How Ancient Agriculturalists Managed Yield Fluctuations through Crop Selection and Reliance on Wild Plants: An Example from Central India[1]

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Smith, Monica L. *(Department of Anthropology, UCLA, Los Angeles, CA 90095-1553; e-mail:* smith@anthro.ucla.edu). How Ancient Agriculturalists Managed Yield Fluctuations through Crop Selection and Reliance on Wild Plants: An Example from Central India. *Economic Botany* 60(1):39–48, 2006. *The use of "average" yields to formulate models of premodern agriculture obscures the dynamic components of agricultural decision-making. Using colonial documents and archaeological data from the Deccan region of central India, this paper illustrates the complexities of how ancient peoples mitigated fluctuations in agricultural yields. Nineteenth-century documents show striking differences in yields from year to year, and illustrate the way in which people compensated for those fluctuations by using wild foods and cultivating alternate crops that were less palatable but more reliable. Archaeobotanical, archaeological, and textual data from the Chalcolithic to the Early Historic periods (c. 1500 B.C. to 300 A.D.) indicate similar adaptive strategies, in which the early inhabitants of the region managed resources at the household level to provide subsistence security as well as the steady provision of a tradable surplus.*

L'Importance des Plantes Sauvages pour les Anciens Agriculteurs de l'Inde. *Les analyses d'agriculture prémoderne, fondées sur un modèle de récoltes "moyennes," cachent les complexités de l'usage de plusieurs stratégies d'agriculture ainsi que de ressources naturels. Ici, l'économie de l'Inde centrale dans les premiers siècles de notre ère est établie par les données de la paléobotanique et d'archéologie, une perspective augmentée par l'étude des documents du dix-neuvième siècle. Ces documents indiquent une grand variation de récoltes d'une saison et d'une année à l'autre, et que les agriculteurs balançaient leurs besoins de soutenance physique et sociale avec plusieurs stratégies parmi lesquel l'usage des produits forestières étaient très important. L'inclusion des ces paramètres pour la période premoderne nous permet de reconstruire non seulement les activités agriculturels, mais aussi l'impact de ces activités sur les activités économiques et sociales outre du foyer domestique.*

Key words: Archaeology, archaeobotany, agricultural yields, colonial texts, India.

Models of ancient agricultural strategies typically are built around three variables: population size, caloric needs, and agricultural yields. Although archaeologists generally are satisfied once they have identified fixed numbers that will let them calculate how much agricultural land would have been required around a given site, comparative anthropological and agricultural studies show that changes in acreage comprise only one component of agricultural dynamics. In this paper, I utilize nineteenth century documents and regional archaeobotanical data to construct parameters for the three variables of population size, caloric needs, and agricultural yields for the site of Kaundinyapura, India, a town of the Early Historic period in central India (c. 3rd century B.C. to the 4th century A.D). Archaeological research at Kaundinyapura shows a widespread distribution of trade goods in the Early Historic period indicating that all, or nearly all, households possessed a standard repertoire of domestic-use items (M. Smith 2001, 2002). Lacking mineral or other natural resources, Kaundinyapura's residents probably traded perishable products, but the production of "surplus" for exchange was an extension of the methods used to address basic food needs.

