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ANIMAL MANAGEMENT STRATEGIES DURING THE CHALCOLITHIC IN THE LOWER GALILEE: NEW DATA FROM MARJ RABBA (ISRAEL)

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Abstract: *The Chalcolithic period in the Southern Levant witnessed increasing social differentiation and economic specialization. Some of the most important sources of economic specialization were animal products, particularly the secondary products of sheep, goats, and cattle. Also important, though neglected in the literature, were pigs. In this paper, we employ faunal data from the recently excavated site of Marj Rabba in the Lower Galilee. In particular, we investigate kill-off patterns, metrical data, and artifactual data. In order to distinguish between sheep and goats, we applied collagen fingerprinting (ZooMS) techniques to caprine teeth. We compare these data to other Chalcolithic sites in the Southern Levant in order to explore the regional differences in animal management strategies during this crucial period of socioeconomic change. In contrast to sites in the Northern Negev and Tulaylat al-Ghassul, animal management strategies at Marj Rabba were not aimed at specialization. Instead, they emphasized risk-minimization. Additionally, similar to sites in the northern Jordan River Valley, domestic pigs were an important resource. Finally, the cattle remains display numerous traction-related pathologies. These pathologies, coupled with the large proportion of sickle blades and the possible architectural remains of grain silos, suggest an emphasis on grain production. The difference between faunal patterns in the Northern Negev, Golan, Jordan River Valley, and Galilee regions points to a highly diverse animal economy in the Southern Levant during the Chalcolithic.*

Résumé : *Le Chalcolithique (4500-3600 cal. av. J.-C.) du Levant Sud est le foyer d'une différentiation sociale et d'une spécialisation économique accrue. Parmi les principales sources de spécialisation économique figurent les produits d'origine animale, particulièrement les produits dérivés des moutons, chèvres et bovins. Les suidés tiennent également une place importante, bien que négligée dans la littérature. Dans cet article, nous utilisons les informations relatives à la faune provenant du site de Marj Rabba en Basse Galilée. Nous étudions en particulier les courbes d'abattage, les données métriques, ainsi que les artefacts. Afin de distinguer les chèvres des moutons, nous avons analysé l'empreinte collagène (ZooMS) des dents de caprinés. Ces données sont comparées à celles d'autres sites chalcolithiques du Levant Sud afin d'explorer les différences régionales en termes de stratégies de gestion des troupeaux durant cette phase cruciale de changements socio-économiques. À l'inverse des sites du nord du Néguev et de Tulaylat al-Ghassul, les stratégies de gestion des troupeaux à Marj Rabba n'étaient pas destinées à la spécialisation. Elles mettent en revanche l'accent sur la minimisation des risques. De plus, comme dans la vallée septentrionale du Jourdain, les suidés constituaient une ressource importante. Enfin, les restes de bovidés de Marj Rabba montrent un nombre conséquent de pathologies liées à l'activité de traction. Cependant, les courbes d'abattage indiquent que les éleveurs n'ont pas cherché à différer l'âge d'abattage des bovins pour utiliser leur force de traction. Les pathologies suggèrent qu'on mettait en avant la production de grains. La différence entre la faune du nord du Néguev, du Golan, de la vallée du Jourdain et de la Galilée, met l'accent sur une économie des produits animaux extrêmement diversifiée dans le Levant Sud au cours du Chalcolithique.*

Keywords: *Chalcolithic; Southern Levant; Animal management strategies; Kill-off patterns; Marj Rabba.*
Mots-Clés : *Chalcolithique ; Levant Sud ; Stratégies de gestion des troupeaux ; Courbes d'abattage ; Marj Rabba.*

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INTRODUCTION

Animal management strategies provide important insights into subsistence economies, and therefore into socio-political structures. Decisions by herders and farmers relate directly to elite control and economic specialization (D'Altroy and Earle 1985; Crabtree 1990; Stein 1994; Earle 1997; Gumerman 1997; deFrance 2009; Sasson 2010). In the Middle East, the emergence of complex societies in the 5th–4th millennia BC relied upon domestic animal economies. Of increasing importance were the secondary products (milk, wool, traction) of sheep, goats, and cattle (Adams 1981; McCorriston 1997). The evolution of animal management strategies in this critical period thus represents one key aspect of developing social complexity.

The Chalcolithic period (4500-3600 cal. BC)[1] in the Southern Levant (fig. 1) witnessed increased ritual and social integration, the use of new metallurgic technologies, and economic specialization.[2] Key to the sociopolitical changes occurring in the Southern Levant was the specialized production of staple resources. It is clear that, in addition to enhancing the production of grain and fruits, Chalcolithic farmers increasingly emphasized secondary animal products. It remains unclear, however, how the intensive use of secondary products differed between regions. Additionally, scholars have largely ignored the significance of swine husbandry in the Southern Levant. Pigs, while not providing secondary products, have important implications for the evolution of complexity.

This paper addresses these issues through a zooarchaeological analysis of the animal management strategies from the Marj Rabba in the Lower Galilee region. Zooarchaeological patterns show little evidence of specialized control of caprines, contrasting with Chalcolithic sites in the Negev and Tulaylat al-Ghassul in the Jordan River Valley. Meanwhile, Chalcolithic farmers across the Southern Levant utilized cattle for traction, probably to maximize the production of grain. Pigs were present in abundant proportions despite the possible difficulty of accessing water at Marj Rabba. In sum, the data from Marj Rabba suggest a mosaic of animal management strategies across the Southern Levant, reflecting regional differences in economic specialization.

1. See Burton and Levy (2001) for radiocarbon dating of the Chalcolithic.
2. For the variable relationships between economic specialization and social inequality, see Paynter (1989).

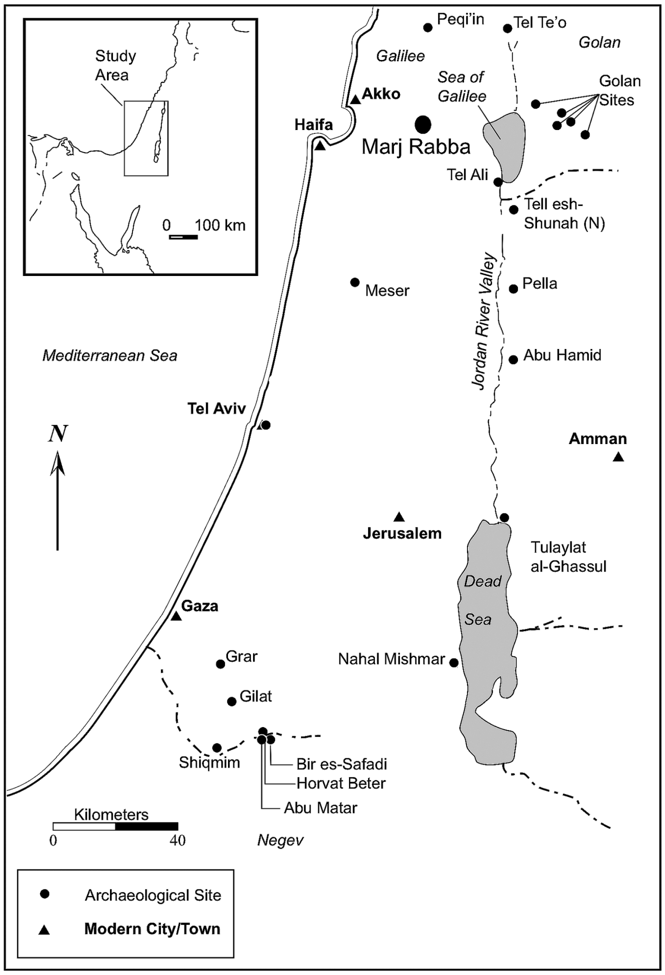

Fig. 1 – *Map of Chalcolithic sites in the Southern Levant.*

STAPLE RESOURCES AND COMPLEXITY IN THE SOUTHERN LEVANTINE CHALCOLITHIC

Social complexity is marked by ranked inequality and specialized production. Comparative anthropological studies of the evolution of complexity (*e.g.*, Binford 1983; D'Altroy and Earle 1985; Gosden 1989; Hayden 1996; Earle 1997) emphasize the role of material goods in the processes of garnering power. Particularly important is the role of surplus staple goods, which elites can employ to mobilize labor and finance ritual activities. The specialized production (*i.e.*, production for exchange) of staple goods tends to generate surplus (Sahlins 1972: 101-148; Flad and Hruby 2007). Thus, the specialization of animal husbandry practices, particularly for

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secondary products, provides a mechanism for the emergence of social complexity (see below).

