Gary O. Rollefson and Kerry J. Pine
Department of Anthropology
Whitman College
Walla Walla, WA, USA

Gary O. Rollefson and Kerry J. Pine

Measuring the Impact of LPPNB Immigration into Highland Jordan

Abstract
An earlier model of the Neolithic human impact on the ecological situation in the ‘Ayn Ghazāl vicinity concentrated on site size as a proxy for population growth and consequent architectural needs, particularly in terms of the fuel requirements for plaster production as well as the detrimental effects of goat browsing (Rollefson and Köhler-Rollefson 1989, 1992). This model was based on two assumptions: 1) a heavy demand on local wood for fuel to manufacture plaster and 2) a consistent growth in population over time. It is clear now that both assumptions were invalid. Instead, it is now posited that 1) while plaster production used much less fuel than was originally imagined, an even greater amount of wood was needed for normal domestic use, an aspect that was overlooked in the original model 2) Furthermore, while ‘Ayn Ghazāl grew at a relatively constant rate during the MPPNB, within a couple of generations after the LPPNB abandonment of farming villages in the Jordan Valley and areas to the west, ‘Ayn Ghazāl and the rest of highland Jordan received a sudden and massive influx of migrants from the afflicted region. A revision of the previous model takes into account the sudden increase in human demands on resources around older settlements such as ‘Ayn Ghazāl and Wādī Shu‘ayb as well as on the countryside surrounding newly founded megasites such as Basṭa and ‘Ayn Jamām after 9500 calBP.

Introduction

Nearly two decades ago the recognition of the sudden and widespread abandonment of the Jordan Valley and areas to the west at ca. 9,500 calBP by farming populations (Rollefson 1989) led to an investigation of possible contributing factors to this calamitous shift in settlement patterns. One model that was developed involved calculations of fuel considered necessary to produce the high demands of lime plaster production that was ubiquitously used in domestic structures in the southern Levant, as well as the effects that goat husbandry in the vicinity of permanent farming settlements had on fragile, local environmental balances (Rollefson and Köhler-Rollefson 1989; Köhler-Rollefson and Rollefson 1990). Based on published accounts of the constitution of the lime plaster from floors at ‘Ayn Ghazāl, a clear picture of the persistent increase in deforestation around farming villages emerged, a situation that could have exposed farmland around the settlements to wind and rain erosion that destroyed the fertility of local fields.

Independent assays of MPPNB floor samples from ‘Ayn Ghazāl were investigated about a decade later in two separate projects, and from the results the researchers obtained, they concluded that the quantity of lime plaster in typical house floors was, in fact, much lower than the earlier analysis indicated, and that the amount of fuel represented by the creation of plaster floors themselves would not have affected tree stands around settlements to any significant degree. Was this the death knell of the “environmental degradation hypothesis”, and must one return to Kenyon’s climate change explanation (Kenyon 1957: 76, 1979: 50)? We submit that environmental degradation is still the most likely reason for the massive translocation of populations from the Jordan Valley and Palestine into the Jordanian highlands. In essence, this was an early example of unintentional “ecological suicide” or “ecocide”, a process by which people in fragile ecological systems inadvertently destroy the resources their societies depend on for survival exploitation practices (Diamond 2005).

A Post-Mortem on an Earlier Environmental Degradation Hypothesis

There were two problems with the environmental degradation hypothesis as it was developed in the late 1980s for the MPPNB evacuation of farmers from the southwestern part of the Levant and, by extension, to the eventual disaster at the end of the LPPNB in highland Jordan. The first has already been mentioned: the amount of lime production by burning limestone was substantially less than was suggested by the information from the Smithsonian study. But a second difficulty was an assumption, based on the first few seasons of excavation at ʻAyn Ghazāl, that population increase was gradual, "normal", and steady (cf. Rollefson and Köhler-Rollefson 1989: TABLE 1). As the scope of excavation expanded at ʻAyn Ghazāl in 1988-1989 and 1993-1996, it became clear that this view of population growth was not correct.

Some publications on the excavations at PPNB Yiftahel (Garfinkel 1985, 1987) revealed how much plaster was involved in the construction of PPNB houses in the southern Levant. Analysis of a couple of samples of lime plaster floors from ʻAyn Ghazāl (Kingery *et al.* 1988) indicated that the floor plaster was composed of 50% lime ($CaCO_3$). This made

TABLE 1. Population growth and deforestation in the vicinity of ʻAyn Ghazāl for the purposes of construction, fuel, and other purposes (modified after Rollefson and Köhler-Rollefson 1992).