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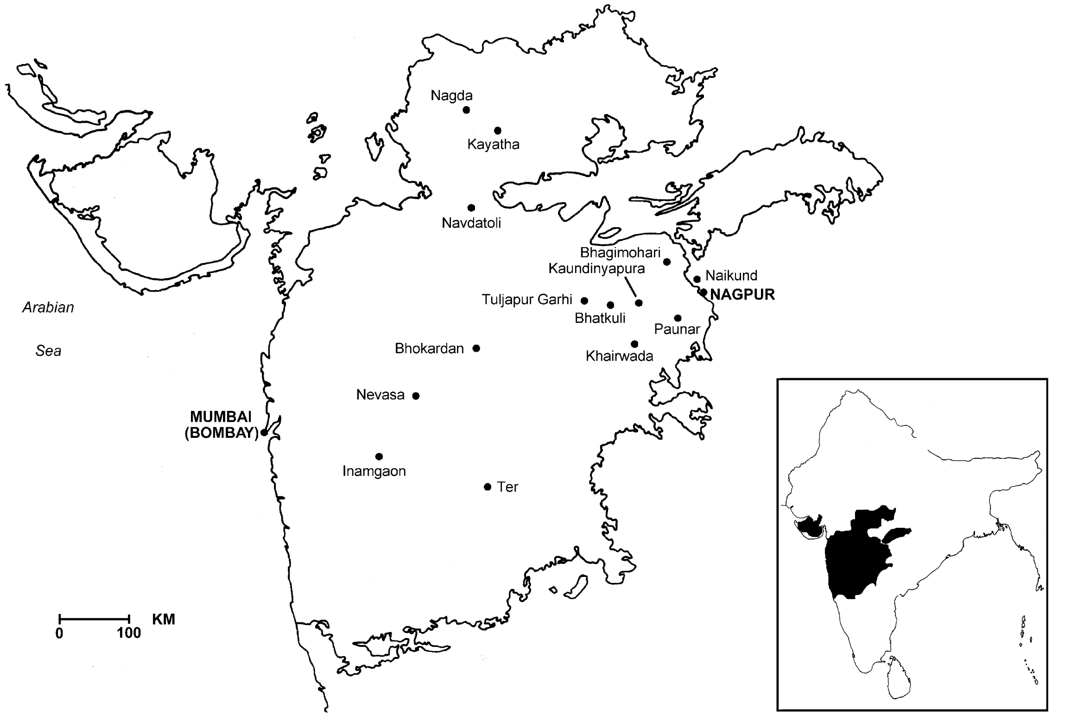

Fig. 1. The Deccan Basalt Province, with sites containing paleobotanical remains from the Chalcolithic to the Early Historic periods (c. 1500 B.C. to 300 A.D.; Kajale 1989; Kajale 1988; Kajale 1976–77; Kajale 1974; Vishnu-Mittre 1966; Vishnu-Mittre 1961; Vishnu-Mittre and Gupta 1968–69; Vishnu-Mittre, Prakash, and Awasthi 1971). Modern cities are noted in capital letters.

The Archaeology of South Asian Agriculture

The earliest evidence of agriculture in the Indian subcontinent comes from archaeological sites dating to the seventh millennium B.C., including the important early site of Mehrgarh in western Pakistan (Costantini 1981; Meadow 1996; Fuller 2002). Central India is a dry upland region where the earliest evidence of agriculture begins considerably later (around 2300 B.C.), but by the late second to early first millennium B.C. there were settlements with permanent housing, well-made pottery, and a double-cropping agricultural cycle of winter and summer cultigens (Fig. 1; Sankalia, Subbarao, and Deo 1958; Dhavalikar and Possehl 1974; Vishnu-Mittre 1974; Shinde 1987; Dhavalikar, Sankalia, and Ansari 1988; Ratnagar 1989; Thomas 1992a; Thomas 1992b; Kajale 1994).

Since the following discussion makes use of previously-published plant identifications, a word about the interpretation of archaeologically recovered botanical information from South Asia is appropriate. As noted by both Fuller (2002) and Meadow (1996), the reporting of ancient plant remains to the species level has been highly problematic in South Asia for a variety of reasons, including lack of comparative material, inappropriate comparison to modern exemplars, the potential presence of extinct species, and the failure to take into account post-depositional effects such as charring on the sizes and shapes of the seed remains. Discussions of wheats, for example, are made complex by variant standards in separating to ploidy level and the presence of a number of overlapping traditional binomials, while the description of millets and pulses is further complicated by physical characteristics that are not mutually exclusive among different binomials in addition to other variations in nomenclature (Fuller 2002:275,292). For the purposes of the discus-