In the Chalcolithic societies of the Southern Levant, resource production increased in intensity throughout the 5th and 4th millennia BC. Excavations in the Negev and the Jordan River Valley in the 1980s and 1990s revealed evidence for both public ritual centers and economic specialization. Levy (1998) interpreted both of these lines of evidence as suggestive of chiefdoms. However, the fact that burial evidence has failed to show any clear signs of social differentiation (Rowan and Golden 2009: 50-56) argues against this conclusion. Whether 'chiefs' existed or not (see Bourke 2001: 151; Gophna and Tsuk 2005; Rowan and Golden 2009: 67; Lovell 2010), the Chalcolithic in the Southern Levant certainly witnessed an increase in the intensity of production of staple resources. This indicates specialization, and there is now clear evidence at some sites for the specialized production and distribution of key resources, such as copper, ivory, basalt, grain, and pastoral products (Levy 1983 and 1998; Bourke 2001; Commenge and Alon 2002; Garfinkel *et al.* 2009; Rowan and Golden 2009: 66-69; Banning 2010). The latter staple resources were particularly key *foci* of economic intensification. Chalcolithic farmers domesticated olives (Galili *et al.* 1997; Epstein 1998; Meadow 2005; Bourke 2007: 25) and regularly exploited figs, dates, almonds, pomegranates, and pistachios (Rowan and Golden 2009: 24, and references therein). Additionally, herders began to exploit secondary animal products (wool, traction, and milk) in a more intensive manner.

THE SECONDARY PRODUCTS REVOLUTION

The so-called secondary products revolution is one of the most conspicuous topics in the literature regarding Chalcolithic subsistence patterns. A *secondary product* is an animal resource which can be exploited multiple times over the life of an individual animal (Greenfield 1988 and 2010: 30), typically milk, fiber (wool), and traction. Following Sherratt (1981 and 1983), many scholars have discussed the 5th-4th millennia BC as the time in which a change in the pattern of the exploitation of these products occurred (see also Chapman 1982; Greenfield 1988; Zeder 1994a; Vigne and Helmer 2007; Greenfield 2010; Marciniak 2011). Recent research has shown that the first exploitation of secondary products occurred in the Neolithic (see Vigne and Helmer 2007; Evershed *et al.* 2008; Helmer 2008; Helmer et Gourichon 2008). However, as Greenfield (2010: 46) points out, the Chalcolithic was the period in which herders began to specialize in the production of milk, wool, and traction. This was presumably an adaptation to increasingly market-oriented economies in which non-specialized production of pastoral resources could no longer supply the needs of consumers (Zeder 1988: 8). As such, the secondary products revolution represents a fundamental shift from general (risk-mitigating) to specialized (risk-taking) animal management strategies which maximized production.

Detecting secondary products in the archaeological record is hampered by the fact that there is rarely anything but indirect evidence for their exploitation. This particularly plagues research in the Southern Levant. With the notable exception of the preserved woolen (or goat hair) textiles from the Chalcolithic Nahal Mishmar hoard (Greenfield 2010: 36), there is no direct evidence of secondary product use. Claims of intensive exploitation of secondary products must be derived from multiple, indirect sources of evidence. Strong arguments for secondary product exploitation, derived from both artifactual and faunal data, have been made at several of the larger sites in the Southern Levant, such as Gilat (Grigson 2006a; Levy *et al.* 2006b) and Tulaylat al-Ghassul.

At Gilat, churns, which likely were used to store and/or prepare dairy products (Bourke *et al.* 2000; Bourke 2001: 117-118), comprised a significant portion of the ceramic assemblage (n=765, 7.3% minimum number of vessels) (Commenge *et al.* 2006: 398). Meanwhile spindle whorls (n=163) (Levy *et al.* 2006b: 176) and an impressive assemblage of weaving-related bone tools (n=278) (Grigson 2006b: 688) point to the importance of textile production—although it is necessary to recognize that flax (*Linum usitatissimum*) may also have provided the raw material for textile production (McCorriston 1997). These artifactual data correspond to zooarchaeological patterns: cattle, goats, and sheep heavily dominated Gilat's faunal assemblage. Caprines at Gilat were slaughtered at a relatively late age, with sheep outliving goats (Grigson 2006a: 276). Finally, cattle remains recovered from Gilat did not show a large number of traction-related pathologies, possibly indicating a limited use of bovines for plowing and pulling. The Gilat kill-off patterns and the paucity of traction scars parallel the findings at nearby Grar (Grigson 1995).

The faunal and artifactual assemblages at Tulaylat al-Ghassul showed similar patterns. The predominance of cattle and caprines in Chalcolithic layers represents a divergence from Late Neolithic patterns. Moreover, the exploitation of older caprines and cattle from the Neolithic to the Chalcolithic paralleled the increase in churns and weaving-related bone tools (Bourke *et al.* 2000 and 2003; Bourke 2001 and 2007). Like

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Gilat, there is only scattered evidence for the use of cattle as beasts of burden.

While the sites mentioned in the previous paragraph present evidence for a focus on secondary products, it is also clear that such animal management practices were not present at all sites. For example, the kill-off profiles at the Northern Negev site of Shiqmim (Kansa *et al*. 1998) do not indicate intensive secondary product exploitation, despite the presence of churns and weaving tools in small numbers (Levy *et al*. 2006a). Moreover, a study by Smith and Horwitz (1984) of caprine post-cranial bones showed that a significant cortical bone loss, indicating extensive lactation over the lifetimes of female animals, did not occur ubiquitously until Early Bronze Age contexts in the Southern Levant. These cases support the notion that heterogeneous animal management practices defined the southern Levantine Chalcolithic. This becomes more apparent when the evidence from the Galilee and northern Jordan River Valley sites are considered. These data, while scant, seem to tell a different story than sites in the Negev and Western Jordan. Marj Rabba, Tel Ali, and Tel Te'o all lack evidence of secondary product exploitation during the Chalcolithic (Lev-Tov 2000; Horwitz 2001). Instead, inhabitants employed generalized strategies of caprine exploitation along with a significant amount of swine husbandry.

