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A new system for computing dentition-based age profiles in *Sus scrofa*

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ABSTRACT

Reconstructing demographic profiles is valuable for revealing animal exploitation strategies at archaeological sites. For pig (*Sus scrofa*), the method presented by Grant (1982) demonstrates a promising technique for estimating age through dental wear pattern analysis. Grant's study is, however, limited as it requires complete or nearly complete mandibles, exclusively uses mandibular teeth, and offers only a relative scale for aging. While some work has been done to establish useful age classes based on tooth eruption and wear patterns in *S. scrofa*, a systematic study producing a standardized and comprehensive methodology for using tooth wear to age pigs remains to be conducted.

The study presented here is part of ongoing research aimed at developing new methods for the construction of *S. scrofa* demographic profiles based on *both* dentition and long bone fusion. In this paper, we present the results of a study of eruption and wear patterns in a large modern assemblage of wild boar which provides the basis for a new method for constructing pig harvest profiles and addresses some of the most serious limitations of Grant's earlier study. The utility of this method in detecting subtle differences in pig prey/harvest profiles is demonstrated through its application to three Near Eastern archaeological assemblages from three distinct time periods: Bronze Age Tell Leilan, Halafian Banahilk, and Epipaleolithic Hallan Çemi, where residents likely employed widely different pig exploitation strategies. The results of these case studies demonstrate the ability of this method to reliably reconstruct age demography and distinguish age profiles between sites with different animal procurement strategies. This method provides a standardized means of collecting accurate and reliable age data crucial in examining patterns of past pig exploitation.

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1. Introduction

Reconstructing the demographic profiles of faunal remains from archaeological sites is essential for revealing the nature of past animal exploitation strategies. Previous work on a wide diversity of species has shown that construction of demographic profiles based on both dental eruption and wear and long bone fusion is a powerful tool for detecting a wide variety of anthropogenic and non-anthropogenic factors that structure prey populations in the past (Davis, 1983; Klein, 1982; Payne, 1973; Stiner, 1990; Zeder, 1991 to name just a few). Demographic profiles have also proven especially useful in tracking the process of animal domestication (Hole et al., 1969; Hesse, 1978; Zeder and Hesse, 2000). Emphasizing the human behavior behind animal procurement, demographic profiles for age and sex composition of harvested animals are capable of revealing subtle patterns in human animal management strategies not visible when utilizing other markers of domestication such as morphology or genetics. Instead, they provide a flexible medium that is capable of documenting even incipient or intermediary episodes in the continuum of human intervention from hunting to herding (Zeder, 2006a).

The sequence and rates of both long-bone fusion and dental eruption and attrition have been used successfully to reconstruct such age profiles at archaeological sites (Ervynck, 1997; Ervynck et al. 2001; Fandén, 2005; Hongo and Meadow, 1998; Hole et al. 1969; Magnell, 2005; Payne, 1973; Rolett and Chiu, 1994; Zeder, 2006a,b). For domestic caprines (Greenfield and Arnold, 2008; Zeder, 2006c) and gazelle (Munro et al. 2009) there has been significant success in calibrating both fusion and dental techniques, establishing age classes with meaningful and useful definitions that can be applied to archaeological assemblages.

These methods have also been applied to pig (*Sus scrofa* spp.) remains, and a quick inspection of the literature reveals a healthy amount of work towards establishing similarly useful methods for constructing demographic profiles in this important species,

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especially methods focusing on dental criteria (Anezaki, 2009; Bull and Payne, 1982; Carter and Magnell, 2007; Grant, 1982; Hongo and Meadow, 1998; Magnell, 2002; Matschke, 1967; Rolett and Chiu, 1994). The problem with these studies is not that the existing body of work is insubstantial or unreasonable, but rather how little these studies agree with one another, and how often they fail to provide an adaptable method that can be confidently reproduced with diverse assemblages from widely differing cultural contexts.

What these studies do have in common is their use of the method introduced by Grant (1982), which serves as their foundation for documenting pig dental wear-patterns. While these efforts at constructing methods for computing dentition based demographic profiles for pig have benefited from this landmark work, they have also inherited some of the limitations of Grant's method. Principle among these is that the method can only be applied to complete, or nearly complete, mandibles dramatically limiting the sample size of ageable remains. Moreover, the method was developed for use on exclusively mandibular and not maxillary dentition, another limitation that reduces sample size. Finally, the method uses only a relative, or floating, scale for aging specimens that is unanchored to the animal's actual age of death (Grant, 1982).

In marked contrast to the focus on developing dentition based demographic profiles in pigs, there has been little parallel attention to the development of aging methods based on pig long bone fusion sequences. While Payne and Bull's study of a population of wild Turkish boar brought new rigor and resolution to computing long bone fusion based pig demographic profiles (Bull and Payne, 1982), most archaeozoologists still turn to the early work of Silver (1969) and Habermehl (1975) to affix long bone fusion age profiles, despite their partial reliance on 19th century data of uncertain origin or accuracy (Legge, 2013).

The study presented here is part of ongoing research aimed at developing new methods for the construction of both domestic and wild *S. scrofa* spp. demographic profiles based on *both* dentition and long bone fusion. In this paper, we present the results of a study of eruption and wear patterns in a large modern assemblage of wild boar which provides the basis for a new method for constructing pig harvest profiles and addresses some of the most serious limitations of Grant's earlier study. The utility of this method in detecting subtle differences in pig prey profiles is demonstrated through its application to three archaeological assemblages from sites whose residents likely employed widely different pig exploitation strategies. Ultimately, this study seeks to move closer to the realization of a comprehensive and definitive methodology for collecting accurate and reliable age data that is crucial to examining patterns of archaeological pig exploitation.

2. Method: a revision

2.1. The modern sample

The modern specimens utilized in this study derive from the Zoology Department of the Field Museum of Natural History in Chicago (FMNH), the Division of Mammals of the National Museum of Natural History in Washington (NMNH), and Sebastian Payne's personal collection of Turkish wild boar utilized in the original 1982 study (Bull and Payne, 1982). A total of 91 corresponding maxillae and mandibles were analyzed for this study, including 46 females, 39 males, and 6 specimens of undetermined sex (Table S1). The specimens analyzed in this sample have a wide distribution across Eurasia. FMNH specimens are primarily comprised of Near Eastern wild boar, with some Indian and Chinese specimens, as well as one Polish wild boar included. These animals were collected by various collectors and expeditions—including the Street Expedition to Iran in 1968, the Field Museum's Near Eastern Expedition in 1934, the Braidwood archaeological expeditions in Iraq and Iran in the 1950s and 1960s, and the Roosevelt and Faunthorpe expeditions to India in the 1920s. NMNH specimens are comprised of mostly Chinese wild boar from expeditions in the early and mid 19th century by A.C. Sowerby and D.C. Graham. The Payne specimens were all collected during the winter of 1974–1975 from forests around Kızılcahamam in central Anatolia in Turkey (Bull and Payne, 1982); this large sample of specimens from a single population mitigates problems that might arise from using animals from a wide geographic range such as those studied here from NMNH and FMNH collections. All animals were identified as wild *S. scrofa* based on information from the expeditions, collectors, and context of locale. Age at death information was not provided for any of the specimens in this sample, and skulls showing wear due to pathologies were not included in the final dataset.

Additionally, the sample was limited to wild boar to control for effects of different nutrition regimes or improved breeding programs on the timing and sequence of tooth eruption and wear in domestic pigs. At least in regards to eruption, however, a recent review of pig molar eruption studies by the late Tony Legge shows that claims of accelerated dental development in domestic pigs may not be entirely substantiated (Legge, 2013). As for the scoring of attrition patterns, we expect that the sequence of wear scores and the resulting age classifications will not vary despite differences in diet and nutrition, because these are shaped by the morphology of pig jaws and the mechanics of how pigs chew, which do not change. The timing of these age classes to absolute ages as well as the duration of a given age class may vary by region and diet, but the relative sequence should remain the same. Thus, while the ages tied to age classes may not agree across wild and domestic pigs, the relative order and composition (i.e. the scores of individual teeth that compose an age class) should. A systematic study of such differences in well-documented modern specimens would provide much needed empirical rigor to the anecdotal or purely hypothetical conjectures about the varying impact of factors like region and diet on tooth wear in pigs and other mammals that cloud the current literature on the subject (see discussion in Moran and O'Connor, 1994).

2.2. New rules

For this study we devised a scoring system for individual teeth—from **0** (pre-developmental absence) through **19** (heaviest wear) (Table 1 and Fig. 1). This system captures the complete history of a tooth, from prior to its emergence (score **0**), through its formation (**1**–**3**), eruption (**4**–**6**), and duration of use throughout the animal's life (**7**–**19**). Finding a close correspondence between visible wear patterns on the modern sample and Grant's tooth wear stages (**a**–**n**), we adapted Grant's drawings of wear stages to characterize wear patterns on teeth following the complete eruption of the tooth (**7**–**19**) (1982:94). Scores for earlier developmental and erupting phases of teeth (**0**–**6**) were compiled from studies conducted in both archaeology and animal sciences on timing and identifying distinct developmental stages of pig teeth (Carter and Magnell, 2007; Matschke, 1967; Bull and Payne, 1982; Tucker and Widowski, 2009).

These individual scores can be grouped into broader categories (Table 1): **0**–**3** for teeth that are either unerupted or forming in the jaw, **4**–**6** for teeth that are in various stages of eruption, **7**–**9** for teeth that are in light stages of wear with only small amounts of dentine exposed on cusps, **10**–**12** for moderate wear stages in which progressively more dentine is exposed, **13**–**16** for heavy wear in which large areas of exposed dentine are ringed by thin margins of enamel, and **17**–**19** which represent teeth with little or no enamel left on occlusal surfaces to teeth in which the crowns are

Table 1
Tooth eruption and wear scale. "TWS" refers to tooth wear stages developed by Grant (1982) and re-illustrated for this system (see Fig. 1, colors correspond to color coding in Tables S2, S3, and S4.).

