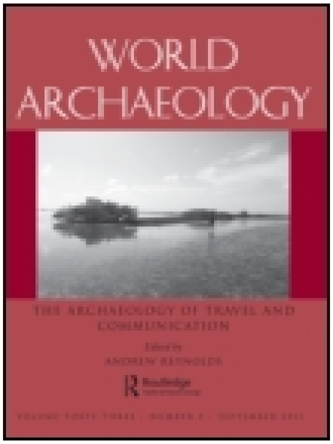

World Archaeology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rwar20

The Secondary Products Revolution: the past, the present and the future

Haskel J. Greenfield [a]
[a] University of Manitoba
Published online: 28 Jan 2010.

To cite this article: Haskel J. Greenfield (2010) The Secondary Products Revolution: the past, the present and the future, World Archaeology, 42:1, 29-54, DOI: 10.1080/00438240903429722

To link to this article: http://dx.doi.org/10.1080/00438240903429722

The Secondary Products Revolution: the past, the present and the future

Haskel J. Greenfield

Abstract

Andrew Sherratt's (1981) model of the Secondary Products Revolution explored the effects of changes in the scale and nature of domestic animal exploitation on Old World societies. He proposed that the earliest domestic stock animals in the Near East (sheep, goat and cattle) were initially domesticated during the Neolithic for their primary products (meat, hide and bone), but that their more intensive exploitation for secondary animal products (milk, wool and traction) appeared in the Near East much later (during the Chalcolithic) and subsequently spread to surrounding regions (Europe and Asia). While the zooarchaeological evidence largely supports the model, questions have been raised about its veracity since there is evidence for pre-Chalcolithic exploitation of secondary products (e.g. ceramic lipid analyses). This paper summarizes past efforts to test the model, presents the results of recent research on the subject (e.g. artefactual, zooarchaeological and lipid analysis) and suggests directions for future research. Some of the discrepancies that have arisen between the archaeological, ceramic lipid and zooarchaeological data will be discussed.

Keywords

Milk; wool; traction; plough; wheel; secondary products; domestication; zooarchaeology; Sherratt.

Introduction

Almost thirty years ago, Andrew Sherratt (1981, 1983) presented his Secondary Products Revolution model to explain the dramatic changes in economic (subsistence, settlement and trade) and political organization that swept across the Near East and Europe during the Chalcolithic and Early Bronze Age (EBA). These are periods of dramatic change when the earliest states and chiefdoms appear in the Near East and Europe, respectively. This grand model proposed that these dramatic changes were the result of *innovations* in the nature of domestic animal production and related technologies. These innovations led to a revolution in food production, mobility, local and inter-regional exchange and settlement

Routledge Taylor & Francis Group

World Archaeology Vol. 42(1): 29–54 *Agricultural Innovation*
 ISSN 0043-8243 print/1470-1375 online
DOI: 10.1080/00438240903429722

patterns. Sherratt drew upon the previously recognized distinction between primary and secondary animal products to account for these changes.

Primary products are those that can be extracted from animals only once in their lifetime (i.e. meat, bone and hide). Secondary products are those that can be repeatedly extracted from an animal through its lifetime, such as milk, wool and power (as agents of traction: Greenfield 1988a, 2005).[1] Essentially, Sherratt (1981, 1983) argued that the initial domestication of stock animals (sheep, goat and cattle) was largely oriented towards primary product exploitation. It was only after several millennia that another *innovation* in animal exploitation occurred – the intensive exploitation of secondary products. As a result, the origins of the large-scale and intensive use of domestic stock for their secondary products in Europe and the Near East did not begin with the earliest Neolithic cultures, but appeared much later in time (with the Chalcolithic and Bronze Age).[2] The exploitation of secondary products before the Chalcolithic was either unlikely or of minimal importance.

The introduction of secondary products had clear economic implications. Milking allowed humans to harvest animal protein without slaughtering the animal. Similarly, wool production provided the raw material for new forms of textiles. The use of large domestic stock for pulling the new technologies of ploughs and wagons enabled the intensification of agriculture (i.e. higher yields per labour unit), expansion of environmental range for agriculture (i.e. heavier soils could now be cultivated) and reduction in the difficulty of transporting people and goods across the landscape. Fewer people could perform the same task at greater energy savings and with increased return.

The adoption of secondary products had significant social and other economic results. It enabled the population of Europe to spread out more easily across the landscape, from the heavy soiled lowlands to the high mountains and deep into the steppes, whether seasonally or permanently. For example, the post-Neolithic of Europe is often characterized by a reduction in settlement size. This appears to be a result of the fissioning of the large Neolithic communities into many and smaller settlements composed of household holdings (i.e. homesteads) since the technology of food production required fewer community members (hoe vs. plough) (Sherratt 1981, 1983).

Ploughs and wheeled vehicles provided more efficient means to till the land and transport bulk goods (including tents, food and other supplies), thereby enabling the exchange in bulk goods to take place more easily. Local food production and exchange and regional trade intensified with the expansion of the geographic range for transport of goods. Social organization became more complex as reflected by the increased hierarchical complexity of settlement types and the appearance of hierarchically differentiated mortuary patterns in the post-Neolithic (Sherratt 1981, 1983).

The introduction of secondary products also had significant ecological ramifications. There was an expansion of the geographic range of settlement locations as new environments were colonized. In temperate Europe, the area under cultivation and settlement expanded. In particular, the agriculturally marginally highlands became extensively settled, leading to greater forest clearance, increased run-off and erosion in the uplands and consequent sediment clogging of streams in the lowlands. In the new agriculturally marginal environments, subsistence would be more pastoral in nature. The new environments were better suited to expansion of herd size and increased production of secondary products than the long-settled and more populous lowlands. A consequence of the growth of herd size was the need to increase the area for grazing. This led to the penetration and colonization of more marginal environments (e.g. highlands) where there are sharp contrasts in climate and terrain within short distances (Greenfield 1984; Sherratt 1981: 286).

The appearance of new goods (i.e. woollen textiles) and intensification of old ones (e.g. milk) provided valuable commodities for subsistence in the more pastorally oriented communities and for trade with the more agriculturally oriented communities. Intensification of both cultivation and animal husbandry would eventually lead to the specialization of production – to the appearance of separate but interrelated regional subsistence systems – i.e. agriculturalists and pastoralists (Sherratt 1981, 1983).

The Secondary Products Revolution model was an intellectual innovation in understanding the profound changes in the archaeological record beginning with the Chalcolithic. First, the model proposed relationships between numbers of previously poorly examined but clearly related variables. Second, it proposed a number of easily testable relationships (i.e. hypotheses). Third, it focused on systemic rather than individual processes; the origins of secondary products were conceived very much in a systemic or processual manner since the search for individual innovators was considered fruitless. Fourth, and perhaps most importantly, the model focused on change in scale rather than trying to find the elusive point or moment of origins. Finally, it clearly demonstrated that our understanding of later periods and the rise of civilizations (or complex societies) was rooted in the changes in production occurring in the Chalcolithic. The Neolithic and initial domestic origins were still important, but were not sufficient to explain the changes leading to the evolution of complex societies. The traditional peasant farming lifestyle of Europe, where cattle, sheep, and goats were used as sources of protein (milk and meat), clothing (wool) and transport and labour (traction), lay in the Chalcolithic.

Sherratt never directly discussed why these innovations in production happened at this moment in time other than to imply that enough earlier changes had occurred to create a synergistic effect on regional cultures. The development of secondary products exploitation was envisioned as a response to the long-term problems of population growth and territorial expansion that began with domestication and sedentism in the Early Neolithic. It was a means of extracting new resources from those already available. The Secondary Products Revolution was clearly associated with the rise of complex societies in the Near East (i.e. Mesopotamia during the Uruk period). Sherratt (1983: 90) maintained this was a critical phase of change in the Old World. Hence, the association of the rise of complex societies and appearance and spread of secondary products across the region was viewed very much as part of a positive feedback relationship characteristic of complex systems. The diffusion of secondary products through the reorganization of economic relationships was envisioned as ultimately laying the basis for the subsequent spread of complex societies from the Near East.

While there has been widespread support (and muted criticism) for the model through the years, questions have been recently raised about its veracity based on evidence for pre-Chalcolithic exploitation of secondary products (e.g. ceramic lipid analyses). This paper summarizes past efforts to test the model, presents the results of recent research on the subject (e.g. artefactual, zooarchaeological and lipid analysis) and suggests directions for future research. Some of the discrepancies that have arisen between the archaeological, ceramic lipid and zooarchaeological data will be discussed. It attempts to cover material across Europe and the Near East, the heartland of Sherratt's concern.

Early critiques and zooarchaeological research

At the time Sherratt proposed his Secondary Products Revolution model, the archaeological evidence for secondary product exploitation was of 'uneven value' (Sherratt 1981: 262). It was based on artefacts and iconographic representations from the Near East and Europe, including ploughing and milking scenes from the Near East; models of carts and yoked cattle from Central Europe; and wool textiles, yokes, ards and plough marks in waterlogged or buried contexts from northern Europe. Sherratt (1983: 90) admitted that the evidence was varied and not conclusive, but hoped that others would test the model more rigorously.

Immediately after the Secondary Products Revolution model was proposed, objections appeared in the literature. The most extensive was by Chapman (1982), who argued that much of the artefactual record from the European Neolithic (particularly in south-east Europe) could be interpreted differently – e.g. that ploughing could have occurred in the Neolithic if red deer antler adzes were plough tips. However, most of the arguments were rebutted (Sherratt 1986) and the objections to the model largely disappeared from the literature as other data appeared increasingly to support Sherratt's position.

Throughout the 1980s, many zooarchaeologists systematically tested the model with data from the Near East, Europe and elsewhere in the Old World (e.g. Davis 1984; Greenfield 1984, 1986, 1988a; Harrison 1985; Horwitz and Tchernov 1989; Legge 1981, 1992). Zooarchaeological harvest profiles (age-at-death) of cattle, sheep and goats were interpreted as indicating a shift in exploitation practices in the Chalcolithic towards slaughtering of more very young (infants and juveniles) and retention of older animals (adults). Frequencies of sub-adults (1–2 for caprines or 1–3 years of age for cattle) increased in comparison to earlier Neolithic harvest profiles. By analogy with modern herding systems (e.g. Cribb 1987; Payne 1973), this change was interpreted as the result of the introduction of secondary product exploitation. Similar data were collected throughout the 1990s and early 2000s across the Mediterranean basin and Europe (e.g. Albarella 1999; Arbuckle 2009; Cantuel et al. 2006; Clark 1991; de Cupere et al. 2006; Greenfield and Fowler 2003, 2005; Grigson 1995; Halstead 1992; various papers in Kotjabopoulou et al. 2003; Legge 1994; Østergaard 2005). All indicate stability in domestic animal exploitation throughout the Neolithic and changes in the nature of cattle and sheep exploitation strategies between the end of the Neolithic and beginning of the Bronze Age. Given the abundant artefactual and zooarchaeological data, the general consensus through the early years of the new millennium was that the Secondary Products Revolution model retained general validity (Greenfield 2005; Grigson 1995; Hüster-Plogmann and Schibler 1997; Legge 1994, 2005).