SWINE MANAGEMENT IN THE CHALCOLITHIC

Although pig remains comprise a substantial part of recovered faunal material from many sites in the Southern Levant, few authors have discussed the implications of pig-management. However, the importance of pig production in the Levant in the Chalcolithic is important to consider, especially because of the decrease in the relative abundance of Chalcolithic sites further east (Grigson 2007). There are also important social and environmental implications of pig raising (*e.g.*, Hesse 1990 and 1994; Zeder 1996; Grigson 2007; Ben-Shlomo *et al*. 2009). Pigs have higher water requirements, breed more quickly, and consume different food resources than caprines and cattle. Swine keepers can manage their livestock in a number of ways, varying from intensive to extensive strategies. Because of this variability, pigs may have played several roles in the structuring of social hierarchies. Swine are amenable to household-level production beyond the purview of controlling elites (Zeder 1988; 1991 and 1994b). On the other hand, being quick-breeding fat- and calorie-rich animals, pigs are also an ideal animal for power-related feasting rituals (see Rappaport 1968; Ben-Shlomo *et al*. 2009).

Most readers are familiar with heavily confined pig populations living in sties or pens and feeding on garbage. However, less spatially restrictive forms of management are also documented. An example comes from the pannage system in medieval England in which domestic populations of pigs were allowed to roam in forests, free to feed on mast and roots but under a closely controlled management system (Grigson 1982). In fact, such a system may have given rise to domesticated pigs in the Middle East (Ervynck *et al*. 2001). Less acknowledged is the possibility of transhumant swine husbandry. Archaeologists, following Flannery (1983: 183), tend to assume that pig raising and mobility are incompatible. While this may be true in the majority of cases, Albarella and colleagues (2011) describe a system of swine herding in modern-day Sardinia in which domestic pig populations are herded and driven to different pasture lands:

> "[T]he pigs would spend the winter in the mountains and the summer in the plains, as this, in terms of food availability, was the most efficient strategy. The distance covered by this journey could be substantial, 100 km or more… [u]p to 100 to 150 animals could be driven along this route, under the guidance of two or three herders." (Albarella *et al*. 2011: 15)

We must re-evaluate the long-held belief that only sedentary farmers occupied sites bearing high relative frequencies of pig bones (*e.g.*, Gilead 1989b: 389).

Pig management has been dismissed under the false assumption that domestic pigs require very specific management: *i.e.*, sedentary communities and societies. However, both the historical and ethnographic data mentioned above show that pig management is anything but standardized, with possibilities ranging from intensive penning to extensive transhumant swine herding. This is particularly the case in Mediterranean climates, such as the Galilee, where the abundance of tree cover, mast, and rain allows for less restrictive management systems.

THE SITE OF MARJ RABBA AND ITS ENVIRONS

The faunal remains from Chalcolithic Marj Rabba provide an important dataset with which to understand animal management strategies, and by implication socio-economic patterns, in the Galilee. Unlike the Negev and the Jordan River

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Valley, very little data exist from this region for this period. Marj Rabba thus offers an opportunity to explore the apparent heterogeneity in Chalcolithic animal management practices across the Southern Levant.

Marj Rabba is a single-period Chalcolithic site excavated since 2009 by the Oriental Institute at the University of Chicago's Galilee Prehistory Project. With Chalcolithic artifacts covering an area of *ca* 4 hectares, Marj Rabba is large by comparison with other known sites in the region. Furthermore, Marj Rabba represents one of the only Chalcolithic village sites in the Galilee to undergo extensive, non-rescue excavation and analysis. At least four phases of architecture are evident. Although radiocarbon dates have yet to be obtained, all phases have been associated with Chalcolithic ceramics and lithics. The architecture consists of the stone foundations of large rectangular houses, as well as a series of 2-3 meter circular stone features, which are vaguely similar to ones found at Abu Hamid (G. Dollfus, personal comm.). These circular features may have functioned as grain silos, although it is also possible that they functioned as raised areas for drying skins or storage. If the interpretation that these structures were grain silos stands, this would suggest that large-scale storage of cereals was present, perhaps a significant fact with respect to increasing social differentiation based on surplus staple products. The faunal remains from Marj Rabba derive mostly from decayed mud-brick fill lying about 50 cm below the topsoil. No strong correlations were found in the faunal assemblage according to context. For this reason, the faunal assemblage from Marj Rabba is treated as contextually homogenous.

MATERIALS AND METHODS

RECOVERY, PREPARATION, AND IDENTIFICATION

Faunal material was collected during the 2009-2011 excavation seasons using 5 mm sieves. All remains were washed with water, and some specimens were soaked in 5% acetic acid for several hours to remove calcrete deposits. After soaking, these remains were rinsed thoroughly with water to prevent further degradation of the bone matrix. Hebrew University's Department of Evolution, Systematics, and Ecology and the Zooarchaeology Laboratory at the University of Haifa provided comparative collections. The full results of the faunal analysis will be published elsewhere. See Table 1 for NISPs of recovered fauna.

Table 1 – *NISPs of fauna recovered from Marj Rabba 2009-2011.*

Taxon	NISP
Mammals	
Bos taurus	251
Ovis/Capra	1107
Capra hircus	112
Ovis aries	69
Sus scrofa	790
Gazella gazella	41
Dama d. mesopotamica	4
Hyaena sp.	1
Canis cf. *familiaris*	19
Vulpes cf. *vulpes*	10
Felis sp.	3
Martes cf. *foina*	2
Ursus cf. *arctos*	1
Ovis/Capra/Gazella	154
Bovid	10
Canid	2
Cervid	5
Med. bovid/cervid	193
Lg. bovid/cervid	9
Sm. Carnivore	6
Sm. Mammal	150
Med. Mammal	3307
Lg. Mammal	514
Microfauna	
Microtus sp.	29
Spalax sp.	73
Cricetinae	5
Pelobates syriacus	1
Gerbillinae	13
Micromammal	143
Reptiles, Birds, Fish	
Testudo graeca	66
Galliform	2
Raptor	2
Serpentes	8
Lg. Bird	2
Med. Bird	5
Sm. Bird	3
Fish (not determined)	7
Not Identified	10162
Grand Total	**17100**

KILL-OFF PROFILES

Epiphyseal fusion and tooth wear represent *skeletal ages* indicative of ontological development, *not calendar ages*. One can, however, associate approximate age ranges with each skeletal age (Payne 1973; Watson 1978; Deniz and Payne 1982). In this study, mandibular cheek teeth distal to the third premolar (*i.e.*, (d)P4, M1, M2, M3) were analyzed for wear and

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grouped into wear stages (Payne 1973 and 1987; Grant 1982). Post-depositional breakage of mandibles coupled with the fact that older animals have more cheek teeth than younger animals can cause over-counting; to reduce these effects, only dP4s, M3s, and whole mandibles were used to generate kill-off profiles (following Stein 1987). This is possible because pigs, cattle, and caprines typically shed the dP4 before the third molar comes into wear. To avoid double-counting individuals, only dP4s with roots were counted.

Similar to mandible wear stages, elements that undergo contemporaneous epiphyseal fusion can be grouped into different fusion groups (Silver 1969; Noddle 1974; Bull and Payne 1982; Bullock and Rackham 1982; Moran and O'Connor 1994; Hongo and Meadow 1998; Zeder 2006). By plotting the proportion of fused elements in each group, one can detect herd kill-off patterns. Differential preservation of certain elements, however, can bias these results. Since epiphyseal fusion data and the tooth wear data matched each other, only teeth are used for caprines and pigs. Because too few cattle mandibular remains were recovered, the epiphyseal fusion data are used to generate *Bos* kill-off profiles.

Since skeletal remains from younger animals are both smaller and more fragile than those from older animals, a taphonomic bias may lead to an under-representation of young animals (Munson 2000; Munson and Garniewicz 2003). This is a serious problem for any analyst attempting to document age-related culling patterns. Although the rigorous use of sieving at Marj Rabba mitigates the problem of differential recovery, the possibility of differential survivorship remains an obstacle.