Score	Description	
0	Unerupted	
1	Perforation in crypt	Formation
2	Tooth visible in crypt	
3	Mineralization of crown complete (from Carter and Magnell 2007)	
4	Tooth erupting through bone	Eruption
5	Tooth 1/2 erupted	
6	Tooth fully erupted with no visible wear	
7	Enamel wear only (TWS a)	Light Wear
8	TWS b	
9	TWS c	
10	TWS d	Moderate Wear
11	TWS e	
12	TWS f	
13	TWS g	Heavy Wear
14	TWS h	
15	TWS j	
16	TWS k	
17	TWS l	Extreme Wear
18	TWS m	
19	TWS n	
S	Shed	

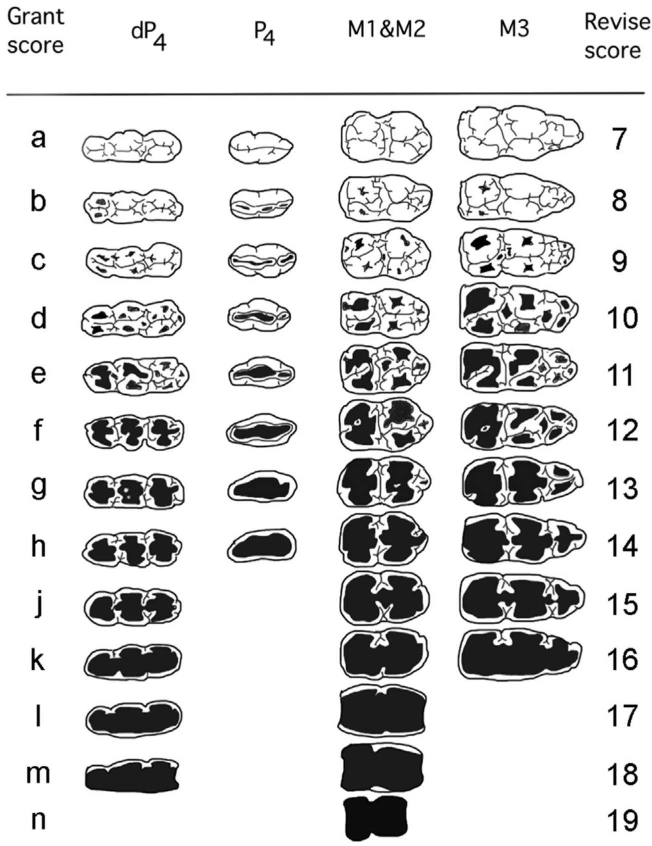

Fig. 1. Revised scoring system for *Sus* dental wear teeth with comparison to Grant (1982) T.W.S. scores.

worn to the roots. For both deciduous and permanent incisors scores for development and eruption (**0**–**6**) as well as enamel wear only (**7**) remain the same. Since Grant did not provide drawn wear stages for these teeth, attrition beyond score **7** is more general and extends only to score **10**, with **8** representing light wear, **9** moderate wear, and **10** heavy wear.

Retaining the wear stages identified by Grant maintains a shared and familiar language, and facilitates the translation of existing data sets into the new system. Additionally, by scoring individual teeth to age specimens rather than whole tooth rows as Grant's MWS (Mandibular Wear Stage) necessitates, the new system addresses the most restrictive requirements of the Grant method, which limits its application to more complete mandibles. A greater number of discrete scores increases the chance of identifying tooth scores that are more likely to be idiosyncratic to a specific age class, allowing for the use of individual teeth.

We have also included maxillary teeth into our sample. Reasons for the exclusion of maxillary teeth in many aging schemes are not entirely clear. In part, they may stem from the lack of an illustrated guide specific to scoring maxillary teeth, like that created by Grant for mandibular teeth (1982:94). Nevertheless, we have found that, the tooth wear patterns illustrated by Grant are, for the most part, analogous to maxillary teeth and comparably useful in scoring them. The only notable exceptions to this similarity are for the deciduous and permanent P^4. In the case of the deciduous p^4, Grant tooth wear stages illustrated for the permanent M_1 and M_2 are used, instead of those used for the p_4 (designated m_1 in Grant, 1982), as these are more consistent with the shape of the upper tooth. Scoring the permanent P^4 uses extrapolated Grant tooth wear stages for the P_4, factoring in the additional cusp and squarer shape of the tooth (Fig. 1).

Another possible justification for the exclusion of maxillary teeth from previous studies may arise from concerns over the repeated count of teeth from a mandible and maxilla belonging to the same individual. While this is possible, especially in assemblages of limited spatial and temporal depth, as we will argue below we believe that the advantages of increasing sample size of ageable material outweighs the drawbacks of including a few double counted individual animals in the sample. Moreover, if the possibility of double counting single individuals is a significant concern, why is it that dental aging systems use material from both right and left mandibles rather than confining the sample to the side with the most specimens? Finally, this double counting potential only becomes a problem if sequences of eruption and wear on mandibular and maxillary teeth (and right and left sides) are different, and if individuals in certain age classes are more likely to be double counted than those in other age classes. Otherwise, double-counting elements from the same individual has no impact on the patterning of the age profiles other than to increase the sample of ageable material. Additionally, if for some reason any one of these categories of elements are more likely to be preserved in animals of different ages (e.g. if maxillae of very old or very young individuals are more likely to be preserved than the mandibles of the same individuals) then broadening of the sample to include maxillary teeth increases the likelihood that these individuals will be included in the sample of specimens used to construct an age profile, mitigating taphonomic biases and making the resulting age profile a more accurate reflection of the harvesting strategies used in the exploitation of a species.

2.3. Scoring the teeth

Using the new scale (Table 1 and Fig. 1), we independently scored and recorded every present tooth—regardless of position or side—of the skulls of the modern wild *S. scrofa* specimens (See Tables S2–S4). We then color-coded the data to highlight broader categories of eruption and wear as defined above (Table 1 and key in Table S2).

A quick scan of the coded data for the 91 paired mandibles and maxillae in our sample demonstrates a consistent correspondence between eruption and wear scores for the upper and lower dentition of individual animals and, consequently, the utility of the aging system presented here for establishing discrete age classes. Our study also confirms previous research showing that bilateral asymmetry is rare, with the teeth of right and left sides of paired mandibles and maxillae almost always receiving the same score (Magnell, 2002). Table 2 looks at the correspondence between mandibular and maxillary scoring in paired specimens more closely by tabulating the number of disagreements between mandibular and maxillary scores awarded to individual teeth. The table presents three sets of tabulations: 1) mismatches in scores (e.g. a maxillary M1 awarded a score of 5 [tooth ½ erupted] and the corresponding mandibular M1 awarded a score of 4 [tooth erupting through bone]); 2) mismatches in which scores awarded to corresponding maxillary and mandibular teeth fall into different broader categories (i.e. a maxillary M3 awarded a score of 12 which falls into the 'moderate wear' category and the corresponding mandibular M3 awarded a score of 13 which falls into the 'heavy wear' category); and 3) mismatches in which the scores awarded to corresponding maxillary and mandibular teeth fall into different age classes (i.e. a maxillary M2 awarded a score of 3 placing it in age class 3 and the corresponding mandibular M2 awarded a score of 4 placing it in age class 4).

As might be expected, score mismatches between paired maxillary and mandibular teeth are evident in every tooth, confirming at least some of the speculation that upper and lower dentition wears at different rates. Mismatches between permanent and deciduous incisors and canines were anticipated to be, and indeed were, quite high due to the more general scoring system and a lack of specific visual diagrams for assigning scores. Permanent and deciduous premolars also demonstrate a propensity for higher score and category mismatches, ranging from as low as 25% for the deciduous p4 to as high as 65.9% and 67.9% for the permanent P1 and deciduous p3, respectively. This high level of mismatches is probably due to the fact that these premolars erupt and come into wear earlier in the maxilla than in the mandible (Matschke, 1967). In fact, the tendency for maxillary teeth to erupt and go into wear earlier than corresponding mandibular teeth (or the inverse in the case of the M3) likely contributes to score mismatching across the entire dental arcade. Another contributing cause for the mismatches in the scores of premolars is the differing shape of upper and lower premolars and the consequent subjective extrapolation required to directly apply the Grant wear pattern system to these teeth. Since, other than in their eruption these teeth are not determinative in defining age classes, the higher level of mismatched scores in premolars does not have any impact on the aging system presented here.

In contrast, for the permanent molars disagreement between scores and categories is quite low. The greatest score mismatch is seen in the M3 with 19.7%, where—not surprisingly—the mandibular M3 is expected to erupt and enter into wear earlier than the maxillary M3 by as much as 4 months (Matschke, 1967). Scores that cross broader categories of eruption and wear affect an even lower percentage of the paired mandibles and maxillae regardless of the tooth, and permanent molars show less than 8% category mismatch. In most of these category mismatches (indeed in almost all cases of mismatched mandibular and maxillary scores) the difference in mismatch is almost always no more than one score.

