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Sayil Revisited: Inferring Terminal Classic Population Size and Dynamics in the West-Central Yucatán Peninsula

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Research at the site of Sayil in the Yucatan Peninsula has provided a valuable database for making inferences about the Terminal Classic (A.D. 750–1000) occupation of the Puuc region. This article evaluates and modifies previous demographic estimates for the site and considers the long-term implications associated with supporting this many people. Although a relatively high level of population was possible because of the excellent soils in the region, their natural fertility could not have been sustained indefinitely. The apparent demographic load on the proposed Sayil system would have required an intensive cropping strategy that may not have been sustainable for more than 75 years. This conclusion not only indicates how long the principal occupation of Sayil may have lasted, but more importantly, how the occupational dynamics during the Terminal Classic may have played out in the greater Puuc region.

KEY WORDS: maya; population; Puuc; chultunes; carrying capacity.

INTRODUCTION

Recent research indicates that many lowland Maya sites during the Classic period (AD 300–900) experienced a long-term, and in some cases a relatively gradual rise and fall in their population levels (Chase, 1990; Culbert *et al*., 1990; Ford, 1990; Rice and Rice, 1990; Webster *et al*., 1992; Webster and Freter, 1990a,b). Numerous social and ecological explanations for the decline of these sites have been put forth (Webster, 2002);

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Fig. 1. The location of Sayil in the Maya region (map by Scott Zeleznik).

the impact of a megadrought beginning around AD 800 (Gill, 2000, p. 271) currently dominates considerable scholarly debate on this issue. One exception to the protracted demographic patterns in most lowland areas occurred in the Puuc region of the Northern Yucatán where sites experienced a rapid population rise and fall during the Terminal Classic period (AD 750–1000).

Investigations at the Puuc site of Sayil, México (Fig. 1) have considerably enhanced our understanding of its Terminal Classic occupation (Carmean, 1990, 1991, 1998; Dunning, 1990, 1992, 1994a,b, 1996; Killion *et al.*, 1989; Sabloff *et al.*, 1985; Sabloff and Tourtellot, 1991; Smyth *et al.*, 1995; Tourtellot *et al.*, 1990). With the intent of adding to these efforts, this commentary reexamines two population estimates for Sayil that were calculated according to 1) the water storage capacity of cisterns, or *chultunes* (McAnany, 1990), and 2) the carrying capacity of its catchment area (Dunning, 1989). These earlier estimates proposed a maximum settlement density for Sayil ranging from 1570 to 3139 persons per km.^{2}

The following discussion has two principal objectives. First, I intend to show that significantly lower, more reasonable estimates using similar approaches indicate a settlement density ranging from 1178 to 1256 persons per km.^{2} Second, and perhaps most important, I suggest that all of the major Puuc polities may not have had strictly contemporary occupations, but rather had prominent phases lasting no more than 100 years within the 250 year Terminal Classic period. This model is similar to the cycling proposed for Mississippian chiefdoms in the Southeastern United States although its primary driving force is ecological rather than sociopolitical (Anderson, 1994). Even my lower estimates indicate that the Sayil polity had a population density hovering close to the maximum carrying capacity of the landscape, at least by the latter part of the Terminal Classic. What may have eventually driven the Maya from the Puuc were the long-term costs associated with cultivating the best soils. It was these highly productive soils that must have supported most of the Terminal Classic inhabitants. They were also probably the first soils to be cultivated when the initial colonists moved into the area. I suggest that the intensive cultivation of these soils could not have been sustained for longer than 75–100 years. In support of this idea, architectural and iconographic evidence from Sayil and Uxmal, another major Puuc center, reflect intensive occupations covering similar, but not simultaneous, periods of time (Andrews, 1985; Andrews and Sabloff, 1986; Dunning and Kowalski, 1994). If the principal occupations of other Terminal Classic Puuc polities also varied, the region may not have been as highly populated as people have generally accepted.

This discussion explores these issues by 1) describing the Puuc geography and the size of Sayil's catchment, 2) reassessing the earlier chultun and carrying capacity estimates, and 3) considering the effects that intensive cultivation had on the Puuc soils. The suggestions offered here support earlier claims that population pressure was an important contributing factor affecting the duration of the Terminal Classic Puuc occupation (Dunning, 1991, p. 26).

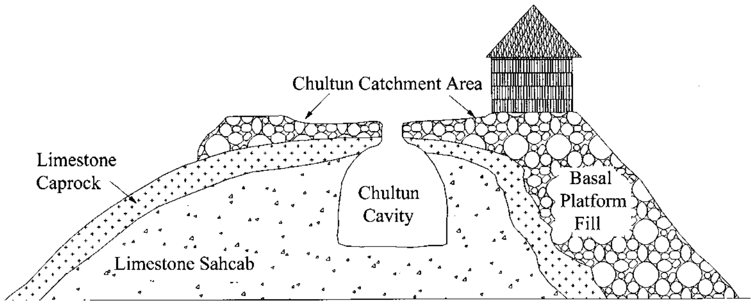

Fig. 2. Schematic cross-section of a Chultun (adapted from University of Pittsburgh Anthropological Papers, No. 2, 1989) (map by Peter van Rossum).