ZOOARCHAEOLOGY BY MASS SPECTROMETRY (ZOOMS)

One of the most problematic aspects in dealing with kill-off profiles from sheep and goats is the difficulty in distinguishing these taxa. While several good indicators are available for identifying to species the post-cranial bones of caprines (Zeder and Lapham 2010), separating teeth and mandible fragments is less reliable (Zeder and Pilaar 2010). This is unfortunate because mandibular teeth are less subject to differential taphonomic bias than post-cranial remains.

Because herders tend to develop different production strategies for sheep and goats, separating archaeological kill-off profiles according to species is vital to understanding animal management strategies. In order to distinguish sheep from goat remains in the Marj Rabba assemblage, dentine and mandibular cortical bone were subjected to collagen fingerprinting (ZooMS) by M. Buckley at the University of Manchester. This method employs a mass spectrometer to determine the masses of peptides in bone collagen. Because there are several differences in the amino acids in the peptides in sheep and goats, ZooMS distinguishes between the caprine taxa in archaeological assemblages (see Buckley *et al.* 2010; Buckley and Kansa 2011). Collagen fingerprints were obtained following modified methods to those described elsewhere.[3] This study represents the first application of ZooMS to Southern Levant Chalcolithic fauna.

BIOMETRY

Post-cranial elements and some teeth were measured following standardized methods (Driesch 1976). Measurements of both fused and unfused long bone end breadths were taken on pigs, cattle, and caprines. These values were converted to Log Size Index values (LSI), following Meadow's (1999) suggestions, employing the formula $LSI_X = \log_{10}(M_S) - \log_{10}(M_X)$, where M_S is the measurement of a standard animal[4] and M_X is the measurement of an archaeological specimen. The coefficient of variation (CV), a normalized measure of spread calculated by dividing the standard deviation by the mean of a distribution, can be used to discern the presence of two or more statistical populations (Payne and Bull 1988). Unfortunately, because the LSI calculation involves a logarithmic transformation, one cannot employ CV as an analytical device. It can, however, be used for non-transformed measurement data (as in table 2).

RESULTS

RELATIVE FREQUENCIES OF TAXA

It is clear that the animal economy of Marj Rabba was heavily dependent on domestic species. Wild taxa—primarily mountain gazelle (NISP = 41) and tortoise (NISP = 64)—account for only 5.7% of the identified taxa. The majority of the domestic taxa belong to caprines, although pigs represent over one third of the assemblage. It is important to note that zoo-

3. See Buckley *et al*. 2009 and appendix.
4. Standards used in this paper: cattle (Degerbøl and Fredskild 1970), pigs (Payne and Bull 1988), sheep and goats (Uerpmann and Uerpmann 1994).

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archaeological remains do not reflect relative herd population size. This is particularly the case for pigs. Since swine breed more quickly and in higher numbers than sheep, goats, and cattle, relatively fewer breeding pairs are required to account for zooarchaeological remains.

The relative proportions of taxa from Marj Rabba are similar to Chalcolithic assemblages in the northern Jordan River Valley and western lowlands (table 2): Tel Te'o, Tel Ali, Meser,[5] and Tell esh-Shuna (Baird and Philip 1994; Grigson 1998; Lev-Tov 2000; Horwitz 2001; Ben-Shlomo *et al*. 2009). Swine are more prominent at Tell esh-Shuna and Meser, while cattle are better represented in the small Tel Te'o assemblage, though this could be due to a lack of rigorous sieving. The very small sample of faunal remains from several Chalcolithic Golan sites (Davis and Grigson 1998) differs strikingly from Marj Rabba and proximate sites. The faunal patterns from the Negev region and Tulaylat al-Ghassul are also quite different.

Table 2 – *Relative frequencies of taxa from Chalcolithic sites in the Southern Levant.*

Site	Cattle	Caprines	Pig	Citation
NEGEV				
Shiqmim (n=304)	15.5%	84.2%	0.3%	Levy *et al.* 1991
Grar (n=1185)	23.1%	60.5%	16.4%	Grigson 1995
Gilat (n=6182)	15.5%	70.7%	13.8%	Grigson 2006
Abu Matar (n=165)	7.3%	92.7%	0.0%	Grigson 1998
Horvat Beter (n=173)	9.8%	90.2%	0.0%	Grigson 1998
Bir es-Safadi (n=3483)	9.0%	90.9%	0.0%	Grigson 1998
JORDAN RIVER VALLEY				
Tulaylat al-Ghassul (n=3771)	14.5%	76.9%	8.5%	Bourke *et al.* 2000
Abu Hamid (n=348)	32.7%	41.4%	25.9%	Dollfus *et al.* 1988
Pella (n=841)	30.1%	50.1%	19.9%	Bourke *et al.* 2003
Tell esh-Shuna N (n=313)	15.0%	38.6%	46.3%	Baird & Philip 1994
Tel Ali (n=111)	14.6%	49.4%	36.0%	Lev-Tov 2000
LOWLAND COAST				
Tel Aviv Jabotinsky St (n= 579)	25.4%	63.6%	11.1%	Grigson 1998
Meser (n=361)	23.3%	28.5%	48.2%	Grigson 1998
GALILEE/GOLAN				
Marj Rabba (n=2148)	**11.7%**	**51.5%**	**36.8%**	**this paper**
Tel Te'o (n=161)	49.1%	34.0%	29.8%	Horwitz 2001
Golan Sites (n=52)	30.7%	65.4%	3.8%	Davis & Grigson 1998

PIGS

The high proportion of pig remains at Marj Rabba speaks against a strong reliance on pastoral products. That being said, prehistoric Middle Eastern sedentary communities in well-watered areas often relied on pigs (Grigson 2007). Communities dependent on pastoral products might raise pigs to supplement the supply of sheep and goats. However, the fact that around one third of the faunal remains recovered from Marj Rabba were pigs suggests that pork was an important staple resource, not an occasional food.

Although wild boar inhabits the Galilee region today, all *Sus* remains recovered from Marj Rabba represent domestic animals based on dental and post-cranial metrics (table 3; fig. 2). Measurements on tooth widths (table 4), which are extremely useful for discerning different populations (*i.e.*, wild *vs* domestic) of pigs (Payne and Bull 1988), were small and consistently showed very low CV values, indicating that the remains derive from a domestic population. The Marj Rabba upper and lower first molar anterior cusp widths (WA) are significantly smaller than those from modern southern Levantine wild boar (M_1WA: $t = 5.946$, $P_{2\text{-tailed}} < .0001$; M^1WA: $t = 8.438$, $P_{2\text{-tailed}} < .0001$).[6] The post-cranial LSI values for Marj Rabba pigs are also significantly smaller than early domestic pigs from Late Neolithic (Level 4) Hagoshrim ($t = 7.951$, $P_{2\text{-tailed}} < .0001$) (A. Haber, personal comm.; see Haber and Dayan 2004).