Century BC ending	Population	Families	Growth rate/ century	n houses	n trees, structural	n trees, fuel and other	Depleted hectares	Depletion radius (km)	Cumulative radius (km)
8,250	[a]300	60		[b]78	[c]312	[d]13,100	131	0.4	0.4
8,150	350	70	16.7%	88	352	15,300	153	0.5	0.9
8,050	410	82	17.1%	103	412	17,900	180	0.6	1.1
7,950	480	96	17.1%	120	480	21,000	210	0.7	1.2
7,850	565	113	17.7%	141	423	24,600	246	0.8	1.5
7,750	660	132	16.8%	165	495	28,800	288	0.9	1.7
7,650	770	154	16.7%	192	384	33,600	336	1.1	2.0
7,550	900	180	16.9%	225	450	39,300	393	1.3	2.3
7,450	[e]1800	360	100.0%	450	[f]1800	78,500	785	2.5	3.7
7,350	2105	421	16.9%	526	2104	91,900	919	2.9	5.4
7,250	2465	493	17.1%	616	2464	107,600	1,076	3.4	6.4
7,150	2885	577	17.0%	721	2884	125,900	1,259	4.0	7.4
7,050	3375	675	17.0%	844	3376	147,300	1,473	4.7	8.7
6,950	3950	790	17.0%	988	3952	172,400	1,742	5.5	10.2
totals					[g]14,780	917,200	9,191		

a – 300 people represent the population at the end of the first century of occupation at ʻAyn Ghazāl.
b – The number of structures includes 20% that were abandoned or otherwise uninhabited.
c – This column represents structural elements such as posts to support ceilings/roofs that incorporate wooden beams. The number of trees or "tree equivalents" begins with six per house, but the ratio per house decreases over time as interior room walls increasingly replace posts to support ceilings or roofs.
d – This column represents the amount of wood used as fuel at the rate of 4.8 tons per household per year over 100 years (cf. Vermeulen *et al.* 1996: 487).
e – Sometime during the middle of the 8th millennium the size (and thus the population) of ʻAyn Ghazāl doubled.
f – The structural needs for trees is now related principally to beams in the ceilings and roofs of structures that are often (if not always) two-storied.
g – Note that the structural total represents only about 1.6% of the total number of trees used at ʻAyn Ghazāl; most of the structural elements were probably used for fuel when they had to be replaced.

it possible to convert the tonnage of floor plaster reported by Garfinkel into the fuel requirements for producing such large quantities of burned lime.

Using the figures provided by Garfinkel and by Kingery *et al.*, calculations were undertaken, and the implications of lime production turned out to be momentous. Together with a model of population growth on a century-by-century basis, we concluded that the wood needs for structural elements of houses and as fuel to manufacture the plaster used for floors and the whitewashing of interior walls resulted in a persistent deforestation around the immediate vicinity of ʻAyn Ghazāl, amounting to as much as 3,200 hectares over the more than 2,200 uncalibrated radiocarbon years that the site was occupied (Rollefson and Köhler-Rollefson 1989: 74-79). This "environmental degradation" model would explain the decline in wood and fauna in the ʻAyn Ghazāl inventory over time without resorting to a climatic change, for which there was no evidence. Furthermore, the deforestation was irreversible, since the browsing habits of goats would have prevented natural reforestation around the settlement (Rollefson and Köhler-Rollefson 1989: 78).

But then other investigations of the nature of the ʻAyn Ghazāl plaster samples themselves emerged. Testing of plaster samples from throughout the Near East, including several samples from ʻAyn Ghazāl, did not repeat the results of the Kingery *et al.* analysis: the amount of lime plaster in the floor samples was far lower than the 50% figure Kingery *et al.* had indicated (1988: Table 1) (Affonso 1997; Teflah and Kafafi 2003), and the amount of fuel necessary to produce the actual amount of lime to use in floors was not enough to influence the environment in terms of deforestation (Affonso 1997: 207, 213). How much less lime was involved is not clear, but the calculations based on the original Kingery *et al.* criteria obviously were incorrect.