However, there was also some unease as the data from specific sites and regions did not always fall neatly into the model's expectations. A number of problems in the model were identified, including that the timing (chronology) of appearance of each of the secondary products varied from region to region and that all products did not always arrive in regions as a constellation (Chapman 1982; Greenfield 1988a, 2005; Greenfield and Fowler 2005; Mulville and Outram 2005). Also, Sherratt largely avoids discussing the difference between initial appearance and change in scale of production leading to confusion in the literature (although he proposes that milking may have existed in the Neolithic: 1983: 95). As a result, he is occasionally charged with arguing for *first time* use of the products only after the Neolithic (Bogucki 1986; Vigne and Helmer 2007), while elsewhere it is maintained that he was arguing for shifts in exploitation *emphasis* (Greenfield 1988a, 2005). As will be shown below, I believe that the intent of the model was to highlight the intensification of production as opposed to first appearance.

Recently, new evidence (lipid analysis, horse milking associated with early domestication, harvest profiles, osteological pathologies, etc.) has produced earlier dates for some components of the model, which seem to undermine Sherratt's thesis. Given this growing body of new evidence, it is time to review the evidence for the model to determine if it simply needs refining or should be discarded in its entirety. Three aspects of the model are considered in this paper since they are the essential innovations associated with the Secondary Products Revolution: milking, wool and traction.

Milk

Goats, sheep and cattle could have been exploited for their milk from the very beginning of their domestication, albeit on a small-scale. The amount of milk available from such animals immediately after domestication would probably have been minimal. Not only would the animals have yielded just small amounts of milk at any single moment in time, but lactation would also have ceased with the weaning of the calf. As a result, milking would have had a negative effect on the growth of the calf. Ruminant milk is a potential nutritional substitute for human infants when the mother dies or is unable to lactate (Amoroso and Jewell 1963; Clutton-Brock 1981).

The earliest unambiguous artefactual evidence for milking is quite late (Early Dynastic period of southern Mesopotamia, *c.* 2600 BC) and occurs in the form of visual representations, such as an inlaid limestone milking frieze from the Ninḫursag Temple at Tell al-Ubaid depicting cows being milked from behind (Hall and Woolley 1927: 111–14, plates 31–4, 38; Moortgart 1969: plate 122). More ambiguous pictorial evidence for milking comes from the earlier Uruk period (*c.* 3500 BC) in the form of a cylinder seal that depicts cattle herds in the upper register. In the lower register, adult cattle are tethered outside huts, which contain calves and large ceramics. The ceramics are interpreted as being used for storage of milk products (Kawami 2001; Sherratt 1981). The need for the calf's presence in order for the cow to let down her milk lasted well into recent times and is still necessary to milk some unimproved breeds of cattle (Clutton-Brock 1981). Other artefactual evidence comes from Neolithic Europe. Bogucki (1984, 1986) proposed that Neolithic ceramic sieves were used to separate curds and whey. However, the rarity of sieves in Neolithic assemblages, in contrast to their greater frequency in the post-Neolithic, was interpreted to indicate either that they were used for sieving other products (e.g. honey) or that milking was a minor component of the diet (Greenfield 1988a).

Some zooarchaeological data indicate changes in milk exploitation in accordance with the expectations of the model. For example, Horwitz and Smith (1984) x-rayed and measured sheep and goat metapodials to observe whether there was a thinning of the cortical bone associated with the suspected introduction of larger-scale milking activities during the Chalcolithic of the southern Levant. For both sheep and goats, a significant reduction in cortical thickness values from the Early Bronze and later samples was found in comparison with the earlier Chalcolithic and PPNB samples. The reduction in cortical thickness is suggested to be indicative of a shift in exploitation emphasis to include a heavier emphasis upon milk since the change is associated with increased frequencies of older, female animals.

The more commonly cited zooarchaeological harvest profiles are much more ambiguous in their evidence for milking. Comparisons of such data from across the Near East and Europe demonstrate a shift in domestic cattle and sheep exploitation during the Chalcolithic towards increased exploitation of the youngest and oldest age groups. This change in age group mortality is interpreted as a shift in exploitation from an emphasis upon primary products to a more mixed exploitation strategy (e.g. Grigson 1995; Helmer et al. 2007; Horwitz and Tchernov 1989; Rowley-Conwy 2000). However, it is often impossible to distinguish whether it was for increased milking or wool production among sheep, or milking and traction among cattle, due to a variety of taphonomic variables (Lyman 1994). Harvest profiles are most useful for observing general trends, but not for identifying specific products (Greenfield 1988a, 2005). Furthermore, most zooarchaeological studies do not distinguish between sheep and goat harvest profiles. But, when the pattern for each taxon is separated, European zooarchaeological harvest profile studies suggest that goats were milked during the Neolithic. Most goats were culled when older, in contrast with sheep who were more intensively exploited while young (e.g. Arnold and Greenfield 2006; Greenfield and Fowler 2005; Phoca-Cosmetatou 2008).

Possibly the most exciting new evidence comes from the study of lipids (animal fats, plant oils, etc.) in ceramics. It is clear from such analyses that milking has its origins in the Neolithic (Copley et al. 2003; Craig et al. 2000, 2005; Evershed et al. 2008; Spangenberg et al. 2006). Milk lipids have now been found in Neolithic ceramics from the Near East (e.g. north-west Anatolian Pottery Neolithic *c*. 6000 BC) and Europe (early sixth-millennium Hungary and late fifth-millennium England). This implies that the practice of milking probably accompanied the spread of farming cultures from the Near East across Europe. Although this evidence suggests that dairying was present from the beginning of the Neolithic, it was probably practised on a small scale. Recent analyses of ceramic lipids from Neolithic and Chalcolithic period sites in the Near East suggest that milking was present already in the Pottery Neolithic (*c*. 6000 BC) of north-west Anatolia. But milk probably formed only a minor component of the diet: a relatively small frequency (*c*. 8 per cent) of Near Eastern sherds yielded evidence for fatty acids indicative of animal fats (Evershed et al. 2008), and similar figures were obtained in Europe (Craig et al. 2000). Thus, milking was practised during the Neolithic, but on a small scale and as part of a broad mixed economy (Craig et al. 2000).

Such studies make a significant contribution to the debate, though there are some issues that need to be kept in mind. First, the lipid studies published to date are not able to distinguish between milk lipids of different species (i.e. sheep, goat and cattle). As a result, it is impossible to determine which animal was being milked. It has been suggested that lipids detected in northern European Neolithic ceramics belong to sheep or goats (Craig et al. 2005: 882), which finds support among the zooarchaeological data for Neolithic milking of goats (above). Second, studies from the Near East (Gregg et al. 2009) suggest that there are methodological issues in comparing Near Eastern and European lipid extraction techniques. Isotopic bench-line values appear to be different for the Near East and Europe. Comparison of animal fat values from the Near East and Europe indicate that the ranges of isotopic ratios for adipose and dairy fats differ substantially and should not be applied between regions. Each region needs its own base-line. Otherwise, it is not possible to distinguish ruminant (cattle, sheep and goat) and non-ruminant (e.g. pig) fats in samples. Thus, while the evidence for Neolithic milking cannot be ruled out, neither is it a certainty. Ceramic vessels likely had multiple uses (Henrickson and McDonald 1983), and could have included cooking of meats and extraction of marrow from both ruminant and non-ruminant animals, as well as the possible heating of milk products (Gregg et al. 2009: 943–4).

While most of the discussion concerning the origins of milking has focused on cattle, sheep and goats, recent studies on the milking of horses has extended the issue in a different direction. Domestication of the horse occurred in the Eneolithic (Botai) Culture of Kazakhstan (*c.* 3500 BC) based on metrical and morphological analyses of horse remains (Anthony 2007). Isotopic analysis of organic residues (δ^{13}C and δD values of fatty acids) demonstrated that horses were used for their milk from the beginning of their domestication, as well as their primary products. Hence, the domestication of the horse appears to be intimately tied together with its exploitation for secondary products, such as milk and traction (Outram et al. 2009). This is an aspect of the Secondary Products Revolution model that needs more exploration.

It is clear that several different sources of data are necessary to reconstruct the nature of milk exploitation. For example, lipid studies enable the discovery of presence or absence of milk, while pictorial representations can indicate the nature of the activity and of the animals involved. Harvest profiles, which can help reconstruct the population structure of ancient domestic bovid herds and the nature and scale of their exploitation over time, are a more reliable source for investigating the *intensity* of production (Legge 2005). Hence, zooarchaeological harvest profiles and lipid studies should be used as complementary techniques (e.g. Helmer et al. 2007; Schibler 2006; Schibler et al. 1997; Vigne and Helmer 2007). From all of these data, it is apparent that, while milking was present during the Neolithic, it was not intensively exploited until the Chalcolithic or later.

Wool production

It has long been recognized that woolly sheep must have appeared at some point long after initial domestication, since wild sheep lack a woolly outer coat. It would have taken a few thousand years for the genetic changes to occur that switched the phenotype from hairy wild to woolly domestic sheep. The microscopic inner woolly fibres of wild sheep had to undergo sufficient genetic change to switch position with the macroscopic outer hairy fibres in order to become useful for exploitation. As a result, the development of a woolly outer coat must have evolved slowly, from isolated tufts to a complete coat. Hence, sheep could not have been domesticated for their wool (Flannery 1965; Ryder 1983, 1992).

The earliest types of wool would have been relative coarse fibres, but still spinnable. Over time, finer wool types evolved with the appearance of fine wool fleeces. But, really fine fleeces did not appear before the first century AD (Good 2001; Ryder 1987). The issue for the Secondary Products Revolution model is: when did the coat of wool become sufficiently developed to be worth exploiting on a large scale?