Table 3 – *Pig tooth biometric data showing very low coefficient of variation values indicative of a single population. WA = width of anterior cusp. See Table 4 for individual measurements.*

Tooth	N	Mean WA (mm)	Stand. Dev.	Range	CV
dP^4	10	10.38	0.57	9.1-11.3	0.055
M^1	9	12.84	0.29	11.8-13.9	0.042
M^2	11	15.75	0.85	14.2-17.1	0.054
M^3	5	15.96	1.02	14.7-17.0	0.064
dP^4	12	6.21	0.10	5.5-6.8	0.054
M^1	11	10.05	0.15	9.3-11.0	0.049
M^2	9	13.02	0.17	12.0-13.8	0.040
M^3	7	14.51	0.24	13.6-15.4	0.044

Figure 3 shows the kill-off patterns inferred from the *Sus* dental remains. The results indicate that about one half of pigs was culled before *ca* one year, while the vast majority was culled before *ca* two years. Although not evident in the tooth-based kill-off patterns shown in Figure 3, a fused proximal humerus, calcaneus, and proximal ulna indicate that some pigs lived beyond their second year. These patterns are very similar to the kill-off patterns of pigs from Late Neolithic Hagoshrim (Haber and Dayan 2004: 1593), as well as from Chalcolithic Grar (Grigson 1995) and Gilat (Grigson 2006a)

5. The details of this excavation, however, are obscure; see Dothan 1959.
6. Data from Kusatman 1991.

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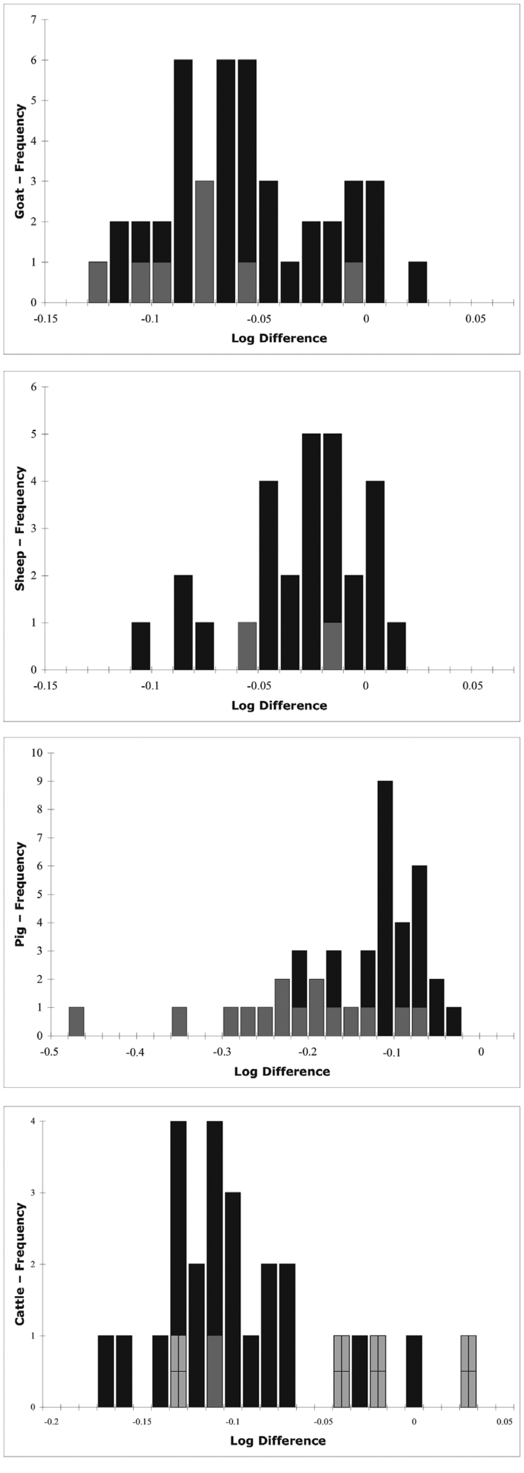

Fig. 2 – *LSI histograms for goats (n=43; standard animal in Uerpmann and Uerpmann 1994: Table 14), sheep (n=28; standard animal in Uerpmann and Uerpmann 1994: Table 12), pigs (n=41; standard animal in Payne and Bull 1988: 40-41), and cattle (n=22; standard animal is the 'Ullerslev cow' in Degerbøl and Fredskild 1970). (Gray bars: unfused remains; black bars: fused specimens. In the cattle histogram, crossed bars: distal metatarsal measurements)*

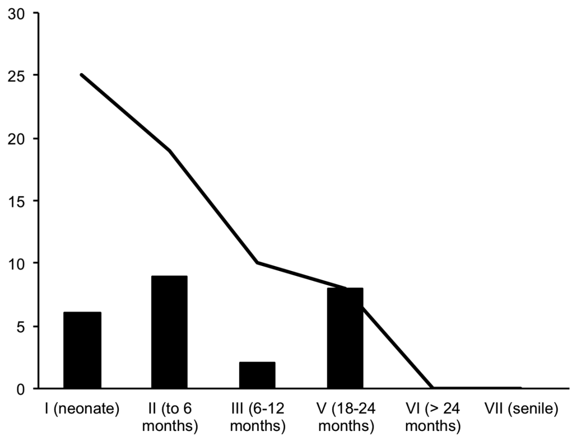

Fig. 3 – *Kill-off data for pigs (based on Ervynck* et al. *2001), and excluding age class IV as discussed by Ervynck* et al. *(2001); n=25. Bars represent frequencies in each age category, while the line shows herd attrition.*

in the Northern Negev, suggesting a temporal and spatial continuity in certain swine management practices.

From the metrical data and kill-off patterns, the management of swine at Marj Rabba seems similar to that in the Northern Negev. However, important differences in swine management may relate to the unique geography of the site. One of the most perplexing problems of Chalcolithic Marj Rabba is its water management. The closest modern source of permanent water is over 1 km away. It is possible, however, that the inhabitants of Marj Rabba built cisterns to trap rainwater, or that there was a still undetected permanent source of water nearby which has since dried up. Future research by the Oriental Institute will attempt to address these possibilities. Whatever the case may have been, daily access to water, especially when temperatures rise above 30°C, is a physiological necessity for pigs (see Choquenot and Ruscoe 2003). This raises the possibility that pigs may have been herded in the environs of Marj Rabba, rather than penned. Such a management strategy may have involved semi-specialized swineherds, as in the English pannage system (Grigson 1982). Several zooarchaeological studies of Middle Eastern sites in parkland environments have concluded, based on almost identical kill-off patterns and environmental conditions to Marj Rabba, that a pannage-esque management system was in place (*e.g.*, Stein 1988; Ervynck *et al.* 2001). Similarly, among the Tsembaga, Rappaport (1968) reported that women raised pigs to forage during the day and return to their houses at night. Both of these management scenarios would have allowed Marj Rabba inhabitants to take advantage of off-site water and mast resources.