It was stipulated by Rollefson and Köhler-Rollefson article that the calculations in their 1989 study "should be viewed with considerable reserve in terms of the absolute values they contain, but they were reasonably derived" on the basis if the available evidence (Rollefson and Köhler-Rollefson 1989: 86). The reasonable derivation may have been fine, but the foundations they relied on were not. One point that should be made at this point is that the environmental degradation of local forest resources was based solely on the use of fuel for structural timbers and as fuel for lime production; nevertheless, 60% of the use of wood in the original calculations was based on structural timbers and roofing (Rollefson and Köhler-Rollefson 1989: 78), so the 40% of the impact erroneously attributed to lime production might be withdrawn, but the structural wood still remains a vital aspect of potential environmental impact, at least for the Middle PPNB (MPPNB)[1].

One factor in the environmental equation that was not addressed originally was the impact of local population demands on nearby wood resources for simple domestic uses, especially as fuel for cooking and to provide light. Studies in Mesoamerica have shown that lime plaster production in the Maya region (where it was lavishly applied to public structures) or for use in residential construction was minimal in terms of environmental impact, but the use of wood for domestic fires greatly exceeded, by staggering amounts, industrial plaster manufacture or structural timbers (Abrams and Rue 1988). This aspect of deforestation was not considered in the original environmental degradation model, but clearly this approach to environmental exploitation must be examined more closely in the Levantine area.

At the present state of research, there is clear evidence that sometime around 7,500 calBC, the size of ʻAyn Ghazāl (and thus also the number of residents) doubled, probably within a few generations (Rollefson 2005a: 6), and this ushered in the Late PPNB (LPPNB) "megasite" that reached ca. 14-15 hectares in size by the end of the LPPNB. Due to the massive in-migration of refugees from the west (who possibly claimed kin relationships to one degree or another with the original inhabitants of ʻAyn Ghazāl), there was an unprecedented campaign of new housing construction, including the establishment of two-story residential "apartment complexes" for the first time (Rollefson 1997: 289-291). We suspect that these buildings housed related families and reflected extended family residences that

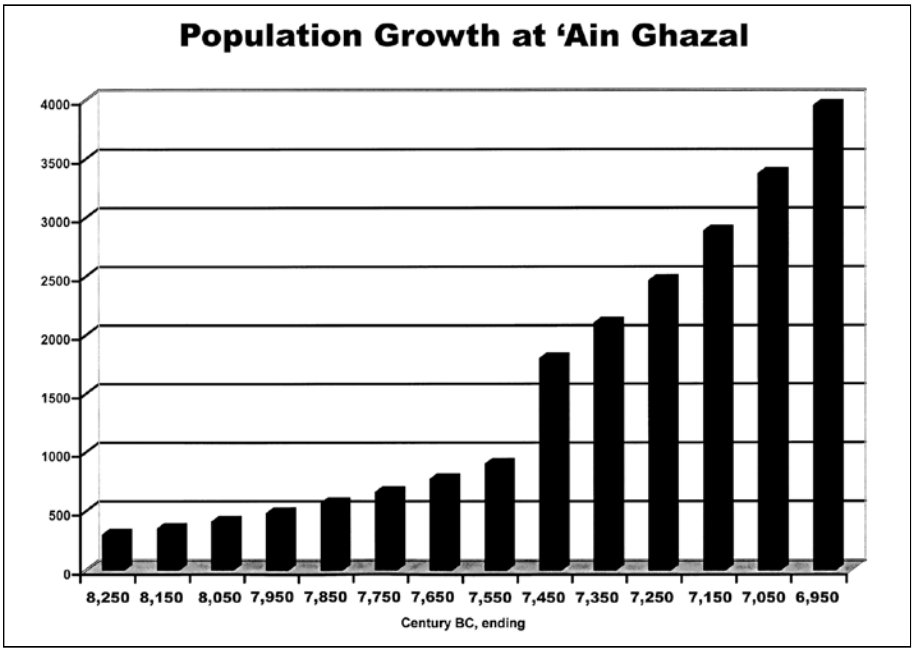
[1] The use of tree trunks as posts to support ceilings/roofs continued throughout the MPPNB, although they decreased in diameter over time; more and more of the ceiling/roof support function was being assumed by interior walls that divided the floor space into discrete walls (cf. Rollefson and Köhler-Rollefson 1992: Table 1). By the onset of the LPPNB at ʻAyn Ghazāl, ceilings and roofs no longer used wooden posts for support. Of course, ceiling/roof beams of wood continued to be used in LPPNB structures just as they had in the MPPNB.

shared not only domestic space, but also pooled the products of their economic contributions. This was a massive departure from the previous small single story, single-family structures during the MPPNB. MPPNB houses were clustered relatively close to each other, and the LPPNB multi-story structures continued this "packing" of populations into considerable housing density. A similar situation appears to have transpired at MPPNB Wādī Shu'ayb (Simmons *et al.* 2001).

