aquatic habitats appears to be relatively rare beyond the Late Formative due to the high probability of soils with a high salt or sand content.

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