PUUC GEOGRAPHY AND THE SAYIL CATCHMENT

To the ancient Maya, the two most important geographic features in the Puuc were its highly fertile soils and exposed bedrock outcrops. Geologically, the region consists of different varieties of folded limestone strata that have produced a low knobby-cone karst hill topography (Dunning, 1989, p. 19). Lying between these hills are flat-bottomed valleys containing rich Mollisol and Alfisol soils. The largest settlements are associated with expanses of limestone outcrops exposed along the edges of these flat-bottomed valleys. Limestone outcrops were important features because they permitted the construction of chultunes, or water cisterns. The outcrops typically have an extremely hard upper layer with a soft underlying marl deposit known as *sahcab.* Chultunes were made by punching through the upper layer and creating large "jug" shaped cavities by removing the sahcab (Fig. 2). Chultunes were essential for the existence of large communities in the Puuc because they were the only significant source of dry season water (Barrera Rubio, 1982; Dunning, 1994a; González Fernández, 1981; Zapata Peraza, 1989).

Puuc catchment zones were defined by Thiessen polygons (Fig. 3), and theoretically represent the political and economic territories of major Terminal Classic polities (Dunning, 1989, p. 14). The Sayil catchment is a polygon encompassing 71 km^2 (Fig. 4). Including nuclear Sayil (3.45 km^2) and its southwestern lobe (1.0 km^2), seven sites constitute an estimated 8.7 km^2 of settlement zone in the catchment (Dunning, 1994a, table 6).[2] Sixteenth

[2]The seven sites in Sayil's catchment constitute 8.3 km^2 of settlement area (Dunning, 1989, p. 3; Sabloff and Tourtellot, 1991; Tourtellot *et al.*, 1990, p. 248). The unyielding nature of the Puuc vegetation precluded the feasibility of a complete catchment survey. To compensate for this, 0.4 km^2 was added to account for sites that may have been missed (Dunning, 1996, table 6). This brings the total to 8.7 km^2 of settlement area.

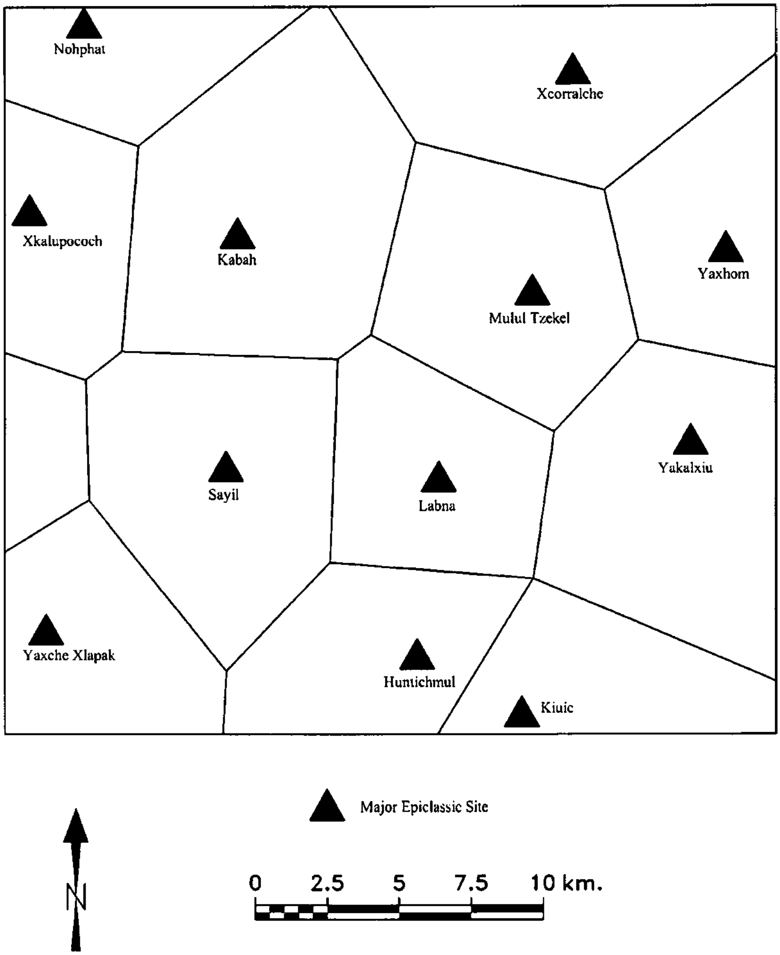

Fig. 3. Proposed catchment zones for major Puuc centers defined by Thiessen Polygons (adapted from Dunning, 1989) (map by Peter van Rossum).

century ethnohistoric information suggests that the Thiessen polygon model may accurately approximate the Terminal Classic political landscape. When the Spanish arrived, the northern plains of the Yucatán contained polities with densely settled communities surrounded by dependent, sparsely settled hinterlands (Marcus, 1993; Roys, 1943, 1957; Tozzer, 1941). Judging from the Puuc archaeological record, its Terminal Classic political structure might have been similar albeit on a much larger and more complex scale.