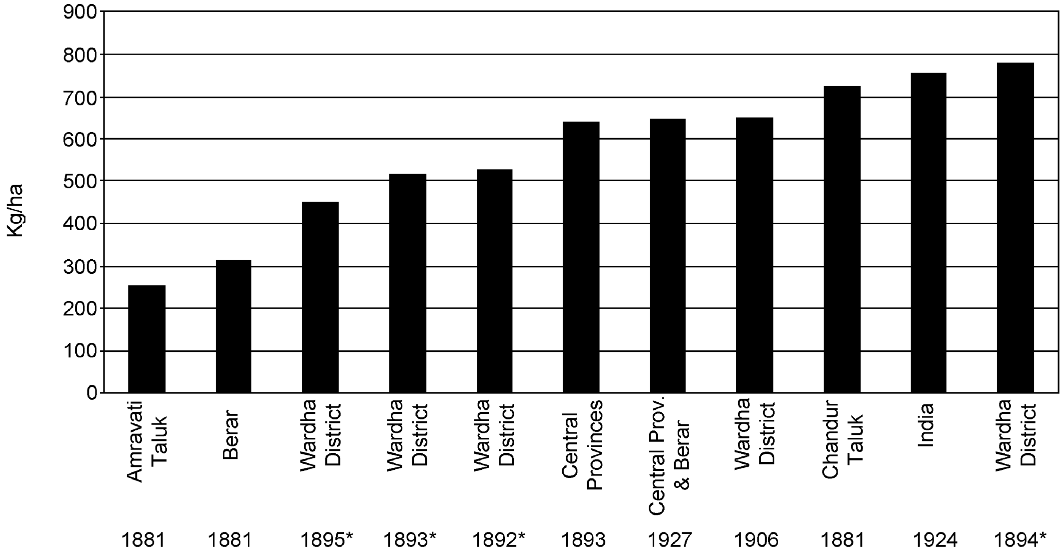

Fig. 2. Wheat (*Triticum* spp.) yields in central India, 1881–1927 (compiled from Carey 1898; Howard 1924; Kitts 1882; Russell 1906; Season and Crop Report for 1927–28, 1928–29, 1929–30). Asterisk denotes experimental crop.

sion below, identification to genus is sufficient to propose the general relationships among different plant types (cf. Weber 1999), although identifications are presented here as they were written by the initial analysts.

Historical Data And The Reconstruction Of Crop Choices In Central India

Census records, reports of crop yields, and gazetteers of the districts under British administration in the nineteenth century provide a wealth of agricultural data for the Indian subcontinent. Although colonial documents are not unproblematic given their authoritarian nature, they remain our most comprehensive source of information about crop yields, plant use, and agricultural strategies prior to the development of chemical inputs and mechanization. The figures below are derived from documents that describe areas in the immediate vicinity of Kaundinyapura, which is located on the eastern edge of central India's Deccan Basalt Province (an area characterized by volcanic-derived soils of high moisture retention; Nidumolu et al. 2004). Figure 2 illustrates wheat (*Triticum* spp.) yields for the years 1881–1927, where the highest yield per hectare is nearly four times the lowest. It is important to note that yields vary by year, and not necessarily by region; for example, in Fig. 2 there are a number of different data points from the area of Wardha District. Variation in the yields of gram (*Cicer arietinum*) is even more dramatic, with the highest yields more than seven times the lowest (Fig. 3). Data for other domesticated crops show a similar annual fluctuation. For example, the yields for jowar (*Sorghum bicolor*) in Wardha District were recorded with abrupt changes in four consecutive years: 1140 kg/ha in 1892–93, 532 kg/ha in 1893–94, 844 kg/ha in 1894–95, and 501 kg/ha in 1895–96 (Carey 1898).

L.S. Carey's summary of crop conditions shows the dramatic impact of weather variability in central India. While conditions in 1892–93 led to satisfactory winter and summer crops, excessive rain in the following year destroyed the ripening *kharif* (summer) crop:

> In that year the wheat crop of Saugor and Damoh was practically a total failure, and very material damage was caused by fungoid disease in other districts, both to wheat and to linseed. In the subsequent year meteorological conditions were decidedly similar. Cotton and til were much injured, while the wheat crop in Jubbulpore was wiped out . . . then followed the year 1895–6, which ushered in the period of drought that culminated in the great famine from which we are now emerging. In