Table 4 – *Individual measurements of* Sus *tooth widths.*

Catalogue No.	*Sus* Tooth Type	Width Anterior (mm)	Width Posterior (mm)
4790	dP_4	5.5	7.9
7470	dP_4	5.9	7.3
1455	dP_4	6	8
2725	dP_4	6	7.9
3802	dP_4	6.1	8.1
8019	dP_4	6.2	
1575	dP_4	6.3	8.5
4824	dP_4	6.3	
7462	dP_4	6.3	8.2
4857	dP_4	6.4	7.9
6452	dP_4	6.4	8.2
803	dP_4	6.5	8.5
1113	dP_4	6.8	8.6
600	dP_4		7.5
7726	dP_4		8.4
1513	dP^4	9.1	10.2
7851	dP^4	10	10.3
2306	dP^4	10.2	11.4
1491	dP^4	10.4	10.5
2290	dP^4	10.4	10.7
2628	dP^4	10.4	11.4
7661	dP^4	10.5	11.2
2205	dP^4	10.7	
3579	dP^4	10.8	10.8
4076	dP^4	11.3	
600	M_1	9.3	
3007	M_1	9.6	10.5
6429	M_1	9.6	10
2294	M_1	9.7	10.7
7462	M_1	9.9	10.2
6211	M_1	10.1	9.6
7726	M_1	10.2	
2908	M_1	10.3	
2951	M_1	10.3	10.7
803	M_1	10.6	10.9
1758	M_1	11	
3981	M_1		10.4
3657	M^1	11.8	12.1
2628	M^1	12.7	12.6
7710	M^1	12.7	13.1
2205	M^1	12.8	13.4
4640	M^1	12.8	13.1
2290	M^1	12.9	13.5
3290	M^1	13	
7938	M^1	13	13.4
3801	M^1	13.9	
6429	M_2	12	12.1
1455	M_2	12.6	
3007	M_2	12.9	13.8
6211	M_2	12.9	12.5
2294	M_2	13	13.3
3007	M_2	13.2	
1416	M_2	13.3	
7709	M_2	13.5	13.6
3582	M_2	13.8	13.8
6629	M_2		13.1
3657	M^2	14.2	14.3
1905	M^2	14.6	14.6
6639	M^2	15.1	15.2
6441	M^2	15.4	14.9
7710	M^2	15.9	15.5
3929	M^2	16	
4640	M^2	16	15.5
4704	M^2	16	15.9
7938	M^2	16.4	
3290	M^2	16.5	16
7896	M^2	17.1	16.9
1631	M_3	13.6	
5036	M_3	13.8	
3007	M_3	14.4	
3007	M_3	14.7	
3582	M_3	14.8	
1407	M_3	14.9	
1133	M_3	15.4	
3657	M^3	14.7	
4704	M^3	15.4	
1905	M^3	15.7	
3929	M^3	17	
7896	M^3	17	

CAPRINES

Remains identified as sheep or goats comprise almost half of the Marj Rabba assemblage by NISP. Since caprines have the potential to produce both fiber and milk, analysts working in the Chalcolithic have given serious attention to kill-off profiles of these animals. While noting that secondary products may be exploited without influencing kill-off patterns, the intensive management of caprines for secondary products should cause changes in them.

Figure 4 shows the kill-off patterns in sheep and goats as a result of the ZooMS test on caprine mandibles (see also table 5). Interestingly, the kill-off patterns for both sheep and goats best conform to Redding's security model (Redding 1981), with heavy culling beginning around 6-12 months of age (wear stage C) and only some (female) caprines surviving into late adulthood. The similarity between the Marj Rabba kill-off pattern and Redding's security profile is consistent with an interpretation of a management strategy emphasizing risk mitigation. The patterns contrast with the expectations for

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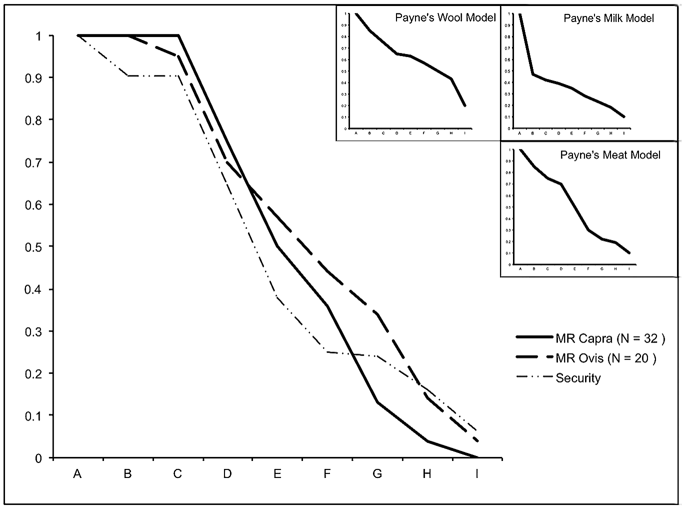

Fig. 4 – *Kill-off data for caprines (based on Payne 1973 and 1987) compared to Redding's (1981) security profile; n=52, with Payne's (1973) models for wool, milk and meat.*

a management strategy emphasizing the specialized production of secondary products.

The lack of evidence for the intensive production of wool is somewhat of a surprise given the large number of loom technology artifacts discovered at Marj Rabba. In addition to several spindle whorls,[7] 41 fragments of perforated bone spatulae were found.[8] These tools were probably used as loom shuttles. Also found were 33 awl points, perhaps also used for weaving (see Grigson 2006b: 689-690). Clearly, as at Gilat (Grigson 2006b; Levy *et al.* 2006b), the textile industry at Marj Rabba was important. However, this did not influence the management of caprine resources in terms of the proportions of older animals or the ratio of sheep to goats. Although it is possible that the textile industry at Marj Rabba was based on flax rather than animal fibers, it is likely that wool, like milk (see below), was exploited, but not in an intensive (*i.e.*, specialized) manner.

Goat remains outnumber those of sheep in the Marj Rabba assemblage in the ratio 1:1.6. Herders might have preferred goats for their milk production, as goats produce more milk than sheep (Dahl and Hjort 1976: 210-212). However, there is no evidence for intensive milk production at Marj Rabba. Although taphonomic processes preferentially eliminate juvenile remains, given the paucity of very young animals in the *Ovis* and *Capra* kill-off profiles, it is unlikely that an intensive strategy of milk exploitation strategy was present at Marj Rabba. The lack of churns, compared to Gilat (Commenge *et al.* 2006), corroborates this

7. However, spindle whorls were not as abundant at Marj Rabba as at Gilat.
8. Classification follows Garfinkel and Horwitz (1988).

Table 5 – *Caprine mandible analyzed using the ZooMS technique, with morphological identification indicated when determined.*

Mandible No.	Locus	Side (R/L)	Teeth Present	Wear Stage	Morph. ID	ZooMS ID
939	16	R	dP4, M1	B		*Ovis*
136	1	L	dP4, M1	C	*Ovis*	*Capra*
1043	20	R	dP4, M1	C		*Capra*
2609	43	R	dP4, M1, M2	C	*Capra*	*Capra*
6545	627	R	dP4	C		*Capra*
6616	627	L	dP4, M1	C	*Capra*	*Capra*
8113	921	R	dP4, M1, M2	C		*Capra*
1838	40	L	dP4, M1, M2	C		*Ovis*
3203	43	R	dP4, M1, M2	C		*Ovis*
6544	627	R	dP4	C	*Ovis??*	*Ovis*
7538	711	R	dP4, M1	C	*Ovis*	*Ovis*
3147	214	L	dP4	C-D		*Capra*
7007	711	L	dP4	C-D		*Capra*
7833	927	L	dP4	C-D		*Capra*
8028	717	R	dP4	C-D		*Capra*
4882	616	R	dP4	C-D		*Ovis*
6022	619	R	dP4	C-D		*Ovis*
304	13	R	P4, M1, M2, M3	D		*Capra*
885	20	R	dP4, M1, M2	D	*Capra*	*Capra*
1750	40	L	M2, M3	D		*Capra*
2286	43	R	P4, M1, M2, M3	D		*Capra*
3649	223	L	dP4, M1, M2, M3	D		*Capra*
7206	625	L	dP4, M1	D		*Capra*
6229	620	L	dP4, M1, M2	D	*Ovis?*	*Ovis*
7274	918	R	M3	D-E		*Ovis*
890	20	L	P4, M1, M2, M3	E	*Ovis*	*Capra*
6063	709	L	M2, M3	E		*Capra*
6280	918	R	M3	E		*Capra*
7954	649	L	P4, M1, M2, M3	E	*Capra*	*Capra*
154	1	R	M3	E		*Ovis*
3322	44	L	P4, M1, M2, M3	E	*Capra?*	*Ovis*
1182	8	L	M1, M2, M3	E-G		*Capra*
112	13	L	M3	F		*Capra*
732	9	L	M3	F		*Capra*
733	9	R	M3	F		*Capra*
4124	600	R	M3	F		*Capra*
6275	916	R	M3	F		*Capra*
7190	625	R	P4, M1, M2, M3	F	*Capra*	*Capra*
8046	723	R	M3	F		*Capra*
1753	40	R	P4, M1, M2, M3	F	*Ovis*	*Ovis*
3749	43	L	M3	F		*Ovis*
7735	711	R	M2, M3	G		*Capra*
749	9	R	M2, M3	G		*Ovis*
7428	718	L	P4, M1, M2, M3	G	*Ovis*	*Ovis*
225	1	L	M3	G-H		*Capra*
4151	609	R	M3	G-H		*Capra*
4665	908	R	M3	G-H		*Capra*
379	13	R	M3	G-H		*Ovis*
1742	40	L	M3	G-H		*Ovis*
2891	210	L	M3	G-H		*Ovis*
5080	620	L	M3	G-H		*Ovis*
3014	43	R	M2, M3	I		*Ovis*