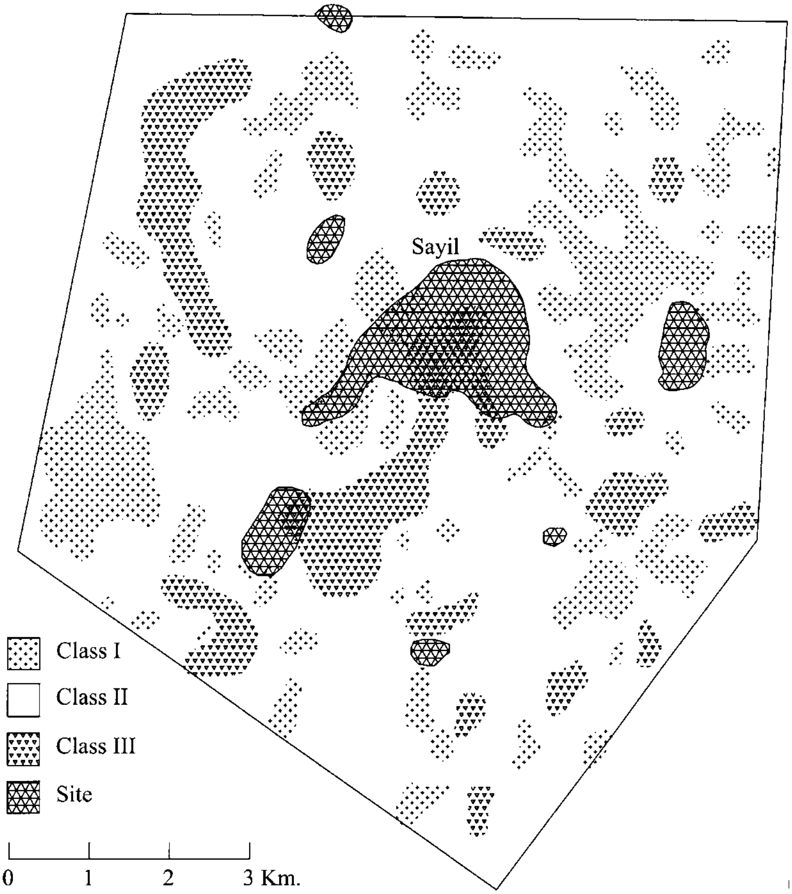

Fig. 4. The Sayil catchment showing dependent communities and the distribution of its three soil types (adapted from Dunning, 1989) (map by Peter van Rossum).

ESTIMATING THE POPULATION OF THE SAYIL POLITY

A dry season dependence on chultunes and the highly fertile Puuc soils were used to estimate the Sayil polity's maximum Terminal Classic population (Dunning, 1989; McAnany, 1990). These estimates are modeled on the number of chultunes associated with settlements and extent of arable soils in Sayil's catchment. The following discussion describes the previous estimates and demonstrates that similar methods can result in lower population estimates.

The Chultun-Based Estimates

As the only significant source of dry-season water, the number of chultunes in a settlement limits the number of people who were able to live there (McAnany, 1990). Estimating population with these features involves identifying how many chultunes there were, calculating their water storage capacity, and then dividing the total capacity by a rate of per capita daily water consumption. The previous estimate was explicitly modeled on *the amount of monthly precipitation that could have been collected by the average chultun catchment area* (McAnany, 1990, pp. 266–269, my emphasis). Although more than 90% of the total Puuc precipitation (1000 mm) falls between May and October, the model assumes a rainy season capture of 2160 L per month. Water in excess of rainy season demand would have been conserved for dry season consumption.

Two hundred and fifty six chultunes have been identified in the mapped portion of nuclear Sayil (2.45 km^2) and an estimated 105 chultunes in the unmapped portion (1 km^2) resulting in a total of 361.[3] To estimate Sayil's population, the amount of monthly water collected by 361 chultunes was then divided by per capita daily consumption rates of 2.4 L (for drinking), and 4.8 L (for drinking, washing, cooking, and construction) (McAnany, 1990, p. 269). With an average monthly capture of 2,160 L, each chultun could have supported 30 people consuming 2.4 L daily, or 15 people consuming 4.8 L daily (Table I). Accordingly, 361 chultunes may have annually supported a population in nuclear Sayil of 5,415–10,830 people (McAnany, 1990, p. 269). These figures convert to a settlement density of 1570–3139 persons per km^2 and a catchment-wide population of 13,659–27,309.