Sherratt, while not the first scholar to point out the significance of sheep-wool production for changes in the social and economic fabric of early complex society, wove the evidence for early wool production quite aptly into his model (pun intended!). He proposed that there was a major shift to woolly sheep associated with the emergence of the temple economies during the Chalcolithic (Uruk) of the Near East (i.e. Mesopotamia) based on the historically known large-scale textile production associated with the temple economy. Since then, the archaeological evidence appears to more or less support his proposal (Pollock 1999).

The textual evidence for wool only appears once woolly sheep have already been well developed. A number of archaic cuneiform signs from the late Uruk period have been interpreted as indicating the presence of wool or woolly sheep (Green 1980). Animal figurines from the Near East suggest the possible presence of woolly sheep from only *c.* 5000 BC or later (Bökönyi 1977: 114). Much clearer pictographic depictions are the reliefs of highly developed woolly sheep on Uruk period stone bowls (3500 BC) (Sherratt 1981). Spindle whorls appear to become more common after the Neolithic (Barber 1991: 56–60), but quantification studies are lacking. Hence, the various technological, pictorial and textual sources suggest that spinnable wool was present by the beginning of the Chalcolithic and widespread by the EBA in lower Mesopotamia (Good 2001).

All preserved cloth remains from prior to the Chalcolithic period are from flax (*Linum usitatissimum* L.: Barber 1991; McCorriston 1997). While no wool remains have been recovered from Chalcolithic or earlier Mesopotamian deposits, actual or putative wool remains begin to appear elsewhere in the Near East during the fourth millennium BC. There is a sheepskin from El Omari in Lower Egypt (Ryder, 1983: 109) and two 'woollen' cloth fragments at Nahal Mishmar in Israel (Bar-Adon 1980). Unfortunately, the former does not appear to be of a spinnable type and the latter may not be wool. The Nahal Mishmar specimens were not subjected to detailed analysis, and it is not clear whether they derive from sheep's wool or goat hair. The latter possibility appears most likely given that the animal bones at the site indicate the presence of only goats and no sheep (Good 2001). There is indisputable evidence for large-scale production of woollen fabrics in eastern Iran (Sharh-i Sokhta) by the EBA. In China, wool begins to appear only in the Bronze Age, reflecting the time lag between the development of woolly sheep and their spread to eastern Asia (Good 1999, 2001).

There is no evidence during the European Neolithic for wool fabrics or associated technology, or woolly breeds. Woollen fabrics begin to appear only in the Chalcolithic of Europe and become more abundant through the Bronze and Iron Ages (Good 2001; Ryder 1987, 1992). One of the earliest examples comes from the Late Neolithic site of Opovo (*c.* 4000 BC), where carbonized flax remains were found amid the collapse of a burned house (Tringham and Bruckner 1985). In the Central European Corded Ware culture, artefact types associated with wool production (e.g. bone and antler needles) become more frequent at this time (Schibler 2006).

On their own, zooarchaeological harvest profiles yield relatively ambiguous evidence for a shift to wool exploitation in sheep herds. Bökönyi (1977: 25) suggests that the harvest profiles of the Tepe Sarab (Iraq, *c*. 6000 BC) sheep indicate a shift to wool (or other secondary products, such as milk) exploitation because sizeable numbers of animals were retained well into adulthood. However, his hypothesis for an early exploitation of wool was refuted by the larger and better-collected assemblages more recently analysed from the region. It is only after 5000 BC (during the Chalcolithic) that dramatic shifts in harvest profiles indicate that many more animals were being kept alive longer into adulthood. These are interpreted as indicating changes in scale of secondary product exploitation, but not specifically for wool (Davis 1984; Mashkour 2002: 36), thereby refuting Bökönyi's earlier date. Pollock's (1999: 103–10) comparison of Uruk period zooarchaeological assemblages from Mesopotamia and south-west Iran suggests that intensification of production of sheep for their wool may have occurred in the lowlands even later (only after 3350 BC).

The zooarchaeological data from across much of Europe indicate the appearance of larger breeds (Bökönyi 1974) and harvest profiles indicate a shift towards older animals (Greenfield 2005; Harrison 1985; Legge 1994; Schibler et al. 1997) with the advent of the Chalcolithic. This has been widely interpreted as indicating the beginning of intensive (and not occasional) exploitation of sheep for their wool. Measurements of osteological remains have long indicated that new and larger varieties of sheep appeared in the Chalcolithic of the Near East and spread to Europe by the EBA (Bökönyi 1974). This change in bone morphology coincides with the appearance of 'woolly' sheep figurines.

In sum, most of the evidence appears to favour a relatively late shift to intensive wool production, i.e. during the Chalcolithic for both the Near East and Europe (Fig. 1). Woolly breeds become increasingly important over time until the rise of productive specialization which occurs first in Mesopotamia by the Uruk period, and later elsewhere (Pollock 1999). By the Late Bronze Age, specialization in sheep production for wool had spread to the Aegean, although there are suggestions that it may have appeared in Crete slightly earlier (Halstead 1999). It takes far longer for such specialization to spread to central and northern Europe, where it appears only with the Roman conquest (Ryder 1983).

While fluffs of wool could have been collected from early breeds of sheep, the development of a wool industry required advanced breeds and sufficient stock. It would appear that the very rapid spread of woolly sheep across and between regions is a reflection of the easy and smooth transition from a flax-based spinning technology to a wool-based one. The textile industry already existed and it simply adopted and substituted the new material (Russell 2004: 328). It was a very different case than with milking, where entirely new technologies had to be introduced, developed and diffused before it could become a mainstay of the economy.

Traction

The literature on traction appears to confuse closely related concepts. Traction is intimately related to the act of pulling something along a surface and usually is discussed

Time (BC)	Near East	*S Mesopotamia*	*Anatolia*	*Levant*	South Balkans	*Greece*	North Balkans	*Serbia*	Central Europe	*Hungary*	*Switzerland, S Germany*	*S Poland*
1000				Iron II			***EIA***	Halstatt	***EIA (800)***	Hallstatt	Hallstatt	
1200	***EIA***	Middle Babylonian	Neo-Hittite	Iron I	***EIA***	Dark Age						Lusatian
1500	***LBA (1600)***	Kassite	Hittite	LBA	***LBA***	Late Helladic	**LBA**	Dubovac-Zuto Brdo	***LBA***	Urnfeld		
2000	***MBA (2100)***	Isin-Larsa, Old Babylonian	MBA	MBA	***MBA***	Middle Helladic	***MBA***	Vatin	***MBA***		Únětice	
		Akkadian, Ur III				Sitagroi V						
2500		Early Dynastic III							***EBA***	Hatvan	Bell Beakers	Bell Beaker
3000		Early Dynastic I/II				Early Helladic	***EBA***	Vinkovci, Bubanj-Hum III			Auvernier, Corded Ware	Corded Ware
	EBA	Jemdet Nasr	EBA (3100)		***EBA***	Sitagroi IV	***Chalco***	Baden-Kostolac	***Chalco***	Bodrogkeresztúr, Baden	Horgen	Baden
3500				EBA (3500)		Sitagroi III		Vinča D	***LN***		Horgen	Funnel Beaker
4000							***LN***	Vinča C		Tiszapolgar	Michelsberg	TRB
4500	***Chalco***	Uruk	Late Chalco	Chalco	***FN***	Rakhmani		Vinča B	***MN***		Rossen	Lengyel
5000						Dimini	***MN***	Vinča A		Tisza		
5500					***LN (5300)***	Larissa				Linearbandkeramik	Linearbandkeramik	
6000	***LN***	Ubaid	Early Chalco	PN	***MN (5800)***	Sesklo I-III	***EN***	Starčevo-Criş	***EN***	Körös		
6500				PPNC	***EN***	Proto-Sesklo						
7000			PN									
7500				PPNB								
8000	***EN***		Aceramic	PPNA								
9000	**Proto-Neolithic**											

Period Abbreviations

PrePottery	PPN
Pottery Neolithic	PN
Early Neolithic	EN
Middle Neolithic	MN
Late Neolithic	LN
Final Neolithic	FN
Chalcolithic	Chalco
Early Bronze Age	EBA
Middle Bronze Age	MBA
Late Bronze Age	LBA
Early Iron Age	EIA

Figure 1 Chronological table of traditional periods and local archaeological cultures across regions under discussion, using calibrated radiocarbon dates. Period and culture dates are approximate.

in relation to wheeled vehicles or ploughs. However, it is often ignored that large domestic stock was capable of pulling various loads (e.g. logs or sledges) and carrying loads on their back.

Domestic cattle were probably used as beasts of burden and for simple traction during the Neolithic. They were probably one of the means by which Neolithic societies spread so widely and rapidly prior to the advent of the wagon (Bogucki 1993). It was not until the Chalcolithic that the next large domesticated animals capable of traction (i.e. horse and donkey) began to spread beyond their areas of domestication (Anthony 2007; Grigson 1995: 258; Olsen et al. 2006).

Most research on the origins of traction has focused on the artefactual data since it is possible to discern which type of instrument is being pulled (i.e. wagon, cart or plough). These data are discussed first since they point more directly to the mode of traction. In contrast, the zooarchaeological evidence is more ambiguous and is discussed afterwards.

The plough

Stone celts and perforated antlers are sometimes proposed as early evidence for plough tips (e.g. Chapman 1982), but this view is generally not accepted. The earliest evidence for the plough comes from Mesopotamia in the form of plough marks found in Susa A contexts (*c*. 5000 BC in Iranian Khuzestan: Wright 1980). After the Susa A marks, there is a long chronological gap. During the Chalcolithic, clear and unambiguous textual and pictorial evidence for ploughs appears in Mesopotamia in the form of cuneiform signs. These show clear continuity of development from archaic (Uruk) into more developed (Early Dynastic) forms. By the latter period, ploughs are depicted on cylinder seals and mentioned in cuneiform texts (Green and Nissen 1987).

In Europe, the earliest evidence for ploughs is later. The restricted distribution of supposed ard marks under north European Neolithic barrows was initially suggested to represent the earliest evidence for ploughing (e.g. the parallel depressions beneath the long-barrow at Sarnowo, Poland: Gabałówna 1970; Wiślański 1969). However, they are now recognized more likely to represent part of the ground preparation during the funerary ritual, rather than evidence of ploughed surfaces for agriculture (Rowley-Conwy 1987; Sherratt 2006: 336–7). At this point, there are no unambiguous instances of plough marks from before the Corded Ware culture (Tegtmeier 1993). All of the Central European examples of buried surfaces with clear-cut plough marks date to the Chalcolithic or later (after 3500 BC). These include marks under barrows in Denmark, Germany and Poland (Kruk and Milisauskas 1999: fig. 47; Sherratt 2006: 336–7). Clearly, the ard plough pulled by yoked cattle diffused into Europe during the Chalcolithic (late fourth/early third millennium BC: Tegtmeier 1993).