Similar huge residential conglomerations appear to be the norm for settlements established for the first time at the beginning of the LPPNB in highland Jordan, presumably by migrants from the west, including Basṭa (ca. 12 hectares, Nissen *et al.* 2004: 22), Ba'ja (Gebel *et al.* 2006), aṣ-Ṣfayya (ca. 12 hectares, Mahasneh 2001: 121), 'Ayn Jamān (8-10 hectares, Rollefson 2005b) and Basīṭ (ca. 8 hectares, Rollefson and Parker 2002). Estimating population sizes for prehistoric communities is a risky undertaking, but we are likely dealing with an influx of people into highland Jordan that is in the neighborhood of several thousand people at the minimum, all of them translocating to earlier MPPNB settlements (e.g. 'Ayn Ghazāl and Wādī Shu'ayb) or founding new ones near permanent springs (Basṭa, aṣ-Ṣfayyah). With individual settlement populations ranging from one to several thousand residents shortly after the beginning of the LPPNB, there was a sudden and growing stress on resources immediately surrounding permanent water sources. While the "lime plaster environmental degradation hypothesis" may be a failed explanation, the likelihood that environmental degradation as a cause for 1) the abandonment of MPPNB farming villages in the Jordan Valley and Palestine at the end of the MPPNB and 2) the ultimate population collapse at the end of the LPPNB in Jordan at the end of the beginning of the 7th millennium calBP remains a strong, vibrant probability.

Population Growth Before and After the 9.5 k.y.a Event

Estimates of population growth rates for prehistoric populations are admittedly a practice that is fraught with many hurdles, but we offer the figures in TABLE 1 as a starting point for discussion. We suggest that expansion of settlement area can be used as a proxy to represent population growth. At the end of the first century of occupation at 'Ayn Ghazāl, ending at ca. 8,250 calBC, families at 'Ayn Ghazāl were spread over a small area, and that the number of families approximated 60, and with a projection that three children would reach reproductive age, this would total ca. 300 people. During the next century, we propose that 10 more families would be added to the community, numbering 350 by ca. 8,150BC, a growth rate of 16.7%; this centurial span represents something like 6 generations, or a growth rate of 2.5% per generation, and further, this reflects a 0.2% growth rate per year (FIG. 1).



1. Population growth at PPNB 'Ayn Ghazāl at a rate of 0.2% per year (16.7% per century).

The population growth rate today is between 0.1% to ca. 3.0% (Anon 2003), and we have intentionally selected the lower end of the scale, which is in keeping with many of the Developing Countries, although much higher rates exists as well.

We have assumed that, in the absence of any particular catastrophe (such as possible epidemic disease or natural calamity), the rate of increase in ʿAyn Ghazāl inhabitants would have been reasonably constant, ranging between 16.7-17.7% over each century. The number of families is augmented at this steady rate under the assumption that as many mates may leave the community as those who are added from the outside, regardless of marriage and residence rules (patri-/matri-/neolocal), and if there were little exchange with other communities, the growth rate may be lower than the current model predicts.

The number of families per century should be placed in relation to the amount of space a household might need. Test pits indicate that the earliest part of ʿAyn Ghazāl was probably not larger than 2-2.5 has (Rollefson and Köhler-Rollefson 1989: 73). This figures to a mean space for each household of ca. 300m^2, including floor space of the dwelling itself, which was not more than 50m^2 (Rollefson 1997: 288). This seems to be entirely plausible. At this rate the estimated number of family houses by 7,550BC would imply that the site would have extended over 5.4 has, which was the original indication in the original model (Rollefson and Köhler-Rollefson 1992). The departure from the earlier model is that the growth rate in population was not steady, and that ʿAyn Ghazāl (and Wādī Shuʿayb, among other established MPPNB settlements in the Jordanian highlands) suddenly expanded to about twice their sizes within a small number of generations. Thus, there is a "bump" in the population curve (FIG. 1) by 7,450BC, so that in the more than 10 has by 7,450BC, family numbers had doubled to 360, comprising a total of 1,800 people.