Regardless of the degree of score and category mismatch, paired maxillary and mandibular teeth almost never result in scores that

Table 2
Mismatched scores for paired mandibles and maxilla.

	dI1 $n = 79$	di2 $n = 154$	di3 $n = 93$	dc $n = 68$	dP2 $n = 113$	dP3 $n = 112$	dP4 $n = 116$	I1 $n = 267$	I2 $n = 273$	I3 $n = 262$	C $n = 263$	P1 $n = 274$	P2 $n = 276$	P3 $n = 229$	P4 $n = 287$	M1 $n = 361$	M2 $n = 326$	M3 $n = 318$
Scored pairs	39	76	22	35	57	56	56	130	134	127	126	129	110	113	141	179	160	157
# Score mismatch	10	26	8	6	18	38	14	32	36	50	14	85	54	46	61	28	26	31
# Category mismatch	6	10	8	2	14	18	8	14	21	20	10	41	31	11	18	4	8	12
# Age class mismatch	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0
% Score mismatch	25.6%	34.2%	36.4%	17.1%	31.6%	67.9%	25.0%	24.6%	26.9%	39.4%	11.1%	65.9%	49.1%	40.7%	43.3%	15.6%	16.3%	19.7%
% Category mismatch	15.4%	13.2%	36.4%	5.7%	24.6%	32.1%	14.3%	10.8%	15.7%	15.7%	7.9%	31.8%	28.2%	9.7%	12.8%	2.2%	5.0%	7.6%
% Age class mismatch	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.9%	0.9%	0.0%	0.0%	0.0%	0.0%

Table 3

Age class definitions.

a. Specific system

Age Class	di1	di2	di3	dc	dp2	dp3	dp4	I1	I2	I3	Canine	P1	P2	P3	P4	M1	M2	M3	Distinguishing Characteristics:
1	**U-7**	**U-7**	**U-7**	**U-7**	**U-6**	**U-7/U-6**	**U-7**	U	U	U	U	U-3/U-4	U	U	U	**U-2**	U	U	**Deciduous teeth in formation to early eruption**. Permanent incisors, canine, P2-P4, and M2-M3 unerupted. P1 entering formation stages. **M1 unerupted to early formation.**
2	8-S/8	7-S/8	8	8	**7-10**	**7-11**	**8-10**	U-6/U	U-6/U	U-5/U-3	U-4	4-6/U-4	U	U	U-3	**3-6**	U-2	U	Deciduous incisors and canine entering into light wear with maxillary i1 -and i2 beginning to shed. **Deciduous premolars in light to moderate wear**. Maxillary I1-3 and P1may be erupting, Canine may be in early eruption. P4 may be in early formation. **M1 in late formation and erupting.** M2 entering early formation. M3 unerupted.
3	8-S/8-9	8-S/8-9	8-S/8-S	8-S	7-S	9-14/8-12	9-11	U-6/U-4	U-6/U-4	2-7/U-6	2-5	4-7/U-7	U	U	U-3	**7-9**	**2-3**	U-2	Deciduous teeth in wear with canine and maxillary i1-p2 beginning to shed. Permanent I1-I3, canine, and P1 in formation to early eruption. P2 and P3 unerupted. P4 may be in early formation. **M1 in light wear. M2 in formation**. M3 entering early formation.
4	S	8-S	S/9-S	S	8-S/10-S	10-14	11-S/11-15	**4-6/2-5**	**4-6**	**4-7**	**4-7**	5-10/6-8	U-7/2-7	U-7	U-7	**9-11**	**4-7**	U-3	All deciduous teeth begininng to shed with with both mandibular and maxillary i1 and canine shed. Maxilliary deciduous teeth generally more likely to be shed and in more advanced stages of wear. **I1-I3 beginning to erupt**. **Permanent canine erupting and coming into wear**. P1 in early to moderate wear, more advanced in maxilla. P2 in early formation. P3 and P4 in formation and beginning to erupt. **M1 in light to moderate wear**. **M2 erupting and coming into light wear**. M3 in formation.
5	S	S/9-S	S	S	S	S	S	5-8	4-8/7-8	7-8	7-8	6-10/7-8	7-9/7-8	8-10	8-10	9-12	**7-9**	**2-4/2-5**	Deciduous i1, i3, canine, and premolars shed. Permanent I1 completely erupted through light wear. I2 in erupting and entering light wear. I3, canine, and P1 in light wear, with maxillary P1 in more advanced wear. P2 in light wear. P3 and P4 light to moderate wear. M1 in moderate wear. **M2 in light wear**. M3 in late formation, with **upper M3 erupting**.
6	S	S	S	S	S	S	S	5-8/8	6-8/7-8	7-8	7-8	6-10/7-9	7-10/7-9	7-11	8-11	10-12	**8-10**	**4-8**	All deciduous teeth shed. Permanent I1 through P4 in early through moderate wear. M1 in moderate wear**. M2 in light to early moderate wear. M3 erupting and entering light wear**.
7	S	S	S	S	S	S	S	8-9	7-9	7-10/7-9	7-9/8-9	6-13/7-9	7-10	7-11	8-12	**13-14**	8-11	5-9	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear, with maxillary teeth showing more advanced wear. **M1 in early stages of heavy wear.** M2 mostly in moderate wear. M3 fully erupted and entering light wear.
8	S	S	S	S	S	S	S	8-10/8-9	8-9	8-10/7-9	8/14/8-9	7-14	8-11	10-13/9-11	10-13/9-13	**14-16**	**10-13**	7-11	All deciduous teeth shed. Permanent I1 through P4 in light through early heavy wear.**M1 in later stages of heavy wear. M2 in moderate to early heavy wear**. M3 mostly in light wear, though may be in early moderate wear.
9	S	S	S	S	S	S	S	9-10	9-10	9-10/8-10	9-10/8-10	12-14/8-14	8-14+/8-14+	12-14/12-13	11-14	**15-19**	**12-16**	10-12	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in extreme wear. M2 in heavy** wear. M3 in mostly in moderate wear.
10	S	S	S	S	S	S	S	9-10	9-10	8-10/8-9	9	9-14/8-11	11-13/8-14	12-14/11-13	13-14	**18-19+**	**16-19**	**12-15**	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in extreme wear (worn to root). M2 in mostly extreme wear, though may be in late heavy wear. M3 in mostly heavy wear, though may be in late moderate wear.**

b. Simplified-A system

Age Class	di1	di2	di3	dc	dp2	dp3	dp4	I1	I2	I3	Canine	P1	P2	P3	P4	M1	M2	M3	Distinguishing Characteristics:
A	**U-7**	**U-7**	**U-7**	**U-7**	**U-6**	**U-7/U-6**	**U-7**	U	U	U	U	U-3/U-4	U	U	U	**U-2**	U	U	**Deciduous teeth in formation to early eruption**. Permanent incisors, canine, P2-P4, and M2-M3 unerupted. P1 entering formation stages. **M1 unerupted to early formation.**
B	8-S/8-9	7-S/8-9	8-S	**8-S**	**7-S**	**7-14/7-12**	**8-11**	U-6/U-4	U-6/U-4	U-7/U-6	U-5	4-7/U-7	U	U	U-3	**3-9**	**U-3**	U-2	Deciduous incisors in wear with maxillary teeth beginning to shed. **Deciduous canine and deciduous p2 in wear and beginning to shed. Deciduous p3-p4 in early to moderate wear**. Permanent incisors, canine, and P1 may be erupting, especially in maxillary teeth. P2 and P3 unerupted. P4 in early formation. **M1 in late formation through light wear. M2 entering early formation.** M3 unerupted.
C	S	8-S	S/9-S	S	8-S/10-S	10-14	11-S/11-15	**4-6/2-5**	**4-6**	**4-7**	**4-7**	5-10/6-8	U-7/2-7	U-7	U-7	**9-11**	**4-7**	U-3	All deciduous teeth begininng to shed with with both mandibular and maxillary i1 and canine shed. Maxilliary deciduous teeth generally more likely to be shed and in more advanced stages of wear. **I1-I3 beginning to erupt**. **Permanent canine erupting and coming into wear**. P1 in early to moderate wear, more advanced in maxilla. P2 in early formation. P3 and P4 in formation and beginning to erupt**. M1 in light to moderate wear**. **M2 erupting and coming into light wear**. M3 in formation.
D	S	S/9-S	S	S	S	S	S	5-8	4-8/7-8	7-8	7-8	6-10/7-8	7-9/7-8	7-10	8-10	9-12	**7-9**	**2-4/2-5**	Deciduous i1, i3, canine, and premolars shed. Permanent I1 completely erupted through light wear. I2 in erupting and entering light wear. I3, canine, and P1 in light wear, with maxillary P1 in more advanced wear. P2 in light wear. P3 and P4 light to moderate wear. M1 in moderate wear. **M2 in light wear. M3 in late formation.**
E	S	S	S	S	S	S	S	5-8/8-9	6-9/7-9	7-10/7-9	7-9	6-13/7-9	7-10	7-11	8-12	**10-14**	**8-11**	**4-9**	All deciduous teeth shed. Permanent I1 through P4 primarily in light to moderate wear, with maxillary P1 likely to be in modre advanced wear. **M1 in moderate to early heavy wear. M2 in light to moderate wear. M3 erupting and entering light wear.**
F	S	S	S	S	S	S	S	8-10	8-10	8-10/7-10	8-10	7-14	8-14	10-14/9-13	10-14/9-14	**14-19**	**10-16**	**7-12**	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in heavy to extreme wear. M2 in moderate to heavy wear. M3 in light to moderate wear.**
G	S	S	S	S	S	S	S	9-10	9-10	8-10/8-9	9	9-14/8-11	11-13/8-14	12-14/11-13	13-14	**18-19+**	**16-19**	**12-15**	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in extreme wear (worn to root). M2 in mostly in extreme wear, though may be in late heavy wear. M3 in mostly heavy wear, though may be in late moderate wear.**

c. Simplified-B system

Age Class	di1	di2	di3	dc	dp2	dp3	dp4	I1	I2	I3	Canine	P1	P2	P3	P4	M1	M2	M3	Distinguishing Characteristics:
I	**U-S**	**U-S**	**U-S**	**U-S**	**U-S**	**U-S**	**U-S/U-15**	U-6/U-5	U-6	U-7	U-7	U-10/U-8	U-4	U-7	U-7	**U-11**	**U-7**	**U-3**	**Deciduous teeth unerupted through shed**. Permenent incisors, canine, and premolars in formation through light wear. **M1 in formation through early moderate wear. M2 in formation through light wear. M3 in formation.**
II	S	S/9-S	S	S	S	S	S	5-8/5-9	4-9/7-9	7-10/7-9	7-9	6-13/7-9	7-10	7-11	8-12	**9-14**	**7-11**	**2-9**	Deciduous teeth shed. Permanent incisors, canine, P1, and P1 in light wear. P2-P4 in light to moderate wear. **M1 in moderate to early heavy wear. M2 in light to early-moderate wear. M3** in final development, **erupting, and entering light wear**.
III	S	S	S	S	S	S	S	8-10	8-10	8-10/7-10	8-10	7-14	8-14	10-14/9-13	10-14/9-14	**14-19**	**10-16**	**7-12**	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in heavy to extreme wear. M2 in moderate to heavy wear. M3 in light to moderate wear.**
IV	S	S	S	S	S	S	S	9-10	9-10	8-10/8-9	9	9-14+/8-11	11-13/8-14	12-14/11-13	13-14	**18-19+**	**16-19**	**12-15**	All deciduous teeth shed. Permanent I1 through P4 in early through heavy wear. **M1 in extreme wear (worn to root). M2 in mostly in extreme wear though may be in late heavy wear. M3 in mostly heavy wear, though may be in late moderate wear.**

KEY:

X-X/X-X	Denotes differences in maxillary and mandibular scores, respectively.
🟥	Distinguishing charcateristic

cause specimens to be assigned to different age classes. In fact, only four instances of this occur, and then almost exclusively in the highly variable and somewhat problematic permanent premolars. Since these teeth are never used individually or exclusively to determine age classes at any scale and any conflicting scores in a single specimen would be corrected by the scores of associated molars, these classification mismatches are extraneous and do not effect the utility of the method.