The rates of per capita daily water consumption used in these estimates are unrealistic. Undoubtedly, the Puuc Maya were efficient water conservationists because this resource was scarce. Research suggests, however, that most people consume more than 2.4 L of water per day.[4]

[3]Estimating the number of chultunes in the unmapped 1 km^2 of nuclear Sayil (3.45 km^2) was calculated according to how many were found in the mapped portion (McAnany, 1990; Tourtellot *et al.*, 1990, p. 253). Since the mapped portion (2.45 km^2) equals 71.01% of the total (3.45 km^2), 0.71 divided into 1 results in a site multiplier of 1.41 (Tourtellot *et al.*, 1990, p. 253). The product of 1.41 $\times$ 256 chultunes (those in the mapped portion), therefore, rounds up to a total of 361 chultunes.

[4]The Geigy Scientific Tables suggest that under favorable conditions at low levels of activity an adult consumes at least 1.5 L per day; the amount increases considerably when working in a hot, dry environment (Lentner, 1981, p. 336). Strenuous exercise in hot climates can require as much as 10 L per day (International Life Sciences Institute, Europe, 1998, p. 31). According to the U.S. Army, a man resting in the shade with an ambient temperature of 25^{o}C must drink about 2.9 L daily; in the same temperature this increases to 3.8 L at a moderate level of work in the sun (Lee, 1968, p. 537). Water demand for food preparation, personal hygiene, laundry, and construction result in even higher rates of consumption. According to

Table I. Population Estimates Based on Chultunes With an Average Monthly Capacity of 2160 L

Per capita daily consumption	2.4 L[a]	4.8 L[a]	6.0 L
People per Chultun	30	15	12
Number of Chultunes	361	361	361
Sayil population estimate[b]	10,830	5,415	4,332
Persons per km^2 settlement[b]	3,139	1,570	1,256
Total catchment population[c]	27,309	13,659	10,927

[a]McAnany, 1990.
[b]Based on 3.45 km^2 of settlement area representing nuclear Sayil.
[c]Based on 8.7 km^2 of settlement area in Sayil's catchment area.

Ethnographic research at the modern Puuc community of Xculoc (Fig. 1) has led to the suggestion that per capita daily water consumption in this region could not have fallen below 6 L (Becquelin and Michelet, 1994, pp. 303–304; Gougeon, 1987). Furthermore, 6 L a day would not have been sustainable for long without seriously affecting the health of a population (Gougeon, 1987). Assuming an absence of significant alternative sources of water,[5] 6 L is used here as an absolute minimum to estimate the Sayil polity's population. Sayil's 361 chultunes, therefore, could have annually supported 4332 people (Table I). This converts to a settlement density of 1256 persons per km^2 and a catchment-wide population of 10,927.

The Carrying Capacity Estimates

The previous carrying capacity estimate was based on the amount of land needed per person under particular cultivation regimes (Dunning, 1994a, p. 27). The model posits different strategies and yields for the major Puuc soil types. All of these soil types are present in Sayil's catchment and are referred to as Class I, II, and III listed in order of increasing

the United Nations (1976, p. 56), total modern per capita water consumption averages 15–20 L for inhouse water use in rural areas supplied by public wells. Worldwide, the average villager consumes about 35 L daily (World Bank, 1984, p. 32–33). Some communities without piped connections have a daily per capita rate of consumption of 40 L of water (White *et al.*, 1972, p. 111).

[5]Additional sources of water in the Puuc region consist of *aguadas, sartenejas* (both limestone solution/collapse features), shallow caves, and deep caves. Although all of these features contained water, the first three were seasonal and therefore were not significant to the large Terminal Classic populations at least during dry periods of the year (Dunning, 1994a, p. 7, 11). Only three deep cave systems with permanent water have been found in the immediate area but passage to these sources is a truly arduous journey (Stephens, 1969[1841]). If these sources did supply water to thousands of people throughout the Puuc during particularly dry years, evidence of the immense logistical system this would have required has yet to be documented.

Table II. Previous Catchment Area Carrying Capacity Estimate (Table Adapted From Dunning, 1989, p. 16)

Agricultural technique	Total ha/ soil type	Viable ha	Crop cycle (yrs)	ha/person/ yr	Persons supported
Bush-fallow (Class I)	1,820	910	11	0.44	188
Grass-fallow (Class II)	3,740	3,740	2	0.44	4,250
Annual (Class III)	1,540	1,540	1	0.13	11,846
Total	7,100	6,190			16,284

productivity.[6] Maize production was used as a general proxy of annual caloric consumption.