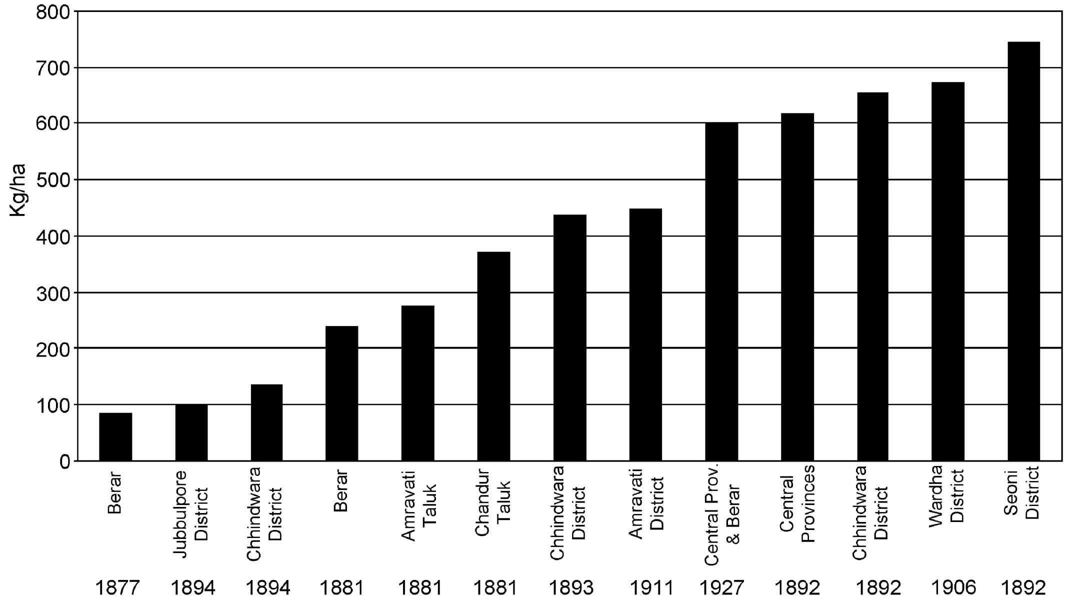

Fig. 3. Gram (*Cicer arietinum*) yields in central India, 1877–1927 (compiled from Carey 1898; Fitzgerald and Nelson 1983[1911]; Kitts 1882; Russell 1906; Season and Crop Report for 1927–28, 1928–29, 1929–30).

> that year the rice crop suffered very severely, but the circumstances were not on the whole unfavourable to staples such as cotton, til and juar . . . (Carey 1898:1–2).

In general, crop productivity also is affected by nutrients and pests (insects, plant pathogens, and weeds). These factors are interdependent, since the variety and quantity of rapidly-reproducing pests can increase or decrease depending on rainfall, humidity, and other climatic factors (Bulla, Kramer, and Speirs 1978). A complex feedback loop thus affects crop yields apart from deliberate choices about what to plant, since loss of agricultural yields through pests and disease impacts both the active cultivation of crops and the period of storage between harvest and use of the stored grains as food or seed stock.

We can now turn to the two other components of the agricultural equation: population size and caloric needs. Although it is difficult to pinpoint the exact size of ancient populations based on archaeological remains, population size can be estimated using a variety of ethnographic and archaeological comparisons that take into account living space, density of individuals per household, and number of estimated households per hectare in villages, towns, or cities. Comparative analysis with other Asian cases suggests that Kaundinyapura's population would have ranged from 350–1,000 individuals, with some fluctuation on an annual or seasonal basis given the region's monsoon climate (M. Smith 2001).

Food requirements, the third component of the agricultural equation, encompass matters of taste and preference in addition to quantifiable aspects such as total caloric value and the presence of proteins, minerals, carbohydrates, and minerals essential to good human health. Calorie requirements for adults vary according to the size and occupation of the individual and there is no single global standard for required caloric intake. While numerous idealistic guidelines exist for nutrition in South Asia, more accurate data are provided by studies of actual farmers, such as that by Edmundson and Edmundson (1988:436) in the Deccan dry-farming region showing a value of 210 kJ (50 kcal) per kg of body weight, which they propose as "close to the minimum energy requirement necessary for subsistence farming."

Under the assumption that caloric values for cultigens have not altered, we can apply those values to the crops known from Early Historic

TABLE 1. SPECIES RECOVERED FROM THE ARCHAEOBOTANICAL RECORD OF 14 ARCHAEOLOGICAL SITES IN THE DECCAN REGION OF WEST-CENTRAL INDIA.