2.4. *Defining the age classes*

Once recorded, we organized specimens by extent of eruption and degree of wear across tooth rows for both the mandibles and maxillae separately (Tables S3 and S4). We then looked for natural groupings of eruption and wear patterns that could be used to define discrete age classes. In both the mandibles and maxillae we identified 10 discrete and corresponding age classes. As demonstrated in Table 2, age classes defined for upper and lower jaws match one another. Paired mandibles and maxillae were assigned to the same age classes in all specimens.

Table 3a summarizes the ‘rules’ for assignment to each of these 10 age classes, providing the range of scores for each tooth of the specimens assigned to these different age classes and highlighting the teeth that are primarily determinative for assignment into each age class. In cases where maxillary teeth and mandibular teeth are not in complete agreement, the table presents the range of scores in the age class for both upper and lower teeth. The table also provides a summary of the state of eruption and wear for each age class, with determinative characteristics for each in bold face type. Early age classes (1–3) are determined on the basis of the eruption, wear and loss of deciduous teeth and the M1, while the eruptions of the M2 and M3 play important (though not exclusive) roles in defining age classes 4–5. Later age classes (6–10) are defined primarily on the basis of molar wear patterns, with the M1 and M2 playing more important roles in defining these classes than the M3, which this study shows to have more variable eruption and wear patterns than the other permanent molars.

In many instances, the same eruption and wear score for an individual tooth may be found in specimens assigned to more than one age class (i.e. mandibular M1s with a score of 11 may be found in specimens assigned to age classes 4–6). Rarely does a specific score for a single tooth allow assignment of the specimen to a discrete age class, although this does occur (i.e. mandibular and maxillary M1s with a score of 13 are specific to age class 7). This means that in most cases assignment to one of the ten age classes requires agreement across multiple teeth in the tooth row – a requirement that (as in the Grant system) limits the sample of specimens that can be assigned to any one of these ten age classes. Thus, while this high resolution ten age class scheme offers the most precise system for defining age classes—capable of recording animals in the first few months, and even weeks, of their lives because it defines age classes more strictly—it requires a higher quality of data from more complete tooth rows, restricting the quantity of data by limiting the number of archaeological samples that can be used to reconstruct age profiles at this level.

We therefore designed two more simplified aging schemes (Table 3b and c) that, while not offering the same resolution as the ten age class or “Specific” scheme, offer the potential of increasing the sample of ageable specimens by broadening age classes and making it possible to include less complete tooth rows (i.e. more single teeth) in the sample.

The first of these schemes (Simplified-A) consists of seven age classes, grouping some of the more nuanced Specific classes together, while retaining the specificity of others (Tables 3b and 4). Under this first simplified system Specific age class 1, which includes neo-natal animals in the first few months of life (based on estimates of pig tooth eruption ages from Matschke, 1967), is retained as a discrete age class A. Specific age classes 2 and 3, however, are combined into Simplified-A age class B that includes animals with erupted deciduous teeth in various stages of wear up to the point that they are shed, along with M1s that are erupting and in early wear. Specific age class 4 becomes age class C in the Simplified-A scheme, including animals with permanent premolars erupting and in early wear, M1s in light to moderate wear, and M2s that are erupting and entering into the earliest stages of light wear. Specific age class 5 is similarly retained in this Simplified-A system, becoming age class D, defined primarily by M1s in moderate wear stages and M2s in light wear. Simplified-A age class E is comprised of Specific age classes 6 and 7, reserved for animals with M1s in later moderate and early heavy wear stages, M2s entering moderate wear stages, and erupting M3s. Similarly, Specific age classes 8 and 9 are combined in the Simplified-A scheme into age class F, defined by M1s in heavy wear, M2s in moderate to heavy wear, and M3s in light to early stages of moderate wear. Finally Simplified-A age class G is the same as Specific age class 10 which includes animals with M1s late stages of heavy wear, M2s in heavy wear, and M3s in late moderate to early heavy wear.

The Simplified-B groups the Simplified-A age classes into four discrete age classes (Tables 3c, and 4). In this lowest resolution scheme Simplified-A age classes A, B, and C (Specific age classes 1–4) are grouped together in age class I, which includes all animals with deciduous teeth and the M1 in early formation. The remaining Simplified-B age classes (II–IV) are defined by various stages of eruption and wear of the permanent molars: age class II (Simplified A classes D–E and Specific age classes 5–7) defined by M1s in moderate to early heavy wear, M2s in light to early moderate wear, and M3s erupting and in light wear; age class III (Simplified-A class F and Specific 8–9) reserved for specimens with M1s in heavy to extreme wear, M2s in moderate to heavy wear, and M3 that are in light to moderate wear; and age class IV (Simplified-A class G and Specific class 10) reserved for the oldest animals.

2.5. *Anchoring the age classes*

Like many specimens in museum collections, the wild boar included in this study were not of known ages, so the various age classes defined here cannot be definitively anchored to specific ages. Anchoring age classes determined on the basis of tooth eruption and wear to absolute ages of death has, in fact, proven difficult in most animals, but especially in pig, which is why most systems follow Grant in assigning only relative, and in Grant's case floating, ages for pig dentition data. There is however, data on dental eruption in known age wild boar (summarized in Table 5 and more completely in Legge, 2013), which show strong agreement in

Table 4
Comparison of three classification systems.

Specific	Simplified-A	Simplified-B
1	A	I
2	B	
3		
4	C	
5	D	II
6	E	
7		
8	F	III
9		
10	G	IV

Table 5
Age of eruption from previous studies used in this paper. See Legge (2013) for a more a complete list of work undergone for *Sus spp.* dental eruption.

Tooth	Matschke (1967)	Briedermann (1965)	Bull and Payne (1982)	Magnell (2002)	Anezaki (2009)
di^1	7–22 d (16.4 d)				
di_1	11–20 d (17.1 d)				>1 m
di^2	2.2–3.9 d (3.2 d)				
di_2	2.1–3.1 (2.6 d)				>1 m
di^3	Birth				
di_3	Birth				Birth
dc^1	Birth				
dc_1	Birth				Birth
dp^2	1.7–2.6 d (2 d)				
dp_2	2.1–3.4 d (2.7 d)		7–11 m		>1 m
dp^3	11–18 d (13.9 d)				
dp_3	23–33 d (27.5 d)		7–11 m		>1 m
dp^4	41–49 d (45.1)				
dp_4	11–20 d (17.1 d)		7–11 m		>1 m
I^1	13–15 m (14 m)				
I_1	13–15 m (14 m)	14–16 m			
I^2	22–27 m (25 m)				
I_2	19–22 m (20 m)	18–20 m	19–23 m	18/18–24 m	
I^3	7–12 m (9 m)				
I_3	8–9 m (9 m)	10–12 m	7–11 m		
C^1	7–12 m (9 m)				
C_1	8–12 m (8 m)	10–12 m	7–11 m	7–12/10–12 m	
P^1	4–7 m (6 m)				
P_1	5–8 m (7 m)				
P^2	16–17 m (17 m)				
P_2	15–17 m (16 m)	14–16 m			
P^3	15–17 m (16 m)				
P_3	14–16 m (16 m)	14–16 m			
P^4	14–19 m (17 m)				
P_4	14–18 m (16 m)	14–16 m			
M^1	5–7 m (6 m)				
M_1	5–6 m (6 m)	4–5 m		5 m	3–5 m
M^2	12–14 m (13 m)				
M_2	12–14 m (13 m)	12 m		12–13/10–12 m	12 m
M^3	26–33 m (29 m)				
M_3	23–26 m (25 m)	21–24 m	19–23 m	18–25/18–34 m	16–30 m

the schedule of tooth eruption in diverse populations of European, Turkish, and Japanese wild boar (Anezaki, 2009; Briedermann, 1965; Bull and Payne, 1982; Hongo and Meadow, 1998; Magnell, 2002; Matschke, 1967).

Although a strong correlation between age and dental attrition has been demonstrated (Magnell, 2002), there is little data that links various stages of tooth attrition to specific ages. One exception is Bull and Payne's landmark study of 18 wild Turkish boar (Bull and Payne, 1982). Although the animals in their sample were not of known ages, all these animals were killed within a narrow span of a few months within a single year. Based on the known birthing season for animals in this region, and using information on the timing of eruption, Bull and Payne were able to estimate the age of animals in their sample (with greater confidence for younger animals) and link these ages to age classes based on a combination of both tooth eruption and wear. Another more recent study recorded tooth eruption and wear pattern data on 32 captive wild pigs of known age (Anezaki, 2009). Attritional data recorded in this study are limited and the patterns observed in these pigs may have been affected by their captive status – due both to the diet of captive pigs and the high degree of competition between litter mates kept in captivity (Anezaki, 2009: 34). Moreover, the sample of captive wild pigs included in this study is comprised almost entirely of animals younger than 20 months of age, with a major gap in the sample between a single 30-month-old boar and two elderly boars of 96 months of age.

Comparing the Anezaki and Bull and Payne studies to an archaeological application by Hongo and Meadow at Çayönü (1998) shows close agreements for the age estimates of maxillae and mandibles based on eruption and wear patterns (Table 6). All three systems also correspond closely to eruption and attritional patterns that form the basis of the age classes defined here. This is especially

Table 6
Comparison of age classes in this study and those from earlier studies (Bull and Payne, 1982; Anezaki, 2009; Hongo and Meadow, 1998).