According to Dunning (1994a, p. 27), modern Puuc farmers annually plant 0.44 ha of Class I and II soils per person. This apparently includes enough land to yield a 33% surplus produced for market exchange. Since annual precipitation in the Puuc varies between 30 and 40%, a surplus of 33% was also factored into the Terminal Classic model to account for production needed to offset shortfalls brought about by these fluctuations (Dunning, 1989, p. 16). An extensive swidden technique of bush-fallow with an 11-year cycle was proposed for the 1820 ha of Class I soils (Table II, Fig. 4). Assuming that half (910 ha) of these soils could not have been cultivated because they occur on very steep slopes (Dunning, 1989, table 2), the model proposes that only 83 ha were annually cropped to support 188 people. A grass-fallow technique based on a 2-year cycle was proposed for the 3740 ha of Class II soils (Table II, Fig. 4). Dunning (1989, p. 15) suggested that annually cropping these soils would have been too costly relative to output. As such, the cultivation of 1870 ha of Class II soils would have supported 4250 people. Because of their extremely high productivity, Dunning (1989, table 2) proposed an annual cropping strategy for the 1540 ha of Class III soils (Table II, Fig. 4). Modern experimental gardens on these soils at Uxmal are presumably so productive that only 0.13 ha is needed to feed one person each year (Dunning, 1989, p. 16). The Class III soils, therefore, would have supported 11,846 people. Consequently, this model indicates that Sayil's catchment soils supported 16,284 people resulting in a settlement density of 1872 people per km^2 (Table II).

I favor a carrying capacity estimate based on calculating the yield per soil type rather than using modern figures on the amount of land needed

[6]The Class I soils are shallow, stony, well-drained Mollisols and Entisols formed by the weathering of residual caprock (Dunning, 1989, p. 14–21; 1994a, p. 14–18). They are considered the poorest for agriculture because they occur on slopes greater than 15 degrees and have minimal depth. The Class II soils are well-drained Alfisols and Mollisols on the valley-margin caprock and the bases of scree slopes that form from the erosion of the adjacent Class I soils. They occur on slopes of 3–15 degrees and have depths ranging from 20 cm to 1 m. The Class III soils are well-drained Alfisols and Mollisols situated in the valley bottoms. They are considered the best for agriculture occurring on slopes of 0–5 degrees with depths exceeding 1 m.

per person. Prehistorically, the per-capita land requirements were most likely higher because Pre-Columbian maize varieties were less productive than their modern counterparts (Kirkby, 1971, p. 408). Also, the amount of Class III land per person used in Dunning's (1989, p. 16) calculations is problematic because the Uxmal experimental gardens were cultivated with "small amounts" of unspecified fertilizers. Synthetic fertilizers can have a considerable impact on yields depending on the quantity used (Kyle, 1995).

What we lack are reliable data on soil productivity that can be used to infer Terminal Classic yields. Nevertheless, a rough estimate of output can be made for computing an alternative assessment of Sayil's population size. Estimating carrying capacity according to food producing capability must be based on years of environmental shortfall because they tend to limit population levels in the absence of any means for intensifying production (Halstead, 1989; Halstead and O'Shea, 1989; Loker, 1989, p. 175; Wingard, 1992, p. 16). As such, I have calculated output based on years of minimal precipitation when average yields were lower.

The modern-day Santa Elena municipio, located about 16 km north of Sayil, reported noticeably lower than average maize yields of 948 kg/ha in 1968–69 (V Censo Agrícola Ganadero y Ejidal, 1970). This harvest was affected by a serious drought in 1968 when the precipitation reported for Mérida, Yucatán, about 70 km north of the Puuc, was nearly one standard deviation below normal (Gill, 2000, fig. 35). The data from Mérida are relevant because its average precipitation is only about 55 mm less than the 1000 mm typical for the Puuc; moreover, the meteorological patterns associated with the Yucatán Peninsula indicate that both regions experience a similar magnitude of inter-annual variation in precipitation (Gill, 2000, p. 154). The 1968 drought is relevant as an event conditioning a long-term adaptation because it fits a pattern of droughts with comparable severity occurring every 5–10 years.

The Santa Elena yields from 1968–69 probably came from Class III soils. During the 1960s the Puuc region was sparsely inhabited and horseback or foot travel was the norm because roads were few and of poor quality. Consequently, the farmers in the area during 1968–69 most likely cropped only the Class III soils. Also, it is doubtful that the yields at this time reflect outputs enhanced by synthetic fertilizers. Accepting Dunning's (1989, p. 16) suggestion that bad year yields were roughly 33.3% less than usual, milpas yielding 948 kg/ha in 1968–69 might produce 1422 kg/ha during normal years. Indeed, swidden dry farming yields of 1422 kg/ha are clearly impressive when compared to yields of less than 1000 kg/ha reported for the Northern Yucatán (Redfield,1934, p. 52; Steggerda, 1941, p. 121). Using this output as a baseline, I have opted to use 1400 kg/ha for normal year yields from Class III soils in my estimate of Sayil's carrying capacity.