Plant Name	Common Name	No. of Sites	Caloric Value (kcal per 100 g edible portion)
*Acacia arabica**	babul	1	
Acacia cf. *nilotica**	Indian gum arabic, babul	1	
Androgon sorghum	jowar	1	
Cajanus cajan	red gram	4	335
*Carthamus tinctoris**	safflower	1	356
Chenopodium cf. *album**	bathua, chandan bathua	1	30
Cicer arietinum	Bengal gram, chana, garbanzo	6	360
*Coix lachryma**	Job's tears, sankru, ranmakka	1	378
Dolichos biflorus	horse gram	4	321
Dolichos lablab	field bean	4	347
Eleusine spp.	ragi	2	328
Hordeum vulgare	barley	7	336
Lathyrus sphaericus		2	
Lathyrus sativus	Kesari dhal, lakh	7	345
Lens culinaris	lentil	1	
Lens esculenta	lentil	5	343
Linum usitatissimum	linseed	1	530
Oryza sativa	rice	9	349
Paspalum scrobiculatum	varagu, kodra, harik	3	309
Pennisetum typhoides	bajra	1	361
Phaseolus aureus	green gram	3	334
Phaseolus mungo	black gram	4	347
Phoenix dactylifera	date palm	1	
Phyllanthus emblica	amla, Indian gooseberry	1	
Pisum arvense	pea	6	
Pisum sativum	pea	1	315
*Ricinus communis**	castor seed	1	
Sorghum sp.	jowar	4	349
*Terminalia belerica**	baheda	1	
Triticum sp.	wheat	8	346
Vicia sp.*	bean	4	71
Vigna mungo	black gram	3	
Vigna radiata	green gram	1	
Zizyphus sp.*	ber, bor	8	74

* Denotes a non-domesticate.

Data derived from the Chalcolithic (1500 B.C.) to the Early Historic (ending 4th century A.D.) periods; see also Fig.1. Calorie figures provided in Gopalan et al. 1992; common names (including Hindi and Marathi) from Fitzgerald and Nelson 1983[1911]; Gopalan et al. 1992; Kajale 1974, 1988.

sites in the Deccan region (see Table 1). The proportion of different foods in the diet can be estimated from anthropological observations such as that by Pushpamma et al. (1981:231) showing that grains (cereals and millets) constituted 75–85% of the calories and protein in the diet. On the basis of modern ethnographic studies, Dhavalikar and Possehl (1974) also estimated a crop mix for ancient populations at the site of Inamgaon consisting of 70% sorghum, 20% wheat, and 10% rice. However, the proportion of the diet provided by one or two grain "staples" may in itself be variable.

Other studies of grain consumption in contemporary India indicate that the percentage of different foods in the diet varies by income level and geographic location. Ramnath, Vijayaraghavan, and Swaminathan (1983) noted that for the wealthiest income group in their survey of central and south Indian households, the category of grain (cereals and millets) provided 56 $\pm$ 11 % of calories, while the poorest

TABLE 2. HECTARES REQUIRED FOR STAPLE CROPS FOR THE AREA OF KAUNDINYAPURA IN THE EARLY HISTORIC PERIOD.

	High Population/ Good Year	High Population/ Bad Year	Low Population/ Good Year	Low Population/ Bad Year
Wheat (*Triticum* spp.) at 60% of diet	225	691	79	242
Wheat (*Triticum* spp.) at 75% of diet	281	864	98	303
Wheat (*Triticum* spp.) at 90% of diet	338	997	118	363
Sorghum (*Sorghum bicolor*) at 60% of diet	152	346	53	121
Sorghum (*Sorghum bicolor*) at 75% of diet	190	433	67	151
Sorghum (*Sorghum bicolor*) at 90% of diet	228	519	80	182
Gram (*Cicer arietinum*) at 60% of diet	226	2,002	79	701
Gram (*Cicer arietinum*) at 75% of diet	282	2,502	99	876
Gram (*Cicer arietinum*) at 90% of diet	339	3,002	118	1,051

THESE DATA ARE BASED ON ESTIMATES USING A high population (n=1,000) and a low population (n=350). Nutritional requirements are based on a total dietary intake of 2,126 calories (see Edmundson and Edmundson 1988); yields are based on nineteenth-century documents of productive capacity for the same region.

income group had 75 ± 15 % of calories from cereals. Similar social distinctions in food preference can be traced through the literary record of the premodern period (e.g., Prakash 1961). For comparative purposes, the calculations below are made at three levels of consumption and project the total agricultural output required for staple grains and pulses at 60%, 75%, and 90% of dietary intake.