Specific	Simplified-A	Simplified-B	Bull & Payne age groups	Bull & Payne ages	Anezaki age	Hongo & Meadow age
1	A	I	Group 1	≤7 mos	<1 mo	Newborn
2	B			≤7 mos	3–5 mos	≤6 mos
3				≤7 mos	6–8 mos	
4	C			7–11 mos	12 mos	6–12 mos
5	D	II	Group 2	19–23 mos	16 mos	12–18 mos
6	E				18–30 mos	18–24 mos
7			Group 3	31–35 mos	nd	
8	F	III	Older	>35 mos	nd	>24 mos but not old
9					96 mos	
10	G	IV			nd	Old

Table 7
Suggested ages for age classes in this study.

Specific	Specific age estimate	Simplified-A	Simplified-A age estimate	Simplified-B	Simplified-B age estimate
1	≤1 mo	A	≤1 mo	I	0–12 mos
2	3–5 mos	B	3–8 mos		
3	6–8 mos				
4	8–12 mos	C	8–12 mos		
5	12–16 mos	D	12–16 mos	II	12–52 mos
6	18–30 mos	E	18–52 mos		
7	30–52 mos				
8	52–72 mos	F	52–96 mos	III	52–96 mos
9	72–96 mos				
10	>96 mos	G	>96 mos	IV	>96 mos

true for the finely drawn early age classes in our Specific scheme and the almost identical correspondence between the Simplified-A system and the system presented by Hongo and Meadow. The Hongo and Meadow system, however, does not correspond in all cases to the specific eruption and wear stages that define the seven age classes in the Simplified-A system proposed here (Table 3a).

Additionally, the wear patterns in the oldest specimens in the Anezaki sample correspond well in M1 and M2 wear stages to our Specific age class 9, anchoring this age class to an age estimate of 96 months or 8 years. It is also interesting to note that specimens in Bull and Payne's "Older" group, for which no age estimate is given (specimens 344 and 350 illustrated in Figs. 4 and 5 of Bull and Payne, 1982 and scored for this study in Tables S2–S4), correspond in attritional patterns to Specific age classes 8 and 10, thereby bracketing the firmer age estimate of 96 months for our stage 9 provided by Anezaki's data. This, then, makes our oldest age class 10 a good proxy for very old animals at the end of their natural life span.

So while we cannot with absolute confidence ascribe specific ages to our age classes, we believe that the close correspondence between our data and that in both the Bull and Payne and the Anezaki studies, as well as the Hongo and Meadow application, provides a good anchor that links our age classes with likely ages of death in wild boar. Table 7 presents age estimates for our age classes in each of the three Specific, Simplified-A, and Simplified-B aging schemes. The degree of confidence in the age assignments made here is quite high for the younger, more finely drawn age classes (1–6) all of which can be anchored to eruption data where, as we have seen, there is a good amount of agreement across a number of studies. The attribution of a 31–35 month age estimate to Bull and Payne's Group 3, with attritional patterns that closely match those in our age class 7 (Bull and Payne, 1982: Fig. 3), is open to question, and it is quite possible that this age class, defined solely on attritional patterns is broader than the 5 month span given by Bull and Payne. If, based on similar attrition patterns we anchor age class 9 to Anezaki's two oldest pigs aged 96 months (or 8 years), then it is possible to space out the older age classes 7–9 across the 66 month period that separates the 30 month end age estimate for age class 6 (anchored to the eruption age for the M3) and the 96 month estimate for age class 9 provided by Anezaki's data.

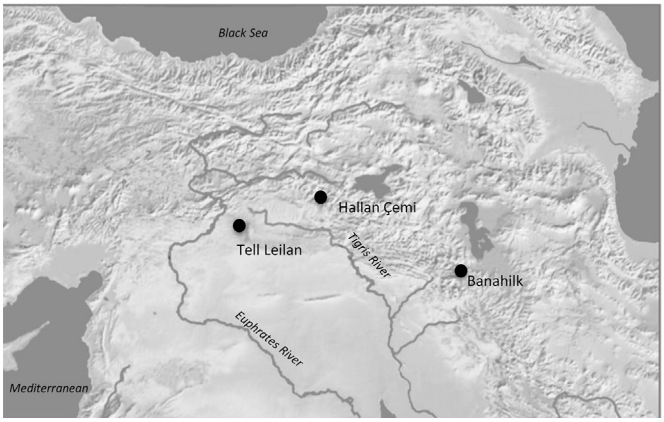

Fig. 2. Location of sites with pig assemblages examined in this study.

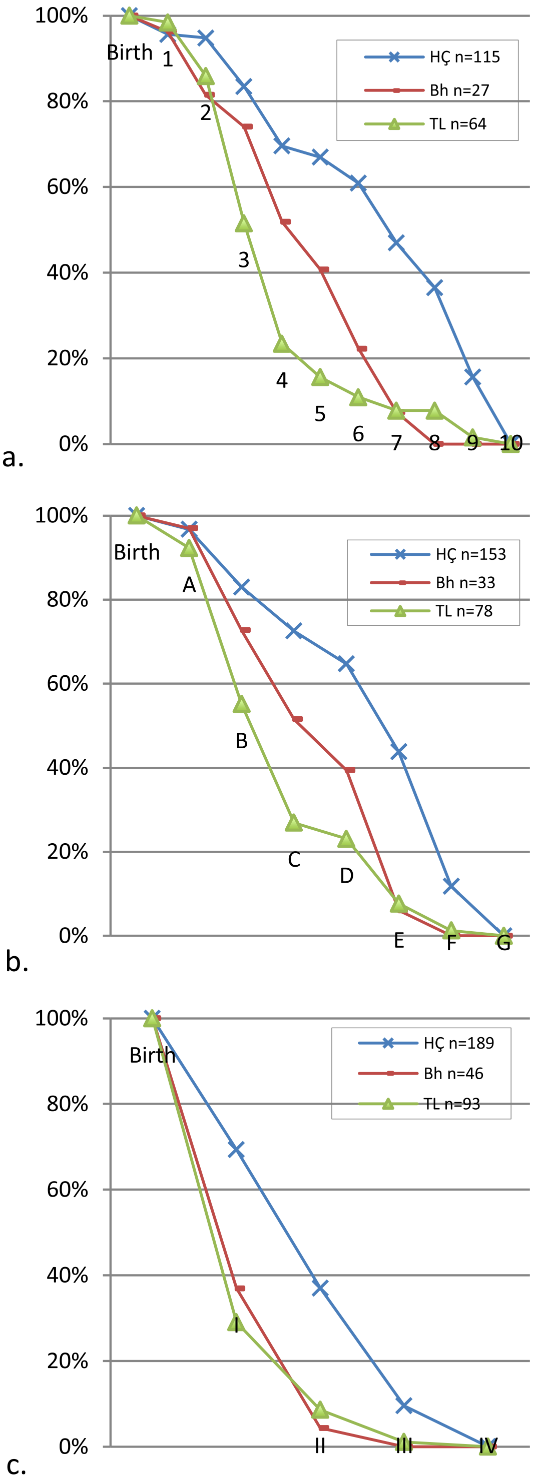

Fig. 3. Survivorship curves for three assemblages examined in this study. a) Specific system, b) Simplified-A system, c) Simplified-B system.

3. Application: three Near Eastern sites

To test the efficacy of this new method of dentition based demographic profiling in pigs, we have applied the aging system to pig assemblages from three different archaeological contexts in which contrasting pig harvesting strategies are likely. The goal of this application is threefold. First, we wanted to examine variations in the size and nature of the assemblages that could be used in constructing each of these different classificatory schemes. Second, we wanted to explore the comparability of age profiles constructed using mandibular and maxillary tooth rows and loose teeth. Finally, and most significantly, we hoped to evaluate the degree to which the three different age classifications were able to detect differences in pig exploitation strategies at these three temporally and culturally distinctive sites.

3.1. Site descriptions

The three assemblages examined here come from: 1) the tenth millennium BC Late Epipaleolithic settlement of Hallan Çemi in southeastern Turkey (Rosenberg et al., 1998); 2) the sixth millennium BC Halafian village site of Banahilk in northwestern Iraq (Watson, 1983); and 3) the third millennium BC Early Bronze Age urban site of Tell Leilan, located in the Khabur Basin of northeastern Syria (Weiss, 1990) (Fig. 2).

Hallan Çemi is a small Late Epipaleolithic site located in the Batman region of southeastern Turkey (Fig. 2) that was occupied for a brief 200–300 years between 11,700–11,270 cal. BP (Starkovich and Stiner, 2009). Faunal and botanical evidence indicate that Hallan Çemi was occupied year-round, establishing it as the oldest year-round, sedentary community in the region (Rosenberg et al., 1998). Faunal remains from Hallan Çemi are remarkably species diverse, comprised of both large and medium bodied game (caprines, red deer, and pig), as well as a wide array of small game animals in which hares, foxes, various bird species, and tortoises are particularly well represented. In a series of articles, Redding and Rosenberg have argued that residents of Hallan Çemi practiced an early form of pig management similar to modern pig husbandry practices in New Guinea, in which managed female pigs are allowed to breed with free-living males (Redding, 2005; Redding and Rosenberg, 1998, 2000; Rosenberg et al., 1998). Dental eruption and wear data for the Hallan Çemi pigs was recorded using this system by Ximena Lemoine and Melinda Zeder as part of a larger study of this assemblage.

Banahilk is a small mound site yielding exclusively Halafian age material that was excavated by Patty Jo Watson as part of the Braidwood expedition to Iraqi Kurdistan (Watson, 1983). Radiocarbon dates place its occupation from approximately 6200–7000 BP (Watson, 1983). The assemblage from the site is dominated by caprines, followed by cattle, with pigs being the third most abundant species at about 15% of the faunal assemblage from the site (Laffer, 1983). In addition to domesticates, Banahilk residents also exploited, in small numbers, wild mammals (primarily deer) and large quantities of land snails (*Helix salomonica*). The pig remains from the site have been identified as domestic on the basis of the small size of their molars and post-cranial bones (Laffer, 1983). Dental eruption and wear data for Banahilk were collected by Katelyn Bishop for this project using the system presented here.