As one continues along the population and families columns in the left-hand columns of TABLE 1, there is a notable discrepancy between the number of projected families and the maximum size of ʿAyn Ghazāl by 6,950BC. Surveys and test pits reveal that the preserved areas of ʿAyn Ghazāl did not exceed 14 has by 6950BC, but the number of families predicted for this time would have "required" almost 24 has. This incongruity is explainable in part by the appearance of multi-family two-story buildings, which could have housed 3-4 nuclear families each (Rollefson 1997: 303). Of course, it is also possible that the ca. 17%/century growth rate had decreased considerably sometime during the LPPNB, and that a population plateau may have been reached sometime between 7,350-7,250BC. The probability seems relatively low that almost 4,000 people lived at ʿAyn Ghazāl by 6,950BC (see below), although there is proxy evidence that the 12 ha site of Basṭa may have hosted 4,000 people at its maximum size (Gebel, pers. comm.).

A New Regard for Deforestation and Environmental Degradation

We would like to iterate that Kenyon's climatic hypothesis is not supported by the situation in the middle of the 8th millennium: if climate deteriorated sufficiently to make agriculture unpredictably reliable in the Jordan Valley and Palestine, then the abandonment of those farming villages should have been matched by contemporary agricultural settlements in highland Jordan. They share the same climatic regime at the present time, and there is no evidence that the situation was different in the past. So, if not climate, what else should be considered?

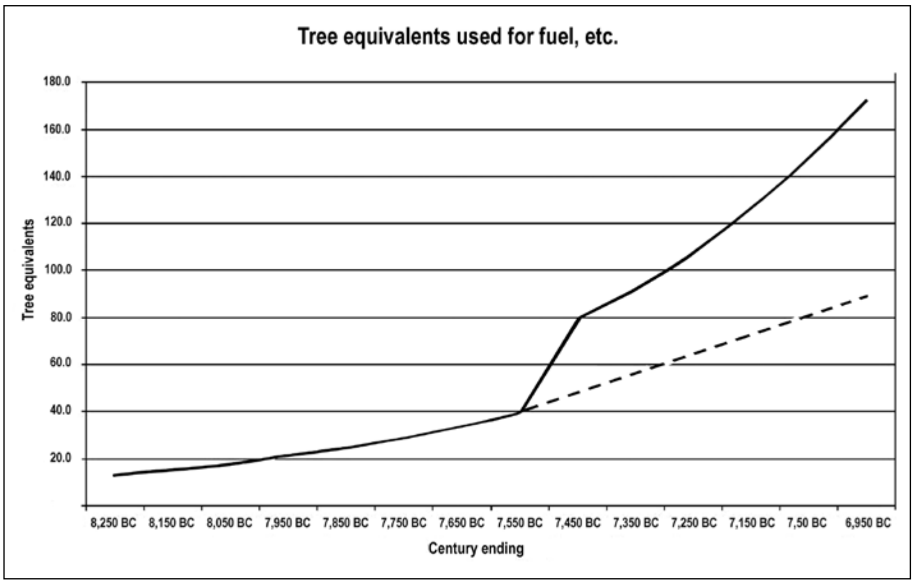
Despite the overturning of the first model of environmental degradation that was based on immense demands of wood for lime plaster production, the model itself remains intact, albeit with a different foundation. In essence, we claim that the needs of fuel by Neolithic groups and the deleterious effects of goat husbandry were still responsible for a growing ecological calamity in a fragile part of the Levant. While Kenyon was correct in describing the ecological fragility of the region, we maintain that human, and not climatic issues, were responsible for the evacuation of the western southern Levant and the ultimate population collapse of LPPNB highland Jordan.

One factor in the environmental equation that was not addressed originally was the impact of local population demands on nearby wood resources for simple domestic uses, especially as fuel for cooking and to provide light. Perhaps because it is ubiquitous in all societies, the use of wood for domestic needs has received little attention. In rural areas across developing countries, it has been claimed that domestic fuel needs account for 75-89% of total fuel wood consumption (Agarwal 1986). Even in tropical regions of Latin America, where forests are dense and extensive, rural, non-industrial needs amounted to approximately 1.5 tons of wood for cooking and light per person per year (or 9 tons of wood per year for a household of six people), and in tropical Kenya the same rate of domestic wood use was measured (Abrams and Rue 1988: 389). In the "hot and equable climate" of Malawi, a family of six consumes a minimum of 1.56 tons of wood per year for cooking alone (Biran *et al*. 2004: 11), although in Tanzania a survey of Maasai households the rate was 1.4 tons per year for the same size household (Biran *et al*. 2004: 12). The wood use for domestic fuel in Zimbabwe ranges from 4.3 (poor families) to 10.3 tons of fuel per year (Vermeulen *et al*. 1996: 488), but that overall the average rate of wood fuel consumption was 4.8 tons per year per six-member household (Vermeulen *et al.* 1996: 487).