Table 2 identifies the crop area required using three examples of a single-cultigen standard: wheat, sorghum, and gram (*Cicer arietinum*). High and low yield values are taken from colonial-era documents for central India: wheat (highest yield 777 kg/ha, lowest yield 253 kg/ha); sorghum (highest yield 1140 kg/ha, lowest yield 501 kg/ha); gram (highest yield 745 kg/ha, lowest yield 84 kg/ha). In addition to the acreage needed to meet the minimum human requirement, additional factors of waste, spoilage, insect damage, and other losses between harvest and consumption must be taken into account (Dhavalikar and Possehl 1974). Y. Pomeranz (1980) provides an estimate of 30% for these losses on average; lacking more precise data for crop losses in the Early Historic period, the calculations in Table 2 use the 30% figure as a proxy added on to the basic human calorie requirements. The resultant total quantities of staple grains and pulses required for a site the size of Kaundinyapura in the Early Historic period thus take into account two maxima (highest estimated population density and best-year crop yields) and two minima (lowest estimated population density and worst-year crop yields), as well as variability in the ratio of basic grain and pulse crops.

The figures in Table 2 can be translated to best-year and worst-year acreage minima and maxima for Kaundinyapura, which is located adjacent to a river, providing a 300-meter wide strip of alluvial land. At the highest estimated population level of 1,000 inhabitants, and assuming the use of all alluvial land in the vicinity of the site, best-year cultivation of staple crops when calculated at the rate of 75% of the diet would have required a relatively small radius from the site for wheat (1.1 km), sorghum (1.3 km), and gram (1.2 km). However, worst-year cultivation of these same crops would have required the exploitation of a considerably larger radius for wheat (3.6 km), sorghum (1.8 km), and gram (10.4 km). The regular zone of cultivation was likely to have been somewhere between the best-year/worst-year land requirements. Long-term corrections probably included labor investment to increase acreage, but it would have been difficult to quickly clear new lands for cultivation in years of shortfall. Instead, agriculturalists would have utilized short-term labor allocations for other strategies, including crop substitution and increased reliance on wild foods.

Crop substitution includes the practice of double-cropping, attested in the archaeological record of central India in the form of winter crops (wheat, barley, peas, lentils) and summer crops (millets, rice, pulses; Fuller 2002; Kajale 1988). Colonial documents show that by double-cropping, farmers can compensate for shortfalls in one season by planting a different crop mixture in the following season. Some plants, such as millets, are particularly hardy and will produce a crop even under drought conditions (Carey 1898). Although millets may be less palatable and thus not a preferred food, their caloric value is the same as wheat or rice (Oke 1983:5). Similarly, the plant known as *lakh* (*Lathyrus sativus*) is not a preferred food since it results in paralysis in some consumers, but it is noted in colonial documents as a food eaten in place of desired alternatives such as the pulses *Cajanus indicus* and *Cicer arietinum* when the latter were unavailable (Howard and Khan 1928). The presence of *Lathyrus sativus* in the archaeobotanical record of a relatively large number of Early Historic sites (n=7) in Table 1 indicates that this plant was known and used in the premodern period as well.

Wild foods comprise another important potential component of agricultural systems, although the role of wild resources is often underappreciated for ancient populations. Investigators may discount the presence of non-cultigens in archaeological deposits as "weeds," may lack sufficient comparative collections to positively identify a range of wild flora, or may unwittingly emphasize cultigens in their reports on sites of time periods where agriculture is known to have been practiced. The visibility of wild resources may further be lowered if primary processing in antiquity took place away from the kinds of domestic contexts where archaeobotanical samples are often taken, or if the resource was completely consumed without leaving archaeological remains. However, there are several reasons why wild resources factored into ancient agricultural decision-making.

As Clement (1999) and B. Smith (2001) have recently discussed, the dichotomy between wild and domesticated plants is an overstated one given the many ways in which cultigens can be manipulated, helped along, or fostered without full domestication. In the case of India, it appears that wild and domesticated strains may have been utilized at the same time, with the transition to a fully "domesticated" form difficult to distinguish (Vishnu-Mittre 1974). Vishnu-Mittre (1961:14) also noted that the archaeobotanical collection from sites such as Navdatoli and Maheshwar "includes the seeds of some weeds which may have been gathered for food"; these include what he identified as *Pisum arvense*, *Lathyrus sphaericus*, *Vicia sativa*, and *Vicia tetrasperma*. Similarly, at least in modern times, the *ber* (*Zizyphus jujuba*) is "not truly wild in India and is seen profusely around former villages or native settlements" (Vishnu-Mittre 1961:24). Several of the plants noted in Table 1 may therefore indicate transitional stages, or plants that were tolerated or assisted but not deliberately cultivated. Use of wild flora can also be extrapolated for Early Historic sites on the basis of recovered faunal materials and paleodental records, which show that "the economy was based on a combination of agriculture and cattle pastoralism, augmented by hunting and the exploitation of aquatic and avian resources" (Thomas 1993:117; see also Lukacs 1981; Thomas 1992b; Mohanty and Walimbe 1993).