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conclusion. Nevertheless, the presence of some churn sherds at Marj Rabba suggests that dairy products were exploited.

Biometrically, the caprines clearly belong to small-sized domestic stocks (fig. 2). Sexual dimorphism is particularly pronounced in goats, a fact which is reflected in the Marj Rabba data. The *Ovis* LSI values are fairly normally distributed, while the *Capra* LSI values show a more bimodal distribution. This reflects the fact that goats tend to be more sexually dimorphic than sheep. Moreover, the presence of castrates creates a third mode in the breadth and width measurements, obscuring the otherwise apparent difference between intact males and females.

One of the most important and difficult questions relates to the possibility that nomadic or transhumant pastoralists supplied Marj Rabba with caprines (Sasson 2010: 14). Such a specialized system of management would have serious implications for nascent elites attempting to control subsistence resources. Nomadic pastoralists tend to drive their herds from the lowlands to the highlands in the summer, and vice versa in the winter (*e.g.*, Salzman 1971; Cribb 1991a and b). Since births occur primarily in winter (Epstein and Herz 1964; Dahl and Hjort 1976; O'Connor 1998), one would expect that relatively lowland sites such as Marj Rabba should show a greater proportion of 0-6 and 12-18 month old caprines and few 6-12 month olds. Unfortunately, the kill-off data is ambiguous: there are very few specimens < 1 year old. However, both age categories are represented. The possibility remains that pastoralists provided caprines in addition to what local farmers raised on site, but this is impossible to test under the given methods. Additionally, archaeological surveys indicate no evidence of ephemeral pastoral camps as in the Negev (Gilead 1989a; Shalem 2008), although this could be an artifact of non-intensive survey techniques. Overall, the data tentatively suggest that the caprine management strategy involved what Abdi (2003) called a village-based herding strategy. That is, local Marj Rabba pastoralists moved their flocks between proximal pastures, rarely staying away from the site for more than a few days.

In sum, the Marj Rabba data point to a focus on herd security and growth by local sheep and goat pastoralists. This exploitation pattern is similar to that inferred from the kill-off material at Tel Ali (Lev-Tov 2000) and also for the PPNB (Makarewicz 2009), indicating a relatively stable exploitation strategy in the region and over time. Combined with the fact that there is no clear evidence for nomadic pastoralists, the data argue for household-level, risk-mitigating production of sheep and goats. Secondary products were exploited, as the presence of the loom technology artifacts and a few churn sherds document. However, the Chalcolithic herders at Marj Rabba were concerned with ensuring subsistence dependability by eschewing risky management decisions emphasizing the production of caprine secondary products.

CATTLE

The kill-off patterns for cattle (table 6), though more ambiguous than the data for sheep and goats due to small sample sizes, similarly indicate that secondary products were not the primary objective of herding strategies during the Chalcolithic. Both the tooth wear and eruption data and the epiphyseal fusion data show that over half of the cattle were killed before they reached around three years of age. Under a heavily milk-emphasizing strategy, herders would cull the majority of male calves, keeping a few for breeding purposes and to induce milk let down (Ryan 2005). The fact that there are very few young cattle in the assemblage indicates that herders did not exploit milk intensively. The cattle kill-off profile portrays an emphasis on 2-4 year old cattle, consistent with a meat-emphasizing economic strategy (Tresset 1996; Vigne and Helmer 2007: 12). Moreover, the kill-off profile lacks a large portion of older animals, which would be expected if traction were important. However —and this points to certain problems with depending too heavily on kill-off profiles to infer management strategies—the frequency of traction-specific pathologies on cattle distal metatarsals and first phalanges documents the fact that cattle were, indeed, intensively used for traction.

Johannsen (2011: 17) employed ethnographic data to compare draught exploitation of cattle, concluding that there is a high degree of variability in the ages and sexes of cattle, as well as in the length of time for which the cattle are employed. On the other hand, when detected, pathologies on the distal hind limbs of cattle are the most conspicuous indicators of traction in the archaeological record. The differential weight distribution placed on draught cattle causes remodeling on the bone, notably

Table 6 – *Kill-off data for cattle (age classes from Hongo 1998: Table 10.1).*

Fusion Group	Elements	Estimated Age (months)	Fused	Unfused	Percent Fused
I	Ds. Scap., Px. Rad., Acetabulum	6-12	9	0	100.0%
II	Ds. Hum., Ph. 1, Ph. 2	12-18	16	2	88.9%
III	Ds. M/carpal, Ds. M/tarsal, Ds. Tib., Calc.	24-42	19	7	73.1%
IV	Px. Hum., Ds. Rad., Px. Ulna, Px. Fem., Ds. Fem, Px. Tib.	42-48	2	10	16.7%

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the widening of the medial trochlea in metatarsals and 'lipping' of the proximal end of first phalanges, and exostotic growth (Bartosiewicz *et al.* 1993; De Cupere *et al.* 2000). Of seven complete cattle distal metatarsals recovered, four displayed pronounced widening of the medial trochlea, and one with slight widening (fig. 5; table 6). This widening can be seen in the four measured distal metatarsals in the cattle LSI histogram (fig. 2). Exostotic growth was recorded on two metatarsals. Of the 19 first phalanges in the Marj Rabba assemblage with surviving proximal portions, two displayed lipping and exostotic growth.

The sample size of biometrical data for cattle from Marj Rabba is too small to reach any concrete conclusions. The distribution (see fig. 2) is notable for being normal with a high degree of peakedness (kurtosis = 1.70). Cattle, like goats, are quite sexually dimorphic and LSI values should form two modes. It is possible, however, that the remains of castrates with intermediate breadth measurements have blurred the expected bimodality. This conclusion makes sense given the high number of traction marks, as oxen are typically used for draught purposes. Additionally, as noted above, the traction related elongation of the distal metatarsals created a right skew. This highlights the ability of biometrical methods to detect patterns in faunal assemblages beyond age, sex, and domestication status (Albarella 2002).