The density of tress is difficult to gauge for prehistoric times, of course, and such data are also relatively rare in the anthropological literature. In Zimbabwe the degraded study area had a wood biomass of only 20.6 tons per hectare, although in a nearby protected state forest, the mean wood biomass was more than triple (67.9 tons/hectare) (Vermeulen *et al*. 1996: 489). For 'Ayn Ghazāl, in the current model we have assumed a tree density of 100 trees per hectare (as opposed to the 17 trees/ha in the original model: Rollefson and Köhler-Rollefson 1989: 79), despite the proximity of 'Ayn Ghazāl to the 250-300mm isohyet, which is at the 4th edge of the steppic zone. To see if this estimate is acceptable, we calculated the weight of this kind of distribution by multiplying the volume of oak trees ($h\pi r^2$, with h = 3.5 m, r = 0.5 m; cf. Rollefson and Köhler-Rollefson 1989: 77-78 and references) times the density of oak (0.8), which results in 2.2 tons per tree (the "tree equivalent"). This would convert to 220 tons/ha, and at the close of the century ending 8,250BC, this equals the use of 131 has x 220 tons = 28,820 tons for the entire century, or 288 tons per year. In relation to the number of families at the end of the century, this corresponds to 4.8 tons/ household/year.

Considering the estimated density of tree stands around 'Ayn Ghazāl, the depletion of trees around 'Ayn Ghazāl is detailed in right side of TABLE 1. There is a slow but constant increase in the number of deforested has per century, but again, this rate of deforestation suddenly doubles at 7,550-7,450BC (FIG. 2). The growth of the depletion radius would not likely be recognizable on a generation-by-generation assessment: over one person's lifetime the increasing distance that people needed to walk to obtain fuel wood probably was probably unnoticeable.

The last column in TABLE 1 is the decisive set of data that supports the environmental degradation hypothesis. In a millennial overview of changes in ecological circumstances in the Mediterranean region, Blondel relates that many ecologists have concluded that there has been severe human-caused deforestation and over-grazing, but that there are areas that are "resilient" to ecological system disturbances (Blondel 2006: 714). That the fragility of the southern Levantine area is prone