Pig remains from Tell Leilan are derived from Leilan Period IIIa through IIb deposits that span the period from urban emergence at 2650 BC up through the period of Akkadian control and the city's subsequent abandonment at 2200 BC. Pigs are often either absent or poorly represented in early urban sites in Mesopotamia, where they have been associated with small-scale pig husbandry efforts by the urban poor as a buffer in an otherwise highly controlled subsistence economy (Zeder, 1991). At Tell Leilan, however, pigs are surprisingly well represented, both in the Lower Town South residential district of the site and in the elite sector on the site's acropolis (Rufolo, 2011; Zeder, 2003). Zeder has proposed that a kind of internal meat production system existed at the site in which elites received pigs (especially younger pigs) from poorer residents of the city who raised them for their own consumption (Zeder, 2003). Material analyzed here comes from both elite and residential sectors of the site and was studied by Rufolo using the Grant system. These data have been translated into the system presented here.

These assemblages, then, represent three potentially quite different pig exploitation strategies ranging from a highly managed pig population in the Late Bronze Age urban context, to well established domestic pig rearing in an established Halafian village economy, to a proposed system of initial husbandry in an early sedentary community of Epipaleolithic foragers. As such, the application of the new method to such diverse archaeological data will provide a model way for evaluating the efficacy of the method in distinguishing among various harvest strategies for pigs.

3.2. The process

The following procedures were used in computing demographic profiles for pig dentition from each of these three sites. For loose teeth, each individual tooth was assigned a score (Table 1 and Fig. 1) and matched to an age class at all three levels of classification (Table 3). If no single age class could be determined, the tooth was not counted in the final sample of that system. For example, a loose M^2 may have a wear score of 8. It would then fall into age classes 5 or 6 for the Specific scale (Table 3a), and as a result could not be used at this scale. Going into the next level, Simplified-A, the same score would place the tooth somewhere between D and E age classes (Table 3b). Once again the specimen would be excluded from the sample for this system. In the system of most inclusion—Simplified B (Table 3c)— this specimen falls into only ONE age class—II—and could then be counted into this system's dataset.

In the case of associated teeth within a mandible or maxilla, each tooth was scored separately and matched to an age class; the modal age class of all the associated teeth in the tooth row was then selected as the age of the complete specimen. For example, a mandible with an M_1 score of 18, an M_2 score of 16, and an M_3 score of 11 would be counted within Specific age class 9 (Table 3a). A score of 18 on the M_1 alone would place the specimen in age classes 9 or 10, as would a score of 16 on the M_2, however the score of 11 on the M_3 is found only in age class 9. Because age class 9 is consistent with all the associated teeth, the specimen would be assigned to that class. This was done for each of the three different classificatory systems, as described above for individual teeth. Tooth rows where no single modal age class could be assigned were excluded from the sample for that classificatory system.

Every individual tooth and every tooth row that could be uniquely assigned to a single age class under any classificatory system (Specific, Simplified-A, or Simplified-B) was then counted as one individual and included in the sample used to construct survivorship curves and mortality histograms for that system of classification. The classification of dentition from each of the three assemblages examined can be found in Tables S5–S7.

3.3. Sample size

One of the potential advantages of the system developed here is that including both mandibular and maxillary dentition, as well as both loose teeth and tooth rows significantly increases the size of the sample of specimens that can be used to compute demographic profiles. Table 8 presents the number of specimens broken down into loose teeth, mandibular and maxillary tooth rows that could be assigned to a single age class in each of the three classification systems for each assemblage. It also presents the total sample of potentially ageable loose teeth and tooth rows for each site. Table 9 presents the proportion of the potentially ageable specimens used in each classificatory system for loose teeth, tooth rows, and for the sample as a whole.

The advantage of including loose teeth and maxillary tooth rows in the sample over the normal practice of limiting the sample to mandibular tooth rows is clear. Looking first at the highest resolution Specific system with its more stringent requirements for inclusion, we see that the size of the Hallan Çemi sample is increased nearly four fold when loose teeth and maxillary tooth rows are included in the sample (from 33 ageable specimens of mandibular rows to a sample of 115 ageable mandibular and maxillary tooth rows and loose teeth, Table 8a). At Banahilk the size of the sample of aged specimens increases from only 9 mandibles to a total of 27 specimens used to compute the Specific system age profile (Table 8b). Finally, including loose teeth and maxillary tooth rows in the sample of ageable dentition in the Leilan assemblage triples the size of the sample in the Specific scoring system—from a modest 19 mandibular specimens assigned to single age classes to a more robust and statistically sound sample of 59 ageable specimens (Table 8c).

The impact of the increasingly broader classificatory systems on sample size is also readily apparent. Once again taking Hallan Çemi as an example, while only a little more than half of the potentially ageable Hallan Çemi sample is used in the Specific classification system with its ten finely drawn age classes, the seven age class Simplified-A system includes more than 70% of the total scored dentition, and the broadly drawn four age class Simplified-B system includes more than 90% of all the potentially ageable loose teeth and tooth rows (Table 9a). Similar gains are seen in the other two, smaller, assemblages from Banahilk (Table 9b) and Tell Leilan (Table 9c) in each of the more inclusive classificatory systems.

3.4. Comparability

Inclusion of both maxillary tooth rows and loose teeth in the system not only increases the size of the sample used to construct age profiles, but it also captures information that would otherwise be lost if the sample were restricted to mandibular tooth rows. Supplementary Tables S8–S10 break down the samples for each of the three assemblages examined here, and for each of the three classificatory systems, by mandibular and maxillary teeth (both in tooth rows and as loose teeth) and by loose teeth and tooth rows (for both mandibular teeth and maxillary teeth), showing the numbers of specimens assigned to each age class for each category. These tables also present mortality profiles for each category (computed by dividing the number of specimens in each age class by the total sample of ageable specimens), which measure the intensity of kill-off in each age class, as well as survivorship profiles (computed by subtracting the youngest mortality score from 100% and then each successive score from the preceding difference), which measure the percentage of animals that live beyond each age class. These results are shown graphically in Supplementary Figs. S1–S4.

Table 8
Numbers of loose teeth, mandibular tooth rows (MDT), and maxillary tooth rows (MXT) used at each classification level compared to total sample of potentially ageable dentition.

a. Hallan Çemi

System	Teeth used	MDT used	MXT used	Total used
Specific	45	33	37	115
Simplified-A	66	43	44	153
Simplified-B	84	50	56	190
Total sample	93	54	62	209

b. Banahilk

System	Teeth used	MDT used	MXT used	Total used
Specific	7	9	11	27
Simplified-A	10	10	11	31
Simplified-B	12	17	17	46
Total sample	12	18	18	48

c. Tell Leilan

System	Teeth used	MDT used	MXT used	Total used
Specific	15	19	25	59
Simplified-A	23	25	30	78
Simplified-B	29	31	34	94
Total sample	30	36	35	101

Table 9
Proportion of loose teeth, mandibular tooth rows (MDT), and maxillary tooth rows (MXT) used at each classification level as a percentage of the total sample of potentially ageable dentition.

a. Hallan Çemi

System	Teeth used	MDT used	MXT used	Total used
Specific	48.4%	61.1%	59.7%	55.0%
Simplified-A	71.0%	79.6%	71.0%	73.2%
Simplified-B	90.3%	92.6%	90.3%	90.9%
Total sample	93	54	62	209

b. Banahilk

System	Teeth used	MDT used	MXT used	Total used
Specific	58.3%	50.0%	61.1%	56.3%
Simplified-A	83.3%	55.6%	61.1%	64.6%
Simplified-B	100.0%	94.4%	94.4%	95.8%
Total sample	12	18	18	48

c. Tell Leilan

System	Teeth used	MDT used	MXT used	Total used
Specific	50.0%	52.8%	71.4%	58.4%
Simplified-A	76.7%	69.4%	85.7%	77.2%
Simplified-B	96.7%	86.1%	97.1%	93.1%
Total sample	30	36	35	101

There are several important observations to be drawn from these data. First, for each assemblage survivorship and mortality profiles computed using mandibular and maxillary teeth from any one assemblage (Figs. S1 and S2), as well as those based on tooth rows and loose teeth (Figs. S3 and S4), are generally consistent with one another and distinct from the profiles drawn for the other assemblages examined here. These patterns become more similar in the lower resolution Simplified-A and -B systems.

There is, however, a tendency for profiles based on maxillary teeth to emphasize older animals (Figs. S1 and S2) – especially clear in the assemblages from Hallan Çemi (S1a–c, S2a–c) and Tell Leilan (S1g–i, S2g–i). The older bias seen among maxillary teeth in the modern specimens cannot account for this difference since the scoring system devised here has been calibrated to account for these slight differences (Table 3). Instead, the higher proportion of older animals represented by maxillary teeth captures the presence of these older individuals among the harvested animals at each site. Profiles computed using loose teeth, in contrast, generally contain a greater number of younger animals than do those based on tooth rows (Figs. S3 and S4). This tendency is not related to the type of teeth included in the loose teeth samples (i.e. that maxillary teeth from older animals are underrepresented among loose teeth). In all assemblages these samples are comprised of a roughly even proportion of upper and lower teeth (Tables S5–S7). Instead, greater representation of older animals among maxillary teeth and of younger animals among loose teeth would seem an artifact of taphonomic factors that result in the differential preservation of mandibular teeth when compared to maxillary teeth, and loose teeth when compared to tooth rows. This would certainly make sense in the case of loose teeth since the jaws of younger animals may be expected to be more friable than those of older animals (Munson and Garniewicz, 2003).

It then follows that continuing the common practice of limiting the sample of teeth used to compute age profiles to just mandibular tooth rows runs the risk of missing a significant segment of the harvested animals. This problem is particularly acute in smaller assemblages, such as those from Banahilk and Tell Leilan, where whole age classes (in all three different classificatory systems) would be unrepresented if loose teeth and maxillary teeth were not included in the sample. At Tell Leilan, for example, age profiles composed solely of mandibular tooth rows would entirely miss the fact that the strong focus on the harvest of young animals (i.e. >1 year) is tempered somewhat by the harvest of at least a few older animals at the site (Fig. 3g–i). Thus any possible impact from double counting single individuals is far outweighed by the clear advantages of basing age profiles on a broader and more representative sample that includes both maxillary and loose teeth that provide a more accurate picture of harvesting practices than do age profiles limited to only mandibular tooth rows.