Wheeled vehicles

The moment or place of origin of such a significant innovation as wheeled vehicles is difficult to identify because they appeared to have diffused so rapidly that it is impossible to discern the process of diffusion archaeologically (Fansa and Burmeister 2004; Piggott 1981). Most of the evidence points to the mid-fourth millennium. While it is impossible to discern a single point of origin for wheeled transportation, the Indo-European etymology for wheeled-vehicle terminology suggests an eastern steppe origin (Anthony 1995: 558, 2007).

The earliest unambiguous evidence for the appearance of wheeled vehicles in the Near East occurs in the form of cuneiform symbols from Late Uruk (level IVa, *c*. 3300–3100 BC). When the frequency of cuneiform signs for wagons and sledges from Uruk tablets are compared, the latter far outnumber the former (three versus thirty-eight) suggesting that wagons were present but of less importance (Anthony 2007: 66–7; Bakker et al. 1999). By the third millennium, wagons become more common across the Near East. They are more frequently mentioned in texts, and depicted on reliefs and as figurines (Fansa and Burmeister 2004; Grigson 1995: 267–8; Piggott 1981).

In Europe, several lines of evidence point to a very late fourth millennium date for the earliest wheeled vehicles. Earlier claims of model wheels from Neolithic south-east European cultures have not been accepted since they are indistinguishable from spindle whorls (Sherratt 1986: 1). From Eastern Europe (southern Ukraine and Russia), there are actual vehicle burials in the Yamna culture (3500–2500 BC, with the earliest Yamna wagon graves *c*. 3100–3000 BC). From Central Europe, there are three-dimensional clay models of solid-wheeled carts in the Baden culture (Chalcolithic) of Hungary (*c*. 3500–3000 BC) and a two-dimensional engraving of a cart on a Late Neolithic TRB ceramic from southern Poland (3700–3100 BC). Further west, water-logged wooden wheels are found at Swiss Lake Dwelling sites near Zürich from the late fourth to early third millennium phases of the Horgen culture (Anthony 1995: 561, 2007: 67–72; Milisauskas and Kruk 1991; Piggott 1981: 38–58; Ruoff and Jacomet 2002). Data from Altyn-Depe (in western Central Asia) suggest that the earliest wheeled transport appeared during the late fourth to early third millennia BC in the form of two wheeled carts. Four-wheeled carts appeared in the region during the second half of the third millennium BC (Anthony 2007; Kirtcho 2009).

These early vehicles would have been large, heavy, slow-moving and awkward. Figurines indicate that they were probably pulled by oxen, which were frequently linked to a yoke and harnessed in pairs (Grigson 1995: 267). Paired burials of animals (i.e. cattle) in Europe appear at the same time, suggesting that they were yoked together (Bartosiewicz et al. 1997: 9). Evidence of wooden yokes appears in the late Chalcolithic and EBA at various sites in the Near East and Europe (Anthony 2007), such as the wooden yoke from Arbon Bleiche 3, Switzerland (3384–3370 BC) (Leuzinger 2002; Ruoff and Jacomet 2002). In the Near East, Europe and Central Asia, it would seem that cattle were the earliest heavy draught animals. Horses and equids were used later on for lighter weight vehicles.

Zooarchaeological approaches to traction

From the zooarchaeological harvest profiles, it is more difficult to discern whether the animals were being used for pulling ploughs or wheeled vehicles. It has largely been assumed that the increased numbers of older cattle in the post-Neolithic harvest profiles was a reflection of their increased use for traction (e.g. Greenfield 1988b, 2005). However, the decrease in the younger age classes may reflect a more conservative and diversified herd management strategy whereby more animals were being kept alive longer (Redding 1984) rather than for any specialized use.

Research on the relationship between traction-induced stress and osteological pathologies has helped zooarchaeologists investigate this issue in recent years. Traction-induced stress pathologies tend to cluster in the distal limbs (phalanges and metapodia), but may include a wide range of bone remodelling, including: exostosis; lipping and osteoarthritis on the proximal articulations of metapodials and phalanges; extension, asymmetry and broadening of the distal epiphyses of metapodia; plantar/palmar grooves or depressions on the articular surfaces of metapodials; striations on the shaft of the metatarsals; 'striated facets' on the metacarpals; fusion of the second to the third metacarpal; and eburnation on the acetabulum of the pelvis and the caput femoris (Baker and Brothwell 1980; Bartosiewicz et al. 1997: 33; de Cupere et al. 2000; Isaakidou 2006: 97).

However, such pathologies may arise from conditions unrelated to traction. Exostosis on distal limb joints can be caused by a variety of heavy activities, of which traction is only one possibility, including moving over uneven ground, carrying loads and genetics (Baker and Brothwell 1980: 117–22). Hence, it is difficult to establish the source of the pathologies, i.e. whether the animals were used as beasts of burden or for traction or type of traction. As Isaakidou aptly notes, '"Traction pathologies" thus pose significant problems of equifinality' (2006:107; cf. Halstead 1998). In spite of this ambiguity, many studies simplistically argue that the presence of distal pathologies indicates the presence of traction. Such pathologies have long been recognized from Neolithic Near Eastern and European assemblages (see numerous sources cited in Bartosiewicz et al. 1997 and Sherratt 1997: 202), but simplistically assumed to be traction-related (e.g. Mateescu 1975).

A more successful approach is to evaluate the pathologies in relation to other evidence for traction. For example, Grigson (1995: 267) summarized the spotty zooarchaeological and artefactual data from the southern Levant to suggest that cattle were used as heavy draught animals from the Chalcolithic onwards, but were employed for carrying loads earlier. Isaakidou's (2006, 2008) more extensive analysis evaluated the frequency of traction-associated pathologies of cattle at Knossos (Crete) in relation to changes in harvest profiles and other evidence. The analysis suggested that cattle were used as draught animals from the Neolithic onwards since traction-associated pathologies occur from the Neolithic through the Bronze Age. Isaakidou (2006: 104) further suggests that Neolithic cattle were more intensively used for traction since pathologies are more common in the Neolithic. She also suggests that females were the main source of draught power during the Neolithic since all pathologies found on morphologically sexable bone elements (pelves) were from adult females, except one (Isaakidou 2006: 107–8, table 8.4). In contrast, traction-associated pathologies in the Bronze Age are few and not found on sexable pelves. Isaakidou (2006: 106, 2008: 96) proposes that since the harvest profiles indicate increased frequency of males surviving into adulthood after the Neolithic, males (instead of or in addition to cows) were used more intensively as draught animals in the Bronze Age, after ploughs and wheeled vehicles are introduced. Hence, the data suggest that traction appeared during the Early Neolithic, well before the advent of ploughs and wheeled vehicles, and that female cattle were used as beasts of burden and to pull other kinds of loads throughout the Neolithic (Isaakidou 2006: 108).

Milisauskas and Kruk (1991) systematically combine data from several sources to argue that traction of carts appears during the Middle (3900–3100 BC) and Late Neolithic (3200–2600 BC) of the North European Plain with most of the evidence falling into the latter half of the fourth millennium. They present depictions of carts on pottery, clay models of carts, changes in harvest profiles and the appearance of bone pathologies on horn cores of domestic cattle from the site of Bronocice (Poland) to argue that cattle were already exploited for traction. Traction-related pathologies among domestic cattle similarly appear in southern Scandinavia in the fourth millennium (Johannsen 2005, 2006). If these traction-related pathologies reflect the use of wheeled vehicles or ploughs, the central and northern European dates are as early as anywhere else, reflecting the rapid spread of this innovation. The late date for these later Neolithic periods in central and northern Europe synchronizes with the Eneolithic and EBA, respectively, of southern Europe (Fig. 1).

It is useful to contrast the Polish and Cretan data with those from Harappa and other Indus River valley sites which show a clear increase in traction-related pathologies from the EBA onwards (late fourth millennium). This trend is associated with the appearance of wheeled vehicle figurines and harvest profiles of cattle that indicate that the vast majority (*c*. 80 per cent) were culled only as adults (Miller 2003, 2004).

In all cases, however, the sample size of traction-related pathological specimens is small, making any conclusions tentative, at best. In general, it would appear that cattle were used primarily as beasts of burden and secondarily for traction during the Neolithic, but that cattle began to be more intensively used for traction-related activities (pulling of wheeled vehicles and ploughs) during the late fourth millennium The increased frequency of traction-related pathologies appears to coincide with the spread of the plough and wheeled vehicles during the Chalcolithic.

Future approaches

Animal genetic studies are an important new direction (Zeder et al. 2006). Geneticists will eventually be able to identify genetic markers for increased milking, woolly coat, etc. While the identification of osteological remains in zooarchaeology was at the cutting edge of the discipline for the past few decades and seen as providing the necessary data to answer questions such as the nature of production and exploitation, it is today a central part of the discipline. During the past few decades, the limits of simple identification have been tested and found wanting. It is now clear that zooarchaeologists can use harvest profiles to help understand changes in scale of production, but not the first onset of such changes. It is perhaps through studies of ancient DNA that many questions (such as the rise of the first woolly sheep, intensively milked animals, etc.) might be finally answered.

Soil science can be used to demonstrate changes in nature of livestock keeping. For example, Lillios (1992) demonstrates a shift from local to more mobile strategies in the Chalcolithic of the Iberian Peninsula suggesting changes in domestic animal exploitation strategies similar to those suggested by the Secondary Products Revolution model.

Collagen isotope studies can help demonstrate changing patterns of mobility. Comparison of strontium isotope ratio (87Sr/86Sr) from human and faunal dental enamel indicates a shift in the range of values from the Late Neolithic to the Copper Age (or Chalcolithic) in Hungary from a very narrow to a much broader range. This suggests increased mobility of humans and domestic livestock which coincides with archaeological evidence for increased interaction over a wide geographical area. The implication is that the population adopted a more mobile agro-pastoral lifestyle during the Chalcolithic (Giblin 2008). Changes in isotope values are also associated with the onset of the Chalcolithic from the Near East (Bocherens et al. 2000). Each of the above studies suggests that the changes in herding and exploitation strategies may be a result of the intensification of production to include secondary products.