Table III. Estimated Corn Yield in Metric Tons per Hectare (ha) of Catchment Land Cropped During Bad Years (Land Area Determined by Dunning, 1989, p. 16)

Soil class	I	II	III
Area cropped (ha)	83	1,870	1,540
Yield per ha (kg)	273	273	938
Total yield (kg)	22,659	510,510	1,444,520

This figure should be considered a maximum estimate because Terminal Classic maize varietals probably resulted in lower yields.

Reducing the normal year yield of 1400 kg/ha by 33.3% to account for output during bad years results in a figure of 938 kg/ha (Table III). Using Dunning's (1994a) proposed cropping strategy (Table II), therefore, the 1540 ha of Class III soils in the Sayil catchment would produce 1,444,520 kg of maize (Table III). Dunning (1989, p. 16) has suggested that the Class III soils may be three times more productive than their Class I and II counterparts.[7] If so, then they would produce only about 273 kg/ha during bad years (Table III). Admittedly, a bad year yield of only 273 kg/ha for the Class I and II soils seems inconsistent with the general view that Puuc soils were highly productive. Given the available information, however, I choose to proceed conservatively. Using this figure, a cropping strategy involving the annual cultivation of 83 ha of the Class I soils would produce 22,659 kg of maize; the annual cropping of 1870 ha of the Class II soils would produce 510,510 kg of maize (Table III).

The average Honduran consumes about 1900 Kcals each day (García *et al.*, 1988). I have used an intake of 1900 Kcals here because the average Terminal Classic Puuc Maya probably had physiological demands similar to most contemporary Honduran peasants. At this rate, each resident in Sayil's catchment zone would have consumed the maize energy equivalent of 0.53 kg each day if one kg of maize equals 3560 Kcals (Davidson *et al.*, 1979, p. 167). This equates to the annual consumption of 193 kg of maize. According to my alternative carrying capacity model, therefore, the Sayil's catchment soils might have supported a maximum of 10,247 resulting in a settlement density of 1178 people per km^2 (Table IV).

The accuracy of this alternative population estimate rests heavily on the assumption that the assessments of output per soil type are reasonably accurate at an order of magnitude level. Even if they are, however, there are other unaccounted for variables that undoubtedly would affect these calculations. Besides a 33% surplus set aside in anticipation of environmental

[7]I base this interpretation on Dunning's (1994a) proposition that only 0.13 ha of Class III milpa is needed per person per year as opposed to 0.44 ha for the Class I and II milpas. I accept that 0.13 ha is roughly 1/3 rd of 0.44 ha.

Table IV. Alternative Estimate of Catchment Area Carrying Capacity

Soil class	Total yield (kg)	Per capita annual needs	Persons supported
Class I	22,659	193 kg	117
Class II	510,510	193 kg	2,645
Class III	1,444,520	193 kg	7,485
Total	1,977,689		10,247

shortfalls, this model does not account for factors such as the possible age structure of the population, seed set aside for the following season, produce consumed by domestic and wild animals, spoilage, and any demands that non-food producers and elites may have had on the potential annual yield (Schroeder, 1999, p. 504; 2001, p. 521; Wood, 1998, p. 109). Incorporating these variables would tend to reduce the population estimate further still.

DISCUSSION

Compared to the previous estimates discussed here (Dunning, 1989; McAnany, 1990), my alternative calculations for Sayil's maximum Terminal Classic population are 40% lower (Table V). This figure may also be more realistic for other Terminal Classic Puuc sites.[8] One might object that significantly reducing population levels would reflect communities incompatible with the shear mass of monumental architecture in the Puuc region. I suggest that such an assertion, however, is purely impressionistic. Experimental research over the last 40 years indicates that modest energetic investments by relatively small populations could have easily produced impressive monuments (Abrams, 1984, 1987, 1989, 1994; Cheek, 1986; Erasmus, 1965; Turner *et al.*, 1981; Webster and Kirker, 1995, p. 376). Although these energetic studies are as profound in their implications as they are elegant in their simplicity, they continue to be rarely cited and largely ignored. Even a rough comparison with the energetic figures calculated for Copán, another Maya polity located in the Copán Valley, Honduras (Webster and Kirker, 1995), indicates that a catchment-wide population of 10,000 people could have built Sayil's impressive architecture with little difficulty.

One could also object to estimating Sayil's upper population limit based solely on its internal year-to-year food producing capability because it negates the role of storage and inter-polity provisioning. Within the Puuc, communities suffering from low yields in one year undoubtedly consumed

[8]Researchers working at the Puuc site of Xculoc have suggested its Terminal Classic population density may have been 30–40% lower than the average alternative figures for Sayil in Table V (Becquelin *et al.*, 2000; Becquelin and Michelet, 1994).