3.5. *Intersite differentiation*

The final, and most important, goal of this application is to assess the effectiveness of this new age classification system in detecting different pig exploitation strategies at these three temporally and culturally distinctive sites where dramatic differences in suid exploitation strategies are likely. Age assignments for the combined samples of mandibular and maxillary tooth rows and loose teeth for each assemblage, and each of the three classificatory systems, are presented in Table 10a–c. These tables also include the mortality and survivorship profiles based on these assignments. Graphic representations of these profiles are presented in Fig. 3, which compares the survivorship curves obtained for the three assemblages in each classificatory system, and Fig. 4, which presents these data as mortality profiles.

Survivorship curves for the three assemblages differ considerably from one another; with the degree of difference between the three assemblages becoming progressively more muted in the lower resolution Simplified-A and -B classificatory systems. In the highest resolution system—Specific—the Hallan Çemi pig harvest pattern differs dramatically from that of Banahilk and, especially, the Tell Leilan profiles (Figs. 3a and 4a–c). Although we see an initial focus on younger animals in age classes 3 and 4 (c. 6–12 months), at this Late Epipaleolithic site (Fig. 4a) 70% of the animals in the Hallan Çemi assemblage were older than one year of age when they were killed (Fig. 3a). This initial harvest is followed by a relative plateau in kill-off between age classes 4–7 (Fig. 4a,

Table 10
Age profiles for archaeological assemblages.

a: Specific system

Specific age class	Hallan Çemi			Banahilk			Tell Leilan		
	N	Mortality	Survivorship	*N*	Mortality	Survivorship	*N*	Mortality	Survivorship
1	5	4.3%	95.7%	1	3.7%	96.3%	1	1.6%	98.4%
2	1	0.9%	94.8%	4	14.8%	81.5%	8	12.5%	85.9%
3	13	11.3%	83.5%	2	7.4%	74.1%	22	34.4%	51.6%
4	16	13.9%	69.6%	6	22.2%	51.9%	18	28.1%	23.4%
5	3	2.6%	67.0%	3	11.1%	40.7%	5	7.8%	15.6%
6	7	6.1%	60.9%	5	18.5%	22.2%	3	4.7%	10.9%
7	16	13.9%	47.0%	4	14.8%	7.4%	2	3.1%	7.8%
8	12	10.4%	36.5%	2	7.4%	0.0%	0	0.0%	7.8%
9	24	20.9%	15.7%	0	0.0%	0.0%	4	6.3%	1.6%
10	18	15.7%	0.0%	0	0.0%	0.0%	1	1.6%	0.0%
Total #	115			27			64		

b. Simplified-A system

Simplified-A age class	Hallan Çemi			Banahilk			Tell Leilan		
	N	Mortality	Survivorship	*N*	Mortality	Survivorship	*N*	Mortality	Survivorship
A	5	3.3%	96.7%	1	3.0%	97.0%	6	7.7%	92.3%
B	21	13.7%	83.0%	8	24.2%	72.7%	29	37.2%	55.1%
C	16	10.5%	72.5%	7	21.2%	51.5%	22	28.2%	26.9%
D	12	7.8%	64.7%	4	12.1%	39.4%	3	3.8%	23.1%
E	32	20.9%	43.8%	11	33.3%	6.1%	12	15.4%	7.7%
F	49	32.0%	11.8%	2	6.1%	0.0%	5	6.4%	1.3%
G	18	11.8%	0.0%	0	0.0%	0.0%	1	1.3%	0.0%
Total #	153			33			78		

c. Simplified-B system

Simplified-B age class	Hallan Çemi			Banahilk			Tell Leilan		
	N	Mortality	Survivorship	*N*	Mortality	Survivorship	*N*	Mortality	Survivorship
I	58	30.7%	69.3%	29	63.0%	37.0%	66	71.0%	29.0%
II	61	32.3%	37.0%	15	32.6%	4.3%	19	20.4%	8.6%
III	52	27.5%	9.5%	2	4.3%	0.0%	7	7.5%	1.1%
IV	18	9.5%	0.0%	0	0.0%	0.0%	1	1.1%	0.0%
Total #	189			46			93		

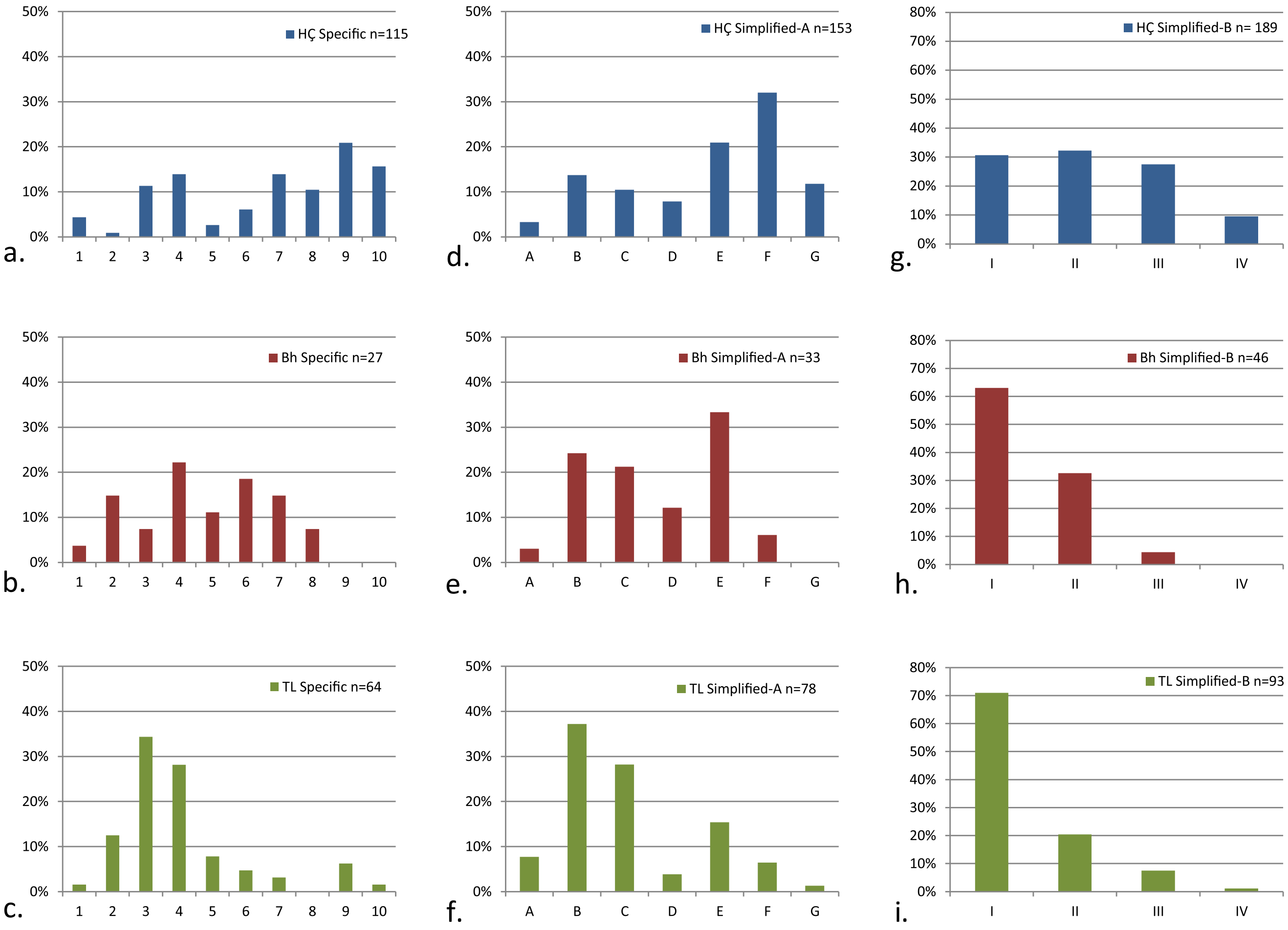

Fig. 4. Mortality profiles for three assemblages examined in this study. a) Hallan Çemi Specific system, b) Banahilk Specific system, c) Tell Leilan Specific system, d) Hallan Çemi Simplified-A system, e) Banahilk Simplified-A system, f) Tell Leilan Simplified-A system, g) Hallan Çemi Simplified-B system, h) Banahilk Simplified-B system, i) Tell Leilan Simplified-B system.

between about 1 and 3 years by the age estimate provided in Table 7). More than 60% of the pigs at this site were killed between age classes 7–10, with a special emphasis on animals in age class 9, estimated to represent animals about 8 years of age. In contrast, age profiles from the urban Tell Leilan indicate a strong focus on young animals, with over 70% of the pigs recovered from the site harvested by age class 3 (6–8 months) (Fig. 3a). As mentioned above, however, the Tell Leilan assemblage also indicates that older animals were harvested at the site, demonstrated by the small number of pigs assigned to age classes 6, 7, 9, and 10 (Fig. 4c). The Banahilk age profiles fall somewhat in-between. Although not as intense as at Tell Leilan, the Banahilk assemblage shows a much stronger emphasis on younger animals than seen at Hallan Çemi, especially on animals in age class 4 (c. 12 months) with continued harvest through age class 7 accounting for the slaughter of more than 80% of the pigs from the site (Fig. 3a). There are no animals older than age class 8 at the site (Fig. 4b).

The Tell Leilan profile, then, would seem consistent with an indirect provisioning system which provided urban residents with very young, and presumably very tender, animals in a narrow age range—especially piglets between about 3 and 8 months of age. The presence of older animals at the site, however, suggests the on-site presence of a breeding population at Tell Leilan as suggested by Zeder's earlier study (2003), as well as, perhaps, some older wild, hunted boar at the site. The Banahilk pig age profiles are also consistent with a village-based economy, where management strategies emphasize the off-take of younger animals (from about 3 to 12 months), but where residents also have access across a broader range of animals with a managed herd. The Hallan Çemi age profile is not consistent with either a village-based herd management or an urban provisioning system. The initial emphasis on younger animals detected here might, as suggested by Redding and Rosenberg (1998, 2000), point to an intermediate exploitation strategy between a managed herd with an emphasis on young animals and the emphasis on prime age adults predicted with the hunting of wild animals (Stiner, 1990; Zeder, 2001). However, it might also reflect a hunting strategy that targets different components of a wild herd at different seasons of the year. Future work directed at constructing sex-specific harvest profiles for the Hallan Çemi pigs will explore these alternatives in greater depth. What is clear, however, is that the Specific age classification system presented here seems to have been successful in distinguishing between these three different exploitation systems at a very high level of resolution.