On a theoretical level, there are also other factors beside food production to consider that are largely ignored by the Secondary Products Revolution model, such as social storage and redistribution. While milk and other secondary products are important for the economy, the widespread adoption of more intensive forms of domestic animal exploitation coincides with the rise of complex societies. Hence, herds of cattle and other stock become visible statements of wealth. This is a pattern that begins in the Neolithic, where there is strong symbolic and ceremonial value associated with certain domestic animals, i.e. cattle (Marciniak 2005, 2008; Russell and Martin 2005; Russell and Meece 2006). Cattle remains are less processed than other animals and appear to have been used more often than smaller domestic stock for feasting (Marciniak and Czerniak 2007). We need to be careful to appreciate that domestic animals are often kept for more than economic/subsistence purposes, which can affect their distribution in the archaeological record.

A final new direction is the need to increase our understanding on the timing of appearance and nature of spread of secondary products exploitation in regions beyond the Near East and Europe. Eastern Asia is the last major geographic region in the Old World where there is little such information and has been largely ignored since Sherratt framed his model. There is little available from India and even less from China. The little available data (e.g. the zooarchaeological harvest profiles from the Late Shang period site of Anyang) indicate that the cattle and sheep were primarily exploited for their primary products. This suggests that the exploitation for their secondary products had not yet arrived at even this very late date – second half of the second millennium BC (Li 2009).

Discussion: changes in scale

The issue of 'scale' has plagued the literature on the Secondary Products Revolution model since it was originally formulated. This has led to all kinds of misunderstandings as specialists weigh in on various aspects of the subject (e.g. Halstead 1996).

One of the major misconceptions is the confusion between initial origins and intensification (or changes in scale) of exploitation practices. In the Secondary Products Revolution model, the issue has never been *when* the innovations were *first* invented or introduced to a new area, but *when the scale of exploitation changed*. As the innovations become commonly used, they affect the rest of the cultural system. Neither Sherratt (1981, 1983) nor others (e.g. Greenfield 1988a; Legge 1989) concerned with testing the model ever explicitly stated that all secondary products began only with the Chalcolithic or Bronze Age. In fact, the issue of first origins is largely avoided in the early Secondary Products Revolution literature since the concern was on *changes in scale*. Later, Sherratt (1997: 31, fn. 8) also complained about the assumptions of 'over-literal' readers of his original texts to imply that there were no secondary uses of animals before the shift in scale towards secondary products. Given the length of time needed for the genetic changes to occur, there is no reason to think that domestic stock animals could not have been exploited on some level for their secondary products from the beginning of the Neolithic. For example, Sherratt always maintained that there was a change in the scale and extent of production that accompanied the rise of increasingly complex societies. The rising importance of secondary products exploitation would result in '*expansion* in the use of livestock, including both dairy cattle and subsequently wool-sheep' (Sherratt 1983: 100, emphasis added).

The larger question has always been and still is: 'What is the scale and nature of exploitation of the various secondary products in these early food producing societies?' Let us take milking as an example. The frequency of sherds with milk lipids in the British and Hungarian sample (25–30 per cent) indicates that milking was an important, but not necessarily the major form of or reason for animal exploitation in the Early Neolithic (Copley et al. 2003; Craig et al. 2000, 2005). Some lipid studies suggested that milk production was initially practised on a small scale as part of a broad mixed agro-pastoral economy (Craig et al. 2005: 882). To suggest that milking was the focus of production (e.g. Vigne and Helmer 2007: 12–13) is to stretch the data beyond what they can support and to confuse the issue of the initial appearance of milking with changes in scale of production. Chemical analyses of ceramics can at best indicate the presence or absence of milk in the pottery at a given site. Any particular vessel may have had multiple uses, including cooking and storage of a variety of foods (e.g. Henrickson and MacDonald 1983). The percentage of ceramic sherds with indications of milk isotopes may be much higher than the actual number of vessels used for milk storage or processing for a variety of reasons (Legge 2005). As a result, methods to determine the qualitative and quantitative importance of milking need to be developed. The opposite is true for wool. It took thousands of years for woolly sheep to develop from initial domestic stock. Wool must have slowly appeared, first as tufts on individual animals and later as the entire coat. Yet, we know little of this earliest phase of wool development.

Another related problem is the lure of finding the 'first' evidence for a particular new innovation. This affects the nature of research since it tends to focus on the origins rather than on their long-term effects. Hence, most data derive from the earliest periods, often ignoring or minimizing later periods. For example, the focus of most lipid studies has been on investigating initial (Neolithic) milking, rather than on comparing Neolithic and post-Neolithic practices. As a result, it is currently difficult to compare the supposed changes in scale of exploitation across time. This does not mean that finding early examples is not important, but that it biases our understanding of the larger picture.

Time is another issue that is often minimized. In order to determine changes in scale, it is best to use longitudinal (long-term) data within a single region with well-dated sequences (e.g. Arbuckle 2009; Cantuel et al. 2006; de Cupere et al. 2008; Greenfield 1988a, 2005; Greenfield and Fowler 2005; Helmer et al. 2007; Schibler 2006). Only after this level of analysis is completed can the next step be undertaken – inter-regional comparisons (Vigne and Helmer 2007).

A related issue is the relationship between individual harvest profiles and specific exploitation patterns. Zooarchaeologists have long struggled with the issue of monitoring changes in production strategies (Cribb 1987; Payne 1973; Reitz and Wing 1999). It is clearly difficult to identify shifts in production strategies from individual assemblages. It has been long recognized that equating single-period zooarchaeologically derived harvest profiles obtained from individual sites with specific animal exploitation patterns is a fruitless task (e.g. Greenfield 1988a). Zooarchaeological harvest profiles never perfectly match the patterns predicted by modern specialized animal exploitation (e.g. meat, milking, wool or traction) studies. Even when it is known from historical texts that herds are being exploited in a particular specialized manner, the harvest profiles of contemporary zooarchaeological samples never approach the theoretically expected age distributions (Russell 2004: 326). While harvest profiles can demonstrate that there were dramatic shifts in exploitation, other sources of evidence (e.g. lipids, pathologies, artefacts, ecofacts, pictures, texts, etc.) must be used to identify particular types of exploitation. Given all the problems noted above, it would seem that no single source of data provides unequivocal answers to all questions about the nature, intensity and history of secondary product exploitation.

Conclusion

It has been and is still commonly thought that the secondary animal products concept is exclusively attributed to Sherratt (for a recent example, see Vigne and Helmer 2007: 11). However, it is important to recognize the contributions of the different scholars whose research led to Sherratt's formulation. Contrary to common academic opinion (as reflected in overwhelming number of citations on secondary products citing Sherratt), it was not Sherratt but Bökönyi (1974) who first proposed the concept of a secondary revolution in the exploitation of domestic animals, i.e. that intensive milking had to be a later development given the nature of lactation patterns among wild and probably primitive domestic stock. Flannery (1965) was the first to argue that the origins of wool production had to occur several thousand years after domestication. This has been supported by the long-term research of Ryder (1987) and more recently by others (e.g. Good 2001).

Sherratt's contribution (1981, 1983) was to weave all these threads into a single coherent theory (or model), which could be tested by hypotheses, known as the Secondary Products Revolution. He attributed the origins of new technologies (wheeled vehicles and plough) and the intensification of the exploitation of domestic stock animals for their secondary products (milk, wool, and traction) to developments in the Chalcolithic of the Near East, whence it spread to Europe. He argued that these *innovations* in technology and animal exploitation strategies were part of the process that led to increasing urbanization and the rise of complex societies. Their diffusion from the Near East to temperate Europe resulted in changes in economy, settlement patterns and population distributions. Some of the economic changes in temperate Europe were the rising importance of secondary products, extensive method of farming and land clearance, colonization of the highlands, beginnings of pastoral transhumance in Europe, population dispersal across the landscape and marked increases in population.

Initially, most tests of the Secondary Products Revolution model were made by analysing the appearance of certain artefact types (e.g. ploughs, wheeled vehicles, etc.). By the middle 1980s, zooarchaeologists were testing the model with the more commonly available faunal data (i.e. harvest profiles) and largely confirmed the concept that there were dramatic changes in the scale of secondary products exploitation with the advent of the Chalcolithic.

Over a decade ago, Sherratt (1997) recognized that various lines of research supported or invalidated various aspects of his model. The Secondary Products Revolution model clearly needs to be revised in light of recent advances in the data. It is clear that milking has its origins in the Neolithic of the Near East and spreads with the first farmers to Europe, but intensification of production happens much later (during the Chalcolithic). It is not clear where wheeled vehicles first develop, but the earliest evidence for ploughing comes from the Near East. The spread of the plough and wheeled vehicles in Europe (during the Chalcolithic) coincides with dramatic shifts in harvest profiles indicating a preference for more adults in cattle herds, suggesting that cattle were more intensively exploited for traction from this point in time. In general, the data appear to support the Secondary Products Revolution model's proposal for a change in scale of exploitation for traction purposes. The model also appears to be relatively correct in the timing of the spread of woolly sheep, which appear earliest in the Near East (*c*. 4000 BC). Their spread from the Near East appears to coincide with the spread of the plough and wheeled vehicles into Europe (*c*. 3500–3000 BC).

The model is strongest conceptually in explaining the dramatic cultural changes beginning in the Chalcolithic. For example, milking does not appear to be the major reason for Neolithic cattle exploitation. Cattle had more important social and ritual functions in Neolithic cultures (e.g. in south-east European Late Neolithic Vinča, Central European LBK and Anatolian Pottery Neolithic), and their Neolithic harvest profiles do not indicate any preference for secondary product exploitation such as milk. The presence of milking alone did not change the nature of these communally oriented Neolithic societies which lived in closely packed or long houses. It was the combination of increased mobility and increased productive potential that was made available with the introduction the plough, wheeled vehicles and woolly sheep that led to the demise of the Neolithic lifestyle and the new more individual household-oriented cultural reconfiguration that appeared with the Chalcolithic of Anatolia and the Balkans and the later Neolithic of the northern Europe.

Thus, the innovations of the Secondary Products Revolution were part of a much larger cultural change occurring across vast areas of the Old World that included the dispersion and fragmentation of human groups, productive specialization and intensification, increasing social diversity and hierarchy, and cultural differentiation. These are part of the general transformation of cultures that occur across the Near East and Europe with the advent of the Chalcolithic (*c*. 6000 BC in Anatolia; 5000 BC in S Levant; 4000 BC in Greece; 3500 BC in the central Balkans; 3500 BC in Poland). These innovations in technology and subsistence have to be viewed within the context of these larger changes – they are not independent or single variable phenomena. But it is when the final combination of all four (not three – milk, wool, plough and wheel) innovations finally comes together that the dramatic cultural changes of the post-Neolithic occur.