Table V. Estimates of Population Densities per Unit of Settlement in the Sayil Catchment Area

Methods	Previous	Alternative
Chultun count	1,570–3,139[a]	1,256
Carrying capacity	1,872[b]	1,178
Average	2,194	1,217

[a] McAnany, 1990.
[b] Dunning, 1994a.

their own food stores and/or imported surplus from their more fortunate neighbors. Although I agree that these strategies were certainly employed, there are at least two reasons why I do not think they make the previous population estimates more reasonable. First, Sayil's carrying capacity is modeled according to the production of a normal year surplus that was set aside in anticipation of future shortfalls. If this model approximates the cropping strategy at Sayil, and similar practices were occurring at other Puuc sites, then there would have been little surplus available for redistribution. Second, the Puuc is a relatively small geographic area. In the absence of empirical data to the contrary, I suspect that there is minimal variation in precipitation throughout the region. Consequently, any available surplus during difficult years probably would have been insufficient to relieve the needs of people in the hardest hit areas.

It could also be argued that inter-polity provisioning periodically took the form of importing food from regions outside the Puuc. I view this as improbable on any significant scale because the Puuc's relatively high population density has led to the suggestion that it was a breadbasket producing enough, at least during normal years, to comfortably export foods to neighboring communities in the Northern Yucatán (Kurjack *et al.*, 1979; Matheny, 1978; Vlcek *et al.*, 1978). If so, then it is difficult to imagine how less populated settlements outside the Puuc would have been able to even periodically support dense neighboring populations. Also, the energetic limitations of Mesoamerican societies (e.g. lack of traction animals) precluded the movement of significant quantities of bulk resources any great distances (Drennan, 1984a,b; Hassig, 1985; Kyle, 1996; Sanders and Santley, 1983).

Puuc polities were not isolated social and political systems but economic provisioning probably did play out within relatively closed, local systems because of energetic constraints. Furthermore, although the previous estimates have been reduced, the region still appears to have had a high level of population. Sayil's population density can be appreciated by comparing it to density figures for Late Classic Copán (Table VI). Since straightforward densities are rarely informative measures of population pressure (Wood, 1998, p. 114), one can calculate an *optimal density* defined

Table VI. Optimal Densities (people/km^2) for the Sayil and Copán Polities

	Amount of prime agricultural land	Maximum population	Optimal density
Sayil	15.4 km^2	10,247	665
Copán	@75 km^2	22,000	293

as the number of people per unit of high quality land in a sustaining region (David Webster, personal communication, 2003). Although different tracts of prime land are not strictly comparable, optimal density reveals the level of pressure on critical agricultural resources in one area relative to those in another. This calculation is a good measure of pressure because the majority of a population was supported by its high quality agricultural land.

Sayil's optimal density is based on a maximum population of 10,247 and the 15.4 km^2 of its high quality Class III soils (Table VI). Copán's optimal density is based on a maximum population of 22,000 people in AD 750 and 75 km^2 of prime agricultural land present in its sustaining region (Wingard, 1992). This comparative measure shows two things. First, it is clear that the Sayil Class III soils were highly productive relative to the prime agricultural lands in the Copán Valley. This is particularly noteworthy given that some of Copán's prime land is fertile bottomland soils annually replenished by the flooding of the Copán river. Second, the level of population pressure on Sayil's prime soils far outweighed (in terms of people per unit area) such pressure in the Copán Valley.

The important question is how long Sayil's catchment could have been intensively cropped? Modeling the sustainable carrying capacity of an area by incorporating a temporal component is necessary for understanding how prehistoric land use played out over time (Fearnside, 1986; Wingard, 1992, p. 14). Fearnside (1986) defines the sustainable carrying capacity as "the maximum number of persons that can be supported in perpetuity on an area, with a given technology and set of consumptive habits, without causing environmental degradation." Clearly, however, with any level of resource exploitation there is a long-term cost, or probability of environmental failure. This is an especially important issue to address when considering the loss of soil fertility in relation to continuous cropping (Baden and Beekman, 2001; Sandor, 1992; Troeh and Thompson, 1993). The duration of time prior to environmental failure is directly proportional to the intensity of exploitation. The cropping strategy proposed for Sayil's catchment (Dunning, 1989) would not have been sustainable indefinitely.

To state the question yet again, how long could the prime Class III soils have been continuously cropped every year without the aid of fertilizer? The only sources of fertilizer available at Sayil were limited amounts of organic mulch and night soil that were probably used on the intensive inter-platform kitchen gardens (Dunning, 1994a, p. 18). Research on the productivity of Alfisols and Mollisols indicate that these soils are generally quite productive (Buckman and Brady, 1969, pp. 316–320). In particular, Mollisols are highly fertile because their natural organic components provide an ample supply of nutrients, including nitrogen, permitting exceptional yields without the aid of fertilization despite continuous cropping (Stevens, 1964, pp. 301–303). Richard Fox (personal communication, 2002), Professor of soil science at Penn State University, suggests that if the Puuc Class III soils do represent extremely high quality Mollisols and Alfisols, all other things being equal, they might have been able to support annual dry-farming yields ranging between 1000 and 1500 kg/ha for 75 years. Interestingly, Sayil and the large Terminal Classic site of Uxmal both contain archaeological evidence indicating principal periods of occupation lasting for a similar length of time. These two pieces of compelling evidence, although circumstantial, may have important implications for understanding the Terminal Classic population dynamics in the Puuc.