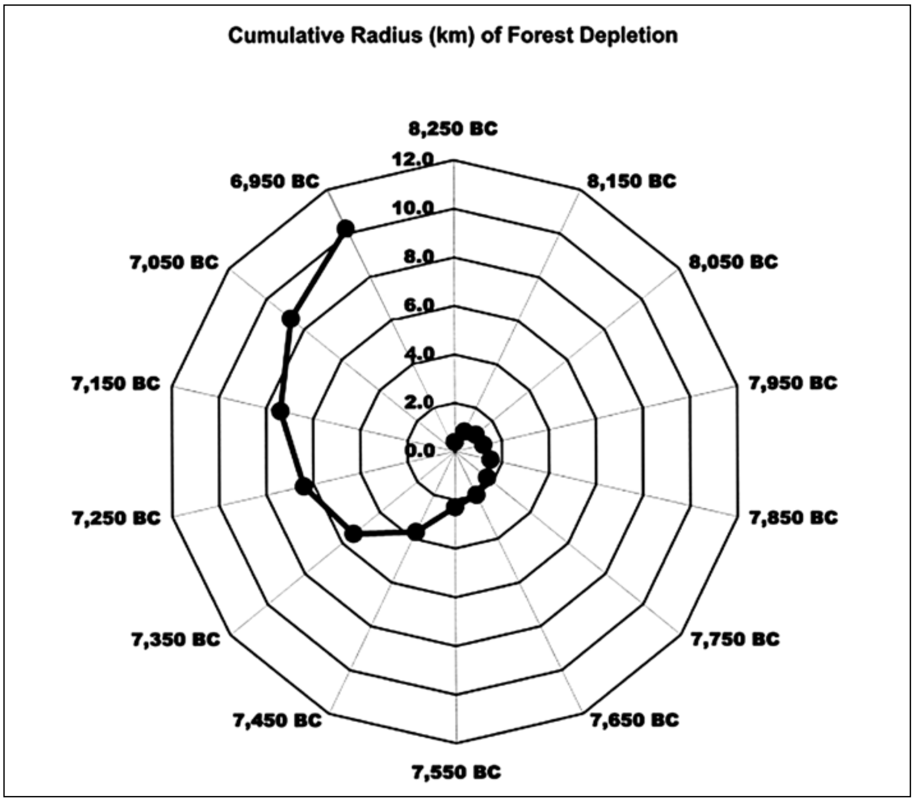


2. Use of wood as fuel, calculated as "tree-equivalents", at the rate of 4.8 tons/year per household. The dashed line represents the projected increase in fuel use if there had not been a major increase of immigrants into 'Ayn Ghazāl ca. 7,500 calBC.

to ecological disturbance is probably unanimously admitted, but resilience in some areas is probably less vigorous than in others, particularly in those territories where permanent water sources (especially springs) are scarce and where the demands of population growth of sedentary agricultural and herding communities approaches the limits of sustainability. The last column in TABLE 1 is a consequence of this fragility in the sense that not only does the area of deforestation increase every century, but that as the result of goat herding, the deforested area is additive every year and century due to the browsing habits of goats. In essence, resilience is prevented because browsing goats prevent the natural reaction to reduced tree stands due to their predilection to eating newly erupted seedlings (Rollefson and Köhler-Rollefson 1992). As a result, the distance people would have had to travel for fire wood approached an absurd level by the end of the LPPNB around 6,950BC: surely, the need to travel up to 4-10km and back to obtain the fuel for household needs must have resulted in accommodations by the inhabitants (FIG. 3). The use of animal dung as fuel at ʻAyn Ghazāl does not appear until well into the 7th millennium BC (Reinder Neef, pers. comm.), so other adjustments were necessary.

While the labor involved in obtaining fire wood may become more and more onerous over time, this drawback paled in comparison to the results of the deforestation itself. Since reforestation was not possible in view of the importance of goat herding to the local economies, more and more open space was exposed to the effects of wind and rain, which removed valuable topsoil every season. Fields that had been in use over long periods of time became less and less productive, and while new areas suitable for crops were opened by the deforestation, the distances to the new plots became so burdensome, especially at harvest time, that it would have been more effective to have moved the settlement to the new fields if there had been permanent water sources in the vicinity.

Based on both factors (the availability of firewood and distance to new fields), it is likely that a population plateau at ʻAyn Ghazāl was reached at around 7250-7350BC, and as Gebel presciently predicted as early as in 1997 (Gebel 2004: Fig. 1 and 5-11), when this plateau was reached at northern mega-sites, excess population was siphoned off to newly founded communities established at previously under-exploited springs or other permanent sources of water, such as those found in southern Jordan at Basṭa, aṣ-Ṣfayyah, and others.



3. Cumulative radial distance of deforestation based on population growth and fuel demands of the people at ʻAyn Ghazāl.

Closing Remarks

Communities were not abandoned because people had to travel long distances to obtain firewood. Instead, the extensive deforestation that was necessitated by huge demands for fuel resulted in the exposure of farmland to erosion, and this resulted in reduced crop yields over time. Eventually, the cost-benefit ratio for farmers became so imbalanced that new solutions had to be adopted, which in many cases meant forced migrations into other parts of the Levant. Eventually, population growth could no longer be accommodated even at the newer farming communities, and the entire southern Levant appears to have witnessed a major dispersal of population during the PPNC and into the Pottery Neolithic periods, when many of the families once associated with farming began an increasingly segregated pattern of nomadic pastoralism (Köhler-Rollefson 1992; Rollefson 1997: 305, 2001: 94-95).

Large population concentrations would not recur until the Chalcolithic period[2]. Notably, the appearance of domesticated pack animals (the donkey) may have alleviated the drudgery of fetching firewood to a great extent, for pack animals could have brought firewood from great distances in large quantities. (Donkeys could also have made fields at greater and greater distances from the settlements less of a problem during harvest time). Whether this meant that there were families who specialized in fuel acquisition and distribution or not can't be resolved at the moment, but it is an element of village- and town-based economies that should be investigated intensively in the future (cf. Levy 1995: 229-235; Quintero *et al*. 2002: 45-46).

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