Where the original Secondary Products Revolution model is weakest is in the view of these innovations as spreading as a 'package'. The innovations of the Secondary Products Revolution did not appear or spread at the same time. Milking appears earliest, followed by woolly sheep and carts and ploughs. Each type of secondary product has a unique history of appearance and nature of spread. There is regional and chronological variation in the appearance, spread and intensification of the different innovations.

The Secondary Products Revolution model has never been about when the first step toward an innovation occurred (e.g. milk drawn from an early domestic sheep, goat or cow or when the first woolly sheep appeared). It has always been about when and how did the scale of exploitation changes occur, and how did they create a series of changes that fundamentally altered human society. The model was proposed in order to recognize the difference between first origins and subsequent intensification, a distinction that often gets lost in the confusing terminology (of which we are all guilty), thereby sowing confusion in the mind of the reader.

The essence of what Sherratt was trying to weave together in his Secondary Products Revolution model was that, while all these individual strands are important and significant (and early occurrences thus worth identifying), the real impact on cultures comes with the application of these innovations on a large scale at the same time. Sherratt's Secondary Products Revolution model dramatically altered the discipline by providing a theoretical basis (with specific testable implications) for the investigation of later European prehistoric societies. In particular, it extended the theoretical debates surrounding the Neolithic origins of agriculture and food producing societies to the Chalcolithic and Bronze Age, thereby providing an intellectual validity for the study of later prehistoric and proto-historic societies beyond the limiting cachet of 'early complex societies'. Finally, it stimulated a generation of archaeologists to go back to the field and collect new and higher quality types of data (i.e. sieved animal remains). While the historical importance of Childe's Neolithic Revolution model for advancing the discipline has long been recognized, Sherratt's Secondary Products Revolution model should be similarly recognized.

Acknowledgement

I would like gratefully to acknowledge the timely and helpful comments provided by Tina L. (Jongsma) Greenfield, Arkadiusz Marciniak, the four anonymous reviewers and Marijke van der Veen during the preparation of this paper. It is only as a result of their constant patience, encouragement (and goading) and editorial comments that it was possible to complete the manuscript. The International Research and Exchanges Board, Fulbright-Hayes Program, National Science Foundation (USA), University of Manitoba, the Social Science and Research Council of Canada, and Team Poznan at Çatal Höyük excavations provided administrative and financial support for much of the research leading to the writing of this article. The views described above reflect my own and any errors are my own responsibility. This paper is dedicated both to the memory of Andrew Sherratt (who inspired my interest in zooarchaeology and provided me with an intellectual validity for my interests in later prehistoric and early proto-historic Old World societies) and to my family (for their continued support even though they were probably often neglected).

University of Manitoba
Greenf@cc.umanitoba.ca

Notes

1 There are other products that are rarely discussed in the context of Sherratt's model: blood, hair and manure (e.g. Guttmann et al. 2005). Blood and hair can be exploited as both primary and secondary products, depending upon the scale of usage. Manure is more clearly a secondary product. However, these are not part of Sherratt's Secondary Products Revolution model and are not discussed further.

2 While the chronological periods discussed in the paper use the traditional culture historical terminology (e.g. Neolithic), this does not mean that the same period is found at the same time everywhere or that each region went through the same evolutionary development at the same time (Fig. 1). The terms are used to signify major changes in the archaeological record characteristic of particular regions, such as the disintegration of early farming cultures and their reconfiguration into new cultural forms. For example, this takes place at the end of the Pottery (or Late) Neolithic of Anatolia (*c*. 6000 BC), the end of the Late Neolithic Vinča culture of the central Balkans (*c*. 3500 BC), the end of the Early Neolithic of Poland (LBK culture) (*c*. 3500 BC). All dates are based on calibrated radiocarbon dates unless otherwise noted.

References

Albarella, Umberto 1999. The animal economy after the eruption of Avellino pumice: the case of La Starza (Avellino, southern Italy). In *L'Eruzione Vesuviana delle 'pomici di avellino' e la Facies di Palma Campania (Bronzo antico): atti del Seminario Internazionale di Ravello 15–17 Iuglio 1994* (ed. C. A. Livadie). Bari: Edipuglia, pp. 317–30.

Amoroso, E. and Jewell, P. A. 1963. The exploitation of the milk-ejection reflex by primitive peoples. In *Man and Cattle* (eds A. E. Mourant and F. E. Zeuner). London: Royal Anthropological Institute of Great Britain and Ireland, pp. 126–37.

Anthony, D. W. 1995. Horse, wagon & chariot: Indo-European languages and archaeology. *Antiquity*, 69: 554–65.

Anthony, D. W. 2007 *The Horse, the Wheel, and Language: How Bronze-Age Riders from the Eurasian Steppes Shaped the Modern World*. Princeton, NJ: Princeton University Press.

Arbuckle, B. S. 2009 Chalcolithic caprines, Dark Age dairy, and Byzantine beef: a first look at animal exploitation at Middle and Late Holocene Çadır Höyük, north central Turkey. *Anatolica*, 35: 179–224.

Arnold, E. R. and Greenfield, H. J. 2006. *The Origins of Transhumant Pastoralism in Temperate Southeastern Europe: A Zooarchaeological Perspective from the Central Balkans*. Oxford: British Archaeological Reports, International Series 1538.

Baker, J. and Brothwell, D. 1980. *Animal Diseases in Archaeology*. New York: Academic Press.

Bakker, J. A., Kruk, J., Lanting, A. L., and Milisauskas, S. 1999. The earliest evidence of wheeled vehicles in Europe and the Near East. *Antiquity*, 73: 778–90.

Bar-Adon, P. 1980. *The Cave of the Treasure: The Finds from Nahal Mishmar*. Jerusalem: Israel Exploration Society.

Barber, E. J. W. 1991 *Prehistoric Textiles: The Development of Cloth in the Neolithic and Bronze Ages*. Princeton, NJ: Princeton University Press.

Bartosiewicz, L., Van Neer, W. and Lentacker, A. 1997. *Draught Cattle: Their Osteological Identification and History*. Annalen, Zoologische Wetenschappen 281. Tervuren, Belgium: Koninklijk Museum voor Midden-Afrika.

Bocherens, H., Billiou, D., Charpentier, V. and Mashkour, M. 2000. Palaeoenvironmental and archaeological implications of bone and tooth isotopic biogeochemistry (13C 15N) in southwestern Asia. In *Archaeozoology of the Near East IV* (eds M. Mashkour, A. M. Choyke, H. Buitenhuis and F. Poplin). Groningen: ARC, pp. 104–15.

Bogucki, P. 1984. Linear Pottery ceramic sieves and their economic implications. *Oxford Journal of Archaeology*, 3: 15–30.

Bogucki, P. 1986. The antiquity of dairying in temperate Europe. *Expedition*, 28: 51–8.

Bogucki, P. 1993. Animal traction and household economies in Neolithic Europe. *Antiquity*, 67: 492–503.

Bökönyi, S. 1974. *History of Domestic Mammals in Central and Eastern Europe*. Budapest: Akademiai Kiado.

Bökönyi, S. 1977. *The Animal Remains of Four Sites in the Kermanshah Valley, Iran: Asiab, Dehsavar and Siahbid: The Faunal Evolution, Environmental Changes and Development of Animal Husbandry VII–III Millennia BC*. Oxford: British Archaeological Reports, ISS 34.

Cantuel, J., Gardeisen, A. and Renard, J. 2006. L'exploitation de la faune durant le Néolithique dans le bassin Égéen. In *Archaeozoology of the Near East VIII: Proceedings of the Eighth International Symposium on the Archaeozoology of Southwestern Asia and Adjacent Areas*, Vol. 2 (eds E. Vila, L. Gourichon, A. M. Choyke and H. Buitenhuis). Lyon: Archéorient, Maison de l'Orient et de la Méditerranée, pp. 279–98.

Chapman, J. C. 1982. The Secondary Products Revolution and the limitations of the Neolithic. *Bulletin of the Institute of Archaeology*, 19: 107–22.

Clark, G. 1991. The contribution of faunal analyses to the study of prehistoric and historical pastoralism in Italy. *Rivista di Studi Liguri*, 57(1–4): 73–80.

Clutton-Brock, J. 1981. *Domesticated Animals from Early Times*. London: British Museum (Natural History)/Heinemann.

Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, A. J., Straker, V., Payne, S. and Evershed, R. P. 2003. Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences of the USA*, 100: 1524–9.

Craig, O. E., Mulville, J., Parker Pearson, M., Sokol, R., Gelsthorpe, K., Stacey, R. and Collins, M. 2000. Detecting milk proteins in ancient pots. *Nature*, 408: 312.

Craig, O. E., Chapman, J., Heron, C., Willis, L. H., Bartosiewicz, L., Taylor, G., Whittle, A. and Collins, M. 2005. Did the first farmers of central and eastern Europe produce dairy food? *Antiquity*, 79: 882–94.

Cribb, R. 1987. *The Logic of the Herd: A Computer Simulation of Archaeological Herd Structure*. Cambridge: Cambridge University Press.

Davis, S. 1984. The advent of milk and wool production in western Iran: some speculations. In *Animals and Archaeology*, Vol. 3, *Early Herders and their Flocks* (eds C. Grigson and J. Clutton-Brock). Oxford: British Archaeological Reports, International Series 202, pp. 265–78.

de Cupere, A., Lentacker, A., Van Neer, W., Waelkens, M. and Verslype, L. 2000. Osteological evidence for the draught exploitation of cattle: first applications of a new methodology. *International Journal of Osteoarchaeology*, 10: 254–67.

de Cupere, B., Duru, R. K. and Umurtak, G. 2006. Animal husbandry at the Early Neolithic to Early Bronze Age site of Bademağacy (Antalya province, SW Turkey): evidence from the faunal remains. In *Archaeozoology of the Near East VIII: Proceedings of the Eighth International Symposium on the Archaeozoology of Southwestern Asia and Adjacent Areas*, Vol. 2 (eds E. Vila, L. Gourichon, A. Choyke and H. Buitenhuis). Lyon: Archéorient, Maison de l'Orient et de la Méditerranée, pp. 367–406.