It appears that Sayil's population began to grow rapidly following the proposed onset of the Puuc colonette style (AD 770), and then markedly declined around AD 860 (Andrews, 1985). On the basis of Puuc architectural styles, therefore, the duration of Sayil's apogee may have been only 70–90 years (Andrews and Sabloff, 1986; Tourtellot *et al.*, 1990, p. 252). The period of maximum population, therefore, may have lasted only 50–75 years. I have suggested that Sayil's catchment could have supported a maximum population of 10,247 people over this length of time. The intensive strategy of cultivation proposed by Dunning (1994a) for longer than 75 years may have resulted in a marked decline of the Class III soil productivity. This would have precipitated even more intensification on the Class I and II soils requiring greater energy expenditures and further hastening the degradation of the environment. Such events would have led ultimately, and rather rapidly, to the large-scale abandonment of its catchment.

Architectural and iconographic evidence from Uxmal indicates a similar, albeit slightly later, occupational duration for this site. Dunning and Kowalski (1994) suggest that Uxmal's major occupation may have begun around AD 850–895 and lasted until AD 925–975, a time span of 75–125 years. During this period, Uxmal may have been the principal polity of a segmentary state system with hegemony over most of the supposedly highly populated eastern Puuc region (Dunning and Kowalski, 1994). Under such circumstances, Uxmal would have integrated a substantial number of people. If, however, the principal occupations of other major Puuc centers such as Nohphat, Labna, and Kabah (Fig. 1) occurred earlier than Uxmal's apogee, then the sites under its control might not have had extremely high population densities. Many of the polities in the region may have been sparsely settled during Uxmal's apogee because their soils had been exhausted by intensive occupations during the previous 100–150 years. It is possible that much of Uxmal's late Terminal Classic population was composed of people who had moved away from other adjacent Puuc centers.

Depending on how rapidly migration into the Puuc region occurred at the beginning of the Terminal Classic, I suggest that the major occupations of most sites may have only lasted no more than 100 years. Such an interpretation is consistent with the long established view that the Puuc Terminal Classic period occurred during a span of 250 years if one assumes that not all of the Puuc polities were intensively occupied simultaneously. Furthermore, the apparently abrupt abandonment of this highly productive area may be predominantly related to the intensive annual cropping of excellent soils whose fertility was eventually exhausted.

CONCLUSION

The success and collapse of ancient societies often encompasses two sides of the same coin. On the one hand, the intensive cultivation of the Puuc's highly fertile soils permitted relatively dense populations because of their exceptional yields. On the other hand, while Terminal Classic (AD 750–1000) agricultural intensification was able to support increasingly more people, the Puuc Maya were probably sowing the seeds of their own demise. The cropping strategies that must have been eventually employed in the absence of rigorous fertilization techniques could not be sustained indefinitely. This commentary has reexamined the earlier chultun (McAnany, 1990) and carrying capacity (Dunning, 1989, 1994a) population estimates for the Sayil polity and considered how long its apogee may have lasted. These issues have brought to light two important points.

First, the previous population estimates for Sayil may be exaggerated. Using more realistic rates of per capita water consumption for the chultun methodology and an assessment of agricultural yields during years of environmental shortfall result in significantly lower population estimates (Table V). These calculations should be regarded as a set of alternative figures worthy of consideration given the limitations of the current data set. Ultimately, the accuracy of these estimates is likely to remain unresolved in the absence of ethnographically informed data on cropping strategies and their impact on the fertility of the Puuc soils.

The second implication builds on the issue of sustainability as a means of supporting both an ultimate reason for the abandonment of the Puuc, and an element of population mobility during its Terminal Classic occupation.

This article suggests that even intensive annual cropping of the best Puuc soils in the absence of any means of fertilization was probably not sustainable for more than 70 years. As such, it is reasonable to suppose that other major Puuc polities may have been bound by similar lengths of time. What is interesting is that iconographic evidence from Sayil and Uxmal indicates that their principal occupations may have lasted no more than 70–100 years, *and that they were not strictly contemporaneous*. If other major sites also had principal occupations that varied temporally throughout the region, then this leaves us with a dynamic picture of shifting social focal points as the Puuc occupation played out over a period of 250 years. It is here that the implications of this discussion are perhaps the most profound. If chronological variation in the principal occupations of sites was widespread throughout Puuc, then earlier assertions of overall population levels in the region will have to be reevaluated as well. This possibility deserves a good hard look by future research efforts aimed at defining the temporal affiliation of the principal occupations of major Puuc sites.

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