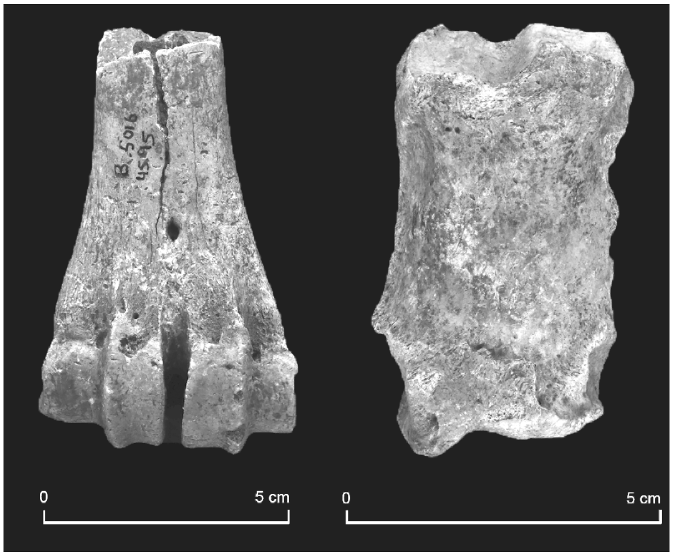

Fig. 5 – *Examples of traction pathologies. Left, medial elongation of* Bos *distal metatarsal trochlea; right, exostotic growth on first phalanx (photos by A.C. Hill).*

DISCUSSION AND CONCLUSIONS

The faunal data from Marj Rabba provide answers to a number of questions relating to Chalcolithic animal management practices in the Southern Levant. The patterns in the Galilee represented by Marj Rabba differ from those in the Negev, Golan, and Tulaylat al-Ghassul. In the Galilee and northern Jordan River Valley, the relative importance of swine was greater. Additionally, caprine herder emphasized risk-minimization. Their counterparts at Grar, Gilat, and Tulaylat al-Ghassul, while still promoting herd security and growth,[9] accepted more risk in order to increase the production of wool and milk. Farmers at Marj Rabba, meanwhile, employed cattle as beasts of burden. However, this did not affect the overall management of cattle herds.

Although the lack of animal product specialization at Marj Rabba contrasts with contemporaneous developments to the south, the faunal data do not rule out an increasing focus on staple resources. In the wetter areas of the Southern Levant, such as the Galilee, the focus may instead have been grain production. This hypothesis finds independent confirmation in the large number of sickle blades in the Marj Rabba lithic assemblage. Moreover, circular structures, possibly grain silos, were a prominent architectural feature. These resemble silo installations at 6th millennium Tsaf in the Jordan River Valley (Garfinkel *et al.* 2009), although G. Dollfus (personal comm.) believes that similar features at Abu Hamid, in modern day Jordan, represent the remains of stone platforms for drying skins or fruits. Whatever architectural interpretation proves correct, the heavy use of cattle for traction and the numerous sickle blade fragments support the conclusion that grain was intensively cultivated beyond subsistence needs at Marj Rabba. Oxen would have provided an important source of labor for cereal production, especially in the karstic, clay-rich soils around Marj Rabba. Employing cattle as agents of traction would have greatly increased the cereal output of farmers in the Chalcolithic farming communities by increasing the amount of labor expendable by a household. For this reason, Bogucki (1993) has argued that cattle became an important source of social differentiation, especially when certain households, unable to mobilize enough labor, became dependent on others. The fact that the kill-off profiles for cattle indicate an emphasis on prime-age animals suggests that the use of oxen was not a production strategy, but rather a by-product of a cattle keeping economy in need of extra labor to increase cereal output.

Similarly, there is no evidence that specialized herders of sheep and goats were operating in the lower Galilee during the

9. While different from a security-based model, the kill-off patterns at the sites do not fit well with Payne's (1973) ideal models for secondary product maximization; see Grigson 1995 and 2006a; Bourke 2001.

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Chalcolithic, as suggested for the Northern Negev (Levy 1983 and 1992; Grigson 1987; Levy *et al.* 1991; Grigson 1995 and 2006a) and Tulaylat al-Ghassul (Bourke *et al.* 2000; Bourke 2001). Marj Rabba did not serve as either a stopover point for transhumant herders wintering in the lower highlands, nor did it serve as summer pasture for Negev herders. Instead, local villagers at Marj Rabba managed caprines. Although secondary products were important, herders did not accept the risk of losing their herds in order to maximize secondary production.

Domestic pigs were an important source of calories and protein. These animals, however, require extensive shading and watering in the summer months. It is possible, therefore, that swine herders raised pigs off-site, perhaps housing them onsite at night. The sociopolitical implications of this strategy are unclear. Zeder (1994b and 1996) has linked pig husbandry to a lack of elite control and specialization. The importance of pigs at Marj Rabba and elsewhere in the region might therefore speak to a less market-oriented economic strategy than further south. However, one should not discount the possibility that specialized swine herders existed in the Southern Levant, as in medieval England (Grigson 1982). Additionally, pigs often serve as living trash disposal units for settlements (Miller 1990; Malcolmson and Mastoris 1998; Vila 1998; Schiere and van der Hoek 2001). Raising pigs to scavenge settlement refuse, to this day, remains one of the most common and cost-effective husbandry strategies in small-scale agricultural villages (FAO 2010: 11-12). Villagers gain an inexpensive food resource as well as waste management system, while pigs acquire a highly dependable food resource. In sum, the complimentary food resources of domestic waste and tree mast likely made extensive swine husbandry an effective strategy at Marj Rabba.

Taken together, the animal management strategies employed for caprines, swine, and cattle at Marj Rabba reflect a concern for low-risk, household-level production of domestic animals. Although villagers exploited secondary products, the inhabitants concerned themselves primarily with keeping their livestock populations secure from disaster and unpredictable loss. This scenario reflects a socio-economic system in which elites—if they existed at all—could not or did not control animal resources in any specialized manner. The contrast to the Northern Negev and Tulaylat al-Ghassul speaks to the heterogeneous nature of animal management and production strategies in the Southern Levant. Moreover, it begs the question of how these areas, and the seemingly different socio-economic systems, interacted with one another.

Rather than by sweeping patterns of economic specialization, the evolution of social complexity in the Southern Levant may have proceeded by regionally-specific staple specialization. Elites in each locality may have controlled what they could to secure and maintain power in regions defined by socio-economic and environmental diversity. In this context, the secondary products revolution may have been more localized than previously thought. In terms of animal management, different regions began intensively exploiting domestic animals for different reasons. The result was a mosaic of production strategies that only became integrated in later state societies.

Appendix – ZooMS Sample Preparation Methods (M.B.)

Briefly, samples of bone or tooth dentine were powdered, demineralized with 1 mL 0.6 M hydrochloric acid (HCl; Fisher Scientific) per 50 mg sample, for 18 h (overnight) at 4°C and centrifuged (13,000 x g). The acid-insoluble residue was then heated at 70°C in 50 mM ammonium bicarbonate for 5 h and following centrifugation (15 min, 13,000 x g) the supernatant was digested with the enzyme trypsin (37°C for 18 h). Following digestion, the samples were centrifuged (10 min; 13,000 x g), the supernatant acidified to a final concentration of 0.1% trifluoroacetic acid (TFA; Sigma) and loaded onto activated C18 pipette tips (Varian OMIX; activated with 2 x 100 μL 50% acetonitrile (ACN) in 0.1% TFA followed by 2 x 100 μL 0.1% TFA). Peptide fractions were eluted following several wash steps (2 x 0.1% TFA) using a stepped gradient (10% followed by 50% ACN in 0.1% aqueous TFA). Eluted fractions were dried using a centrifugal evaporator, resuspended with 10 μL 0.1% TFA and then 1 μL spotted onto a Bruker ultraflex target plate, mixed together with 1 μL of α-cyano-4-hydroxycinnamic acid matrix solution (1% in ACN/H_2O 1:1 v:v) and allowed to dry. Each spot was analyzed by MALDI-MS using a Bruker ultraflex II MALDI TOF/TOF mass spectrometer equipped with a Nd:YAG smart beam laser.

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