Evershed, R. P., Payne, S., Sherratt, A. G., Copley, M. S., Coolidge, J., Urem-Kotsu, D., Kostas, K., Özdogan, M., Özdogan, A., Nieuwenhuysen, O., Akkermans, P. M. M., Bailey, D., Andeescu, R.-R., Campbell, S., Farid, S., Hodder, I., Yalman, N., Özbasaran, M., Bycaky, E., Garfinkel, Y., Levy, T. and Burton, M. M. 2008. Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature*, 455: 528–31.

Fansa, M. and Burmeister, S. (eds) 2004. *Rad und Wagen: Der Ursprung einer Innovation: Wagen im Vorderen Orient und Europa (Wheel and Wagon: Origins of an Innovation)*. Mainz am Rhein: Verlag Philipp von Zabern.

Flannery, K. V. 1965. The ecology of early food production in Mesopotamia. *Science*, 147(3663): 1247–56.

Gabałówna, L. 1970. Wyniki analizy C-14 wegli drzewnych z cmentarzyska kultury pucharów lejkowatych na stanowisku 1 w Sarnowie z grobowca 8 i niektóre problemy z nimi zwiazane. *PMMAiE w Łodzi, Seria Archeologiczna,* 17.

Giblin, J. I. 2008. Strontium isotope analysis of Neolithic and Copper Age populations on the Great Hungarian Plain. *Journal of Archaeological Science*, 36: 491–7.

Good, I. L. 1999. The ecology of exchange: textiles from 3rd millennium BC Iran. Doctoral dissertation, Department of Anthropology, University of Pennsylvania, Pittsburgh.

Good, I. L. 2001. Archaeological textiles: a review of current research. *Annual Reviews of Anthropology*, 30: 209–26.

Green, M. 1980. Animal husbandry at Uruk in the Archaic period. *Journal of Near Eastern Studies*, 39: 1–35.

Green, M. W. and Nissen, H. J. 1987. *Zeichenliste der Archaischen Texte aus Uruk*. Ausgrabungen der Deutschen Forschungsgemeinschaft in Uruk-Warka no. 11. Berlin: Gebr. Mann Verlag.

Greenfield, H. J. 1984. A model of changing animal exploitation strategies during the later prehistory of the central Balkans. In *Animals and Archaeology*, Vol. 4 (eds J. Clutton-Brock and C. Grigson). Oxford: British Archaeological Reports, ISS 227, pp. 45–55.

Greenfield, H. J. 1986. *The Paleoeconomy of the Central Balkans (Serbia): A Zooarchaeological Perspective on the Late Neolithic and Bronze Age (4500–1000 BC)*. Oxford: British Archaeological Reports, International Series 304.

Greenfield, H. J. 1988a. The origins of milk and wool production in the Old World: a zooarchaeological perspective from the Central Balkans. *Current Anthropology*, 29: 573–93.

Greenfield, H. J. 1988b. On the origins of milk and wool production in the Old World: reply to comments. *Current Anthropology*, 29: 743–8.

Greenfield, H. J. 2005. A reconsideration of the secondary products revolution: 20 years of research in the central Balkans. In *The Zooarachaeology of Milk and Fats (Proceedings of the 9th ICAZ Conference, Durham 2002)* (eds J. Mulville and A. Outram). Oxford: Oxbow, pp. 14–31.

Greenfield, H. J. and Fowler, K. D. 2003. Megalo Nisi Galanis and the Secondary Products Revolution in Macedonia. *Annual of the British School at Athens*, 9: 145–51.

Greenfield, H. J. and Fowler, K. D. 2005. *The Secondary Products Revolution in Macedonia: The Faunal Remains from Megalo Nisi Galanis, A Late Neolithic-Early Bronze Age Site in Greek Macedonia*. Oxford: British Archaeological Reports, International Series 1414.

Gregg, M. W., Banning, E. B., Gibbs, K. and Slater, G. F. 2009. Subsistence practices and pottery use in Neolithic Jordan: molecular and isotopic evidence. *Journal of Archaeological Science*, 36: 937–46.

Grigson, C. 1995. Plough and pasture in the early economy of the southern Levant. In *The Archaeology of Society in the Holy Land* (ed. T. E. Levy). New York: Facts on File, pp. 245–68.

Guttmann, E., Simpson, I. and Davidson, D. 2005 Manuring practices in Antiquity: a review of the evidence. In *Fertile Ground: Papers in Honour of Susan Limbrey* (eds D. N. Smith, M. B. Brickley and W. Smith). Symposia of Association for Environmental Archaeology, Vol. 22. Oxford: Oxbow, pp. 68–76.

Hall, H. R. and Woolley, C. L. 1927. *Al-'Ubaid: Ur Excavations*, Vol. 1. Oxford: Oxford University Press.

Halstead, P. 1992. Agriculture in the Bronze Age Aegean: towards a model of palatial economy. In *Agriculture in Ancient Greece: Proceedings of the Seventh International Symposium at the Swedish Institute at Athens, 16–17 May, 1990* (ed. B. Wells). Stockholm: Paul Åströms Förlag, pp. 105–17.

Halstead, P. 1996. Pastoralism or household herding? Problems of scale or specialization in early Greek animal husbandry. *World Archaeology*, 28: 20–42.

Halstead, P. 1998. Mortality models and milking: problems of uniformitarism, optimality and equifinality reconsidered. *Anthropozoologica*, 27: 3–20.

Halstead, P. 1999. Missing sheep: on the meaning and wider significance of *O* in Knossos sheep records. *Annual of the British School at Athens*, 94: 146–66.

Harrison, R. J. 1985. The 'Policultivo Ganadero', or the Secondary Products Revolution in Spanish agriculture, 5000–1000 BC. *Proceedings of the Prehistoric Society*, 51: 75–102.

Helmer, D., Gourichon, L. and Vila, E. 2007. The development of the exploitation of products from Capra and Ovis (meat, milk and fleeces) from the PPNB to the Early Bronze in the northern Near East (8700 to 2000 BC cal.). *Anthropozoologica*, 42: 41–69.

Henrickson, E. F. and McDonald, M. M. A. 1983. Ceramic form and function: an ethnographic search and an archeological application. *American Anthropologist*, 85: 630–43.

Horwitz, L. K. and Smith, P. 1984 Radiographic evidence for changing patterns of animal exploitation in the Southern Levant. *Journal of Archaeological Science*, 11: 467–75.

Horwitz, L. K. and Tchernov, E. 1989 Animal exploitation in the Early Bronze Age of the southern Levant: an overview. In *L'urbanisation de la Palestine à l'âge du Bronze ancien* (ed. P. de Miroschedjii). Oxford: British Archaeological Reports, International Series 527, pp. 279–96.

Hüster-Plogmann, H. and Schibler, J. 1997. Archäozoologie. In *Ökonomie und Ökologie Neolithischer und Bronzezeitlicher Ufersiedlungen am Zürichsee. Ergebnisse der Ausgrabungen Mozartstrasse, Kanalisationssanierung Seefeld* (eds J. Schibler, H. Hüster-Plogmann, S. Jacomet, C. Brombacher, E. Gross-Klee and A. Rast-Eicher). Monographien der Kantonsarchäsologie Zürich, Bd. 20. Zürich: AKAD/Pressehaus und Mythenschloss in Zürich and Egg, pp. 40–121.

Isaakidou, V. 2006. Ploughing with cows: Knossos and the 'Secondary Products Revolution'. In *Animals in the Neolithic* (eds D. Serjeantson and D. Field). Oxford: Oxbow, pp. 95–112.

Isaakidou, V. 2008. The fauna and economy of Neolithic Knossos revisited. In *Escaping the Labyrinth: The Cretan Neolithic in Context* (eds V. Isaakidou and P. Tomkins). Oxford: Oxbow, pp. 90–114.

Johannsen, N. 2005. Palaeopathology and Neolithic cattle traction: methodological issues and archaeological perspectives. In *Diet and Health in Past Animal Populations: Current Research and Future Directions* (eds J. Davies, M. Fabiš, I. Mainland, M. Richards and R. Thomas). Oxford: Oxbow, pp. 39–51.

Johannsen, N. 2006. Draught cattle and the South Scandinavian economies of the 4th millennium BC. *Journal of Environmental Archaeology*, 11: 93–109.

Kawami, T. S. 2001. The cattle of Uruk: stamp seals and animal husbandry in the Late Uruk/Jemdet Nasr Period. In *Seals and Seal Impressions* (eds W. W. Hallo and I. J. Winter). Proceedings of the XLV Rencontre Assyriologique International, Part II. Bethesda, MD: CDL Press, pp. 31–48.

Kirtcho, L. B. 2009. The earliest wheeled transport in southwestern Central Asia: new finds from Altyn-Depe. *Archaeology, Ethnology and Anthropology of Eurasia*, 37: 25–33.

Kotjabopoulou, E., Hamilakis, Y., Halstead, P. and Gamble, C. 2003. *Zooarchaeology in Greece: Recent Advances (Annual of the British School at Athens 9)*. Athens: British School at Athens.

Kruk, J. and Milisauskas, S. 1999. *Rozkwit i upadek społeczeństw rolniczych neolitu*. Kraków: Instytut Archeologii i Etnologii Polskiej Akademii Nauk.

Legge, A. J. 1981. Aspects of cattle husbandry. In *Grimes Graves, Norfolk Excavation: 1971–72*, Vol. 1 (ed. R. Mercer). London: HMSO, pp. 79–103.

Legge, A. J. 1989. Milking the evidence: a reply to Entwhistle and Grant. In *The Beginnings of Agriculture* (eds A. Milles, D. Williams and N. Gardner). Oxford: British Archaeological Reports, International Series 496, pp. 217–42.

Legge, A. J. 1992. *Excavations at Grimes Graves, Norfolk 1972–1976: Animals, Environment and the Bronze Age Economy*. London: British Museum Press.

Legge, A. J. 1994. The animal remains and their interpretation. In *Moncín: Un Poblado de la Edad del Bronce (Borja, Zaragoza)* (eds R. J. Harrison, G. C. Moreno-López and A. J. Legge). Gobierno de Aragon, Zaragoza: Cometa, pp. 453–82.

Legge, A. J. 2005. Milk use in prehistory: the osteological evidence. In *The Zooarchaeology of Fats, Oils, Milk and Dairying (Proceedings of the 9th ICAZ conference)* (eds J. Mulville and A. Outram). Oxford: Oxbow, pp. 8–13.