Nineteenth-century documents from central India indicate that many wild plants were used as "famine foods," a practice echoed in Early Historic texts as well. The *Sirupanattrupadai*, a South Indian poem of the early centuries BC/AD, paints the scenario of ". . . the wife of the drummer with a lean and slender waist and bangled wrists whom cruel hunger gnawed did saltless cook the herb her sharp nails plucked from refuse heaps, and made a meal of it with poor relations, having closed the door ashamed to be so seen by prying folk" (lines 180–186; trans. Chelliah 1985:155). The archaeobotanical record for Early Historic India indicates some wild foods with a high calorie value (such as *Coix lachryma*, with 378 calories/100 gr value, placing it in the same range as grain cultigens; Gopalan et al. 1992). Another ethnohistorically known famine food represented in the archaeological record is *Acacia nilotica*, the bark of which is edible when ground and whose seeds can be eaten roasted or raw (Publications and Information Directorate 1985).

Even when they are well supplied by domesticates, however, agricultural groups regularly use a number of wild foods as Pieroni (1999) has shown for twentieth-century Italy and Tardío et al. (2005) have illustrated for modern Spain. Wild resources are gathered for ritual purposes or to provide nutrients inadequately supplied by cultigens; other categories of use, such as medicinal plants, are of constant but low-intensity demand. In India today, parts of the acacia species *Acacia nilotica* are used as medicine (Publications and Information Directorate

1985), as are the leaves and juice of chenopodium (*Chenopodium album*; Publications and Information Directorate 1992). Other medicinal plants include *Acacia catechu*, used as an astringent, *Acacia leucophloea*, which provides a medicinally-useful gum, and *Achyranthes aspera* (Publications and Information Directorate 1985).

Nineteenth-century documents from the Deccan region show that forest resources and other non-cultigens were also used as fodder, fuel, resins, dyes, and tannins, sources of lac and wax, and timber for crafts and structures (e.g., Grant 1984[1870]; Russell 1906; His Majesty's Secretary of State 1908; Fitzgerald and Nelson 1983[1911]; Roy 1921). These flora would have been available within a 20-kilometer radius of Kaundinyapura in Early Historic times, when forest resources were more abundant than at present (His Majesty's Secretary of State 1908:307). The presence of *Acacia arabica* and *Acacia* cf. *nilotica* in the archaeobotanical record of Early Historic India confirms that the plant was known, available, and used. *Acacia nilotica*, also known as "Indian gum arabic," is a multipurpose source of fuel as well as being suitable for load-bearing components like handles and cart-axles. Ethnographic observations show that the pods are eaten by cattle, goats, and sheep; the gum is used in printing and dyeing of cotton and silk; the bark can be treated to render a substitute for soap; and unripe pods are used for ink (Publications and Information Directorate 1985). Applying these examples as a model for the premodern era at Kaundinyapura, tannin extracted from *Acacia leucophlaea*, *Acacia nilotica*, and *Anogeissus latifolia* could have been used to convert surplus domestic animals (or wild animals) into hides suitable for exchange, while cloth from locally-produced cotton could have been enhanced by dyes from wild plants such as *Carthamus tinctoris* as well as several *Acacia* species.

Conclusion

Historical documents enable us to develop complex models for early agricultural societies by showing that yield fluctuations require both seasonal and long-term adjustment in crop planning and that wild resources continue to be an important part of agricultural economies. In addition, archaeological evidence for consistent trade activities shows that humans manage their environments for more than just the achievement of biological subsistence. Household viability in a community is not measured merely by human survival but also by the ability to acquire a set of basic goods and to participate in socially integrative activities such as festivals and life-cycle ceremonies in a process that can be characterized as "social subsistence" (Smith 1999:127). Data from the central Indian site of Kaundinyapura show that familiarity with wild species provided additional economic inputs at every level of agricultural productivity. In all years, wild resources were the principal source of fodder, fuel, and medicine, but in bad years they provided a critical fallback to crop failure and in good years they provided additional raw materials for labor-added trade goods.

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