Leuzinger, U. 2002. Holzartefakte. In *Die jungsteinzeitliche Seeufersiedlung Arbon/Bleiche 3: Funde* (eds A. de Capitani, S. Deschler-Erb, U. Leuzinger, E. Marti-Grädel and J. Schibler). *Archäologie im Thurgau*, 11: 76–114.

Li, Z. 2009. Archaeozoology at Anyang. *International Council for Archaeozoology Newsletter*, 10(2): 5.

Lillios, K. T. 1992. Phosphate fractionation of soils at Agroal, Portugal. *American Antiquity*, 57: 495–506.

Lyman, R. L. 1994. *Vertebrate Taphonomy*. Cambridge: Cambridge University Press.

Marciniak, A. 2005. *Placing Animals in the Neolithic: Social Zooarchaeology of Prehistoric Farming Communities*. London: University College London Press.

Marciniak, A. 2008. Communities, households and animals: convergent developments in Central Anatolia and Central European Neolithic. *Documenta Praehistorica*, 35: 93–109.

Marciniak, A. and Czerniak, L. 2007. Social transformations in the Late Neolithic and the Early Chalcolithic periods in central Anatolia. *Anatolian Studies*, 57: 115–30.

Mashkour, M. 2002. Chasse et élevage au nord du Plateau central iranien entre le Néolithique et l'Âge du Fer. *Paléorient*, 28: 27–42.

Mateescu, C. N. 1975. Remarks on cattle breeding and agriculture in the Middle and Late Neolithic on the lower Danube. *Dacia*, 19: 13–18.

McCorriston, J. 1997. The fiber revolution. *Current Anthropology*, 38(4): 517–48.

Milisauskas, S. and Kruk, J. 1991. Utilization of cattle for traction during the later Neolithic in southeastern Poland. *Antiquity*, 65: 562–6.

Miller, L. J. 2003. Secondary products and urbanism in South Asia: the evidence for traction at Harappa. In *Indus Ethnobiology: New Perspectives from the Field* (eds S. Weberand and W. R. Belcher). Lanham, MD: Lexington, pp. 251–326.

Miller, L. J. 2004. Urban economies in early states: the Secondary Products Revolution in the Indus civilization. Doctoral dissertation, Department of Anthropology, New York University.

Moortgart, A. 1969. *The Art of Ancient Mesopotamia: The Classical Art of the Near East*. London and New York: Phaidon.

Mulville, J. and Outram, A. (eds) 2005. *The Zooarchaeology of Fats, Oils, Milk and Dairying (9th ICAZ conference proceedings)*. Oxford: Oxbow.

Olsen, S. L., Grant, S., Choyke, A. M. and Bartosiewicz, L. 2006. *Horses and Humans: The Evolution of Equine-Human Relationships*. Oxford: British Archaeological Reports, International Series 1560.

Outram, A., Stear, N. A., Bendrey, R., Olsen, S. L., Kasparov, A., Zaibert, V., Thorpe, N., and Evershed, R. P. 2009. The earliest horse harnessing and milking. *Science*, 6 March.

Østergaard, J. S. 2005. Lîga: Copper Age strategies in Bulgaria. *Acta Archaeologica (Copenhagen)*, 76(1): 132–9.

Payne, S. 1973. Kill-off patterns in sheep and goats: the mandibles from Aşvan Kale. *Anatolian Studies*, 23: 281–303.

Phoca-Cosmetatou, N. 2008. Economy and occupation in the Cyclades during the Late Neolithic: the example of Ftelia, Mykonos. In *Horizon: A Colloquium on the Prehistory of the Cyclades* (eds N. J. Brodie, J. Doole, G. Gavalas and C. Renfrew). Cambridge: McDonald Institute for Archaeological Research, pp. 37–43.

Piggott, S. 1981. *The Earliest Wheeled Transport: From the Atlantic Coast to the Caspian Sea*. Ithaca, NY: Cornell University Press.

Pollock, S. 1999. *Ancient Mesopotamia: The Eden that Never Was*. Cambridge: Cambridge University Press.

Redding, R. 1984. Theoretical determinants of a herder's decisions modeling variation in the sheep/goat ratio. In *Animals and Archaeology*, Vol. 3, *Early Herders and their Flocks* (eds J. Clutton-Brock and C. Grigson). Oxford: British Archaeological Reports, ISS 202, pp. 223–42.

Reitz, E. and Wing, E. 1999. *Zooarchaeology*, 2nd edn. Cambridge: Cambridge University Press.

Ruoff, U. and Jacomet, S. 2002. Die Datierung des Rades von Zürich-Akad und die stratigraphische Beziehung zu den Rädern von Zürich-Pressehaus. In *Schleife, Schlitten, Rad und Wagen: Zur Frage früher Transportmittel nördlich der Alpen* (eds J. Köninger, M. Mainberger, H. Schlichtherle and M. Vosteen). Landesdenkmalamt Baden-Württemberg: Gaienhofen-Hemmenhofen, pp. 35–7.

Rowley-Conwy, P. 1987. The interpretation of ard marks. *Antiquity*, 61: 263–66.

Rowley-Conwy, P. 2000. Milking caprines, hunting pigs: the Neolithic economy of Arene Candide in its West Mediterranean context. In *Animal Bones, Human Societies* (ed. P. Rowley-Conwy). Oxford: Oxbow, pp. 124–32.

Russell, N. 2004. Milk, wool, and traction: secondary animal products. In *Ancient Europe 8000 B.C.–A.D. 1000: Encyclopedia of the Barbarian World* (eds P. Bogucki and P. J. Crabtree). Farmington Hills, MI: Scribner, pp. 325–33.

Russell, N. and Martin, L. 2005. Çatalhöyük mammal remains. In *Inhabiting Çatalhöyük: Reports from the 1995–99 Seasons* (ed. I. Hodder). Cambridge: Monograph of the McDonald Institute and the British Institutes of Archaeology at Ankara, pp. 33–98.

Russell, N. and Meece, S. 2006. Animal representations and animal remains at Çatalhöyük. In *Çatalhöyük Perspectives: Reports from the 1995–99 Seasons* (ed. I. Hodder). Cambridge: Monograph of the McDonald Institute and the British Institutes of Archaeology at Ankara, pp. 209–30.

Ryder, M. L. 1983. *Sheep and Man*. London: Duckworth.

Ryder, M. L. 1987. The evolution of the fleece. *Scientific American*, 257: 112–19.

Ryder, M. L. 1992. Wool fibres in cloth remains throw light on fleece evolution. *Circaea*, 9: 7–9.

Schibler, J. 2006. Economy and environment in the northern Alpine foreland. *Environmental Archaeology*, 11: 49–64.

Schibler, J., Hüster-Plogmann, H., Jacomet, S., Brombacher, C., Gross-Klee, E. and Rast-Eicher, A. 1997. *Ökonomie und Ökologie Neolithischer und Bronzezeitlicher Ufersiedlungen am Zürichsee. Ergebnisse der Ausgrabungen Mozartstrasse, Kanalisationssanierung Seefeld.* Monographien der Kantonsarchäologie Zürich, Bd. 20. Zürich: AKAD/Pressehaus und Mythenschloss in Zürich.

Sherratt, A. G. 1981. Plough and pastoralism: aspects of the Secondary Products Revolution. In *Pattern of the Past* (eds I. Hodder, G. Isaac and N. Hammond). Cambridge: Cambridge University Press, pp. 261–306.

Sherratt, A. G. 1983. The Secondary Products Revolution of animals in the Old World. *World Archaeology*, 15: 90–104.

Sherratt, A. G. 1986. Wool, wheels, and ploughmarks: local developments or outside introductions in Neolithic Europe? *Bulletin of the Institute of Archaeology*, 2: 31–15.

Sherratt, A. G. 1997. *Economy and Society in Prehistoric Europe: Changing Perspectives*. Princeton, NJ: Princeton University Press.

Sherratt, A. G. 2006. La traction animale et la transformation de l'Europe néolithique. In *Premiers chariots, premiers araires: La diffusion de la traction animale en Europe pendant les IVe et IIIe millénaires avant notre ére* (eds P. Pétrequin, R-M. Arbogast, A-M. Pétrequin, S. van Willigen and M. Bailly). Paris: CNRS, pp. 329–60.

Spangenberg, J. E., Jacomet, S. and Schibler, J. 2006. Chemical analyses of organic residues in archaeological pottery from Arbon Bleiche 3, Switzerland: evidence for dairying in the late Neolithic. *Journal of Archaeological Science*, 33: 1–13.

Tegtmeier, U. 1993. *Neolithische und bronzezeitliche Pflugspuren in Norddeutschland und den Niederlanden*. Archäologische Berichte 3. Bonn: Wissenschaftlicher Verlag/Medien.

Tringham, R., Brukner, B. 1985. The Opovo Project: A study of socioeconomic change in the Balkan Neolithic. *Journal of Field Archaeology*, 12: 425–44.

Vigne, J.-D. and Helmer, D. 2007. Was milk a 'secondary product' in the Old World Neolithisation process? Its role in the domestication of cattle, sheep and goats. *Anthropozoologica*, 42: 9–40.

Wiślański, T. 1969. *Podstawy gospodarcze plemion neolitycznych w Polsce północno–zachodniej*. Wrocław: Ossolineum.

Wright, H. T. 1980. *An Early Town on the Deh Luran Plain: Excavations at Tepe Farukhabad*. University of Michigan Museum of Anthropology Memoir 13. Ann Arbor: University of Michigan Museum of Anthropology.

Zeder, M. A., Bradley, D. G., Emshwiller, E. and Smith, B. D. (eds) 2006. *Documenting Domestication: New Genetic and Archaeological Paradigms*. Berkeley: University of California Press.

Haskel J. Greenfield, PhD, CUNY, 1985, is currently a full Professor of Anthropology at the University of Manitoba, Winnipeg, Canada. His research focuses on the evolution of early agricultural and complex societies in the Old World, specializing in zooarchaeology, spatial analysis, and ancient butchering technology. Aside from his research on the Secondary Products Revolution, he has also conducted extensive studies of regional subsistence and land use systems, the spatial dynamics of intra-settlement organization, and the spread of new technologies (i.e. metallurgy) in the Neolithic, Bronze and Iron Ages of Europe, Near East, and southern Africa. Most recently, he has been studying the spatial organization of Early Bronze Age communities in the Near East by examining the distribution of faunal remains from early urban sites in SE Turkey and Israel.