The somewhat lower resolution Simplified-A classificatory system, which increased sample sizes between 20 and 50%, seems to also be largely successful in distinguishing between these three different exploitation strategies (Figs. 3b, 4d–f). Again, Hallan Çemi clearly diverges from the other two curves, beginning at age class B (about 3–8 months), with the middle age classes C to E (age classes

4–7 in the Specific scheme) representing the largest disparities (Fig. 3b). The clear drop-off after age class E, and the emphasis on animals in age class F (32%) (Fig. 4d), reflects the same emphasis on older animals indicated under the Specific system. The emphasis on the harvest of older animals at this site is drawn into sharper relief by the combination of age classes 6 and 7 and age classes 8 and 9 to form age classes E and F in the Simplified-A system (compare Fig. 4a and d). Though somewhat muted, the steep drop-off in survivorship in young animals at Tell Leilan is also evident using the Simplified-A system where less than 30% of animals survive beyond age class C (c. 12 months), and 40% of the sample fall into age class B (c. 3–8 months, Fig. 4f). Grouping the more discrete age classes of the Specific system, however, has the effect of flattening the curve between age classes B and E, making the differences between the Tell Leilan and Hallan Çemi curves less pronounced than when using the Specific system; compare a 51.3% difference in survivorship between the two at age class 5 at the Specific level (Fig. 3a) to a reduced 41.6% at the equivalent Simplified-A age class D (Fig. 3b).

Banahilk too retains patterns detected using the higher resolution classificatory system. The grouping of specific age classes 6 and 7 into Simplified-A age class E, however, gives the impression of a more focused emphasis on this older age class than was evident in the more evenly distributed kill-off of animals across stages 5–8 captured in the Specific classificatory system (compare Fig. 4b and e). Grouping age classes together also has the effect of making the differences between Tell Leilan and Banahilk seem less dramatic than when using the Specific classificatory scheme. Survivorship rates over age classes B through E at Banahilk and Leilan are more similar to one another in the Simplified-A survivorship curves (Fig. 3b), than their equivalents (age classes 2–7) when using the Specific scale (Fig. 3a).

The most inclusive Simplified-B system increases the size of the usable samples an additional 20–30%. It does so, however, at the expense of the resolution of the resulting age profiles (Figs. 3c and 4g–h). While the Hallan Çemi survivorship and mortality patterns still clearly stand out in their emphasis on older animals (Figs. 3c and 4g), the Banahilk and Tell Leilan age profiles appear almost identical (Figs. 3c and 4h–i). The focused exploitation on a narrow range of very young animals at Tell Leilan is almost entirely masked by the grouping of younger age classes (Specific age classes 1–4 and Simplified-A age classes A–C) in a single age class I. The bimodal nature of the Leilan age profile and the more gradual kill-off of older animals at Banahilk are likewise blurred by the grouping of finer resolution Specific and Simplified-A age classes into age classes II and III using the Simplified-B system.

Thus, the Specific and Simplified-A systems, with their more rigorous parameters for defining age classes, produce mortality and survivorship profiles that reveal detailed patterns in pig procurement. By defining age classes within a stricter and more detailed spectrum, these systems emphasize differences and provide a method for differentiating even sites with similar procurement strategies. Conversely, the more generalized Simplified-B system highlights similarities between sites by condensing age classes into broadly inclusive super groups, thereby only detecting grosser differences in exploitation strategies. However, what it lacks in detail and resolution it makes up for with an increase in the available sample size. Given this loss of resolution, then, the Simplified-B system is likely best used only with very small or fragmentary assemblages with samples of ageable specimens too small to render reliable results using either of the higher resolution systems.

4. Conclusions

This study of eruption and wear patterns in 91 modern specimens of wild *S. scrofa* provides a robust new method for constructing pig harvest profiles that addresses the limitations in resolution and sample size of previous methods. The continued use of Grant's (1982) tooth wear patterns as the foundation for documenting tooth wear, as well as the incorporation of previous archaeological studies on both eruption and wear (Anezaki, 2009; Bull and Payne, 1982; Carter and Magnell, 2007) retains a common vocabulary to more universally share data and apply new techniques to previously analyzed material. What this study presents is a new grammar that organizes these fundamental components into an improved method for construction of dentition-based harvest profiles in pigs.

While previous systems are largely restricted to mandibular tooth rows, our study of the paired mandibles and maxillae of these 91 specimens has demonstrated that with proper calibration of the parameters for maxillary to mandibular tooth scores within age classes, age profiles can be computed using *both* mandibular and maxillary dentition, as well as loose teeth no longer associated with mandibular or maxillary tooth rows. The obvious benefit of broadening categories of ageable dentition in this way is that it vastly enhances sample size, addressing a chronic problem in previous methods. Perhaps even more significantly, we have also shown that the inclusion of maxillary tooth rows and loose teeth in the sample of aged dentition also compensates for heretofore largely unrecognized biases in age profiles constructed using only mandibular tooth rows. The greater likelihood of representation of younger individuals among loose teeth and older individuals among maxillary tooth rows compliments the portion of the harvested population captured by mandibular tooth rows, resulting in an age profile that more accurately represents ancient exploitation strategies. Thus, incorporating maxillary tooth rows and loose teeth into this type of analysis provides two benefits: 1) it increases the available sample for aging, and 2) it tempers distortion of data caused by factors that may increase the unequal proportion of elements.

As is true for most modern skeletal collections of wild animals, the ages at death of the boar specimens included in this study were not known. Thus, this study does not definitively address the lack of an absolute scale for determining age at death in other methods for computing dentition based age profiles for pigs. The high degree of agreement between different studies on age of eruption for various deciduous and permanent teeth in pigs, however, does allow us to anchor the younger age classes of our system with some confidence to an absolute age scale. As for our older age classes, the correspondence between wear patterns used to define these age classes and the patterns seen among older animals in the Bull and Payne study and, in particular, in the Anezaki study, allows us to provide a relatively secure calibration for our system that extends into the latest stages of the animals' lifespan.

The study of this large sample of modern wild boar specimens also permitted the creation of meaningful and useful age classes based on patterns present in animals under more comparable dietary conditions to those being studied archaeologically. This study generally upholds previous work done on the subject (Table 6), and, as the most comprehensive study done to date, provides a more detailed and finer-grained system for assigning animals to age classes. The creation of a three level system for constructing pig age profiles allows for analysis to be conducted from a high resolution Specific scale (with ten age classes) at one extreme, to the broadly defined scale of Simplified-B (with only four age classes) at the other extreme, with an additional, more intermediary method for the Simplified-A scale (with 7 age classes).

While the Specific level system picks up on nuances and subtleties in patterns of animal exploitation, this level of detail comes at the cost of reducing the available sample. The Simplified-A system, which sees a minimum 20% increase in sample size, still has some of the level of resolution necessary for detecting the patterns revealed in the finer grained Specific system. This more broadly defined classificatory system may even, in some cases, allow some patterns to be represented more clearly than they are in the Specific system; take for example the clearer differences between the exploitation patterns of older animals seen in the comparison of the Simplified-A mortality curves for Hallan Çemi and Banahilk (Fig. 4d and e). This grosser classificatory scheme, however, does make differences between the two managed populations at Banahilk and Tell Leilan seem less obvious than they did with the Specific system (Figs. 3b and 4b and c compared to 4e and f). At the most inclusive level of classification, Simplified-B, sample size increases most dramatically by as much as 66% between Specific and Simplified-B systems. However, the broadly grouped nature of age classes at this level blurs patterns of exploitation at every site in this study. Some patterns, such as the emphasis on older animals at Hallan Çemi, become practically indiscernible, while Tell Leilan and Banahilk—which both showed marked differences in exploitation at the other two levels—are almost identical when using this scale.

In sum, the study presented here provides a method for classifying archaeological pig assemblages to age classes that is grounded in the most robust study of modern specimens to date. It presents evidence for the confident use of both maxillary and mandibular tooth rows and loose teeth in archaeological analysis, vastly increasing the sample of dentition used to construct age profiles and correcting for taphonomically driven sample biases that may arise in methods restricted only to mandibular tooth rows. It provides, moreover, a means by which these profiles can, with some confidence, be anchored to an absolute scale of age at death that extends throughout the pig lifespan. Finally, this flexible three-level, hierarchical system provides a method for computing age profiles at different levels of resolution capable of detecting both finer and broader differences in pig exploitation strategies that accommodates assemblages of varying size and context.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.04.002.

References

Anezaki, T., 2009. Estimating age at death in Jomon Japanese wild boar (*Sus Scrofa Leucomystax*) based on the timing of molar eruption in recent comparative samples. Mamm. Soc. Jpn. 34.2, 53–63.

Briedermann, L., 1965. Les composantes de l'alimentation du sanglier en Europe Centrale. Rapports du VIIème Congrès de l'Union des Biologistes du Gibier, Belgrade, pp. 207–213.

Bull, G., Payne, S., 1982. Tooth eruption and epiphysial fusion in pigs and wild boar. In: Wilson, B., Grigson, C., Payne, S. (Eds.), Ageing and Sexing Animal Bones from Archaeological Sites, BAR British Series, vol. 109, pp. 55–71.

Carter, R., Magnell, O., 2007. Age estimation of wild boar based on molariform mandibular tooth development and its dpplication to deasonality at the Mesolithic dite of Ringkloster, Denmark. In: Albarella, U., Dobney, K., Ervynck, A., Rowley-Conwy, P. (Eds.), Pigs and Humans: 10,000 Years of Interaction. Oxford University Press, Oxford, pp. 197–217.

Davis, S.J.M., 1983. The age profiles of gazelles predated by ancient man in Israel: possible evidence for a shift from seasonality to sedentism in the natufian. Paléorient 9, 55–62.

Ervynck, A., 1997. Detailed recording of tooth wear (Grant 1982) as an evaluation of seasonal slaughtering of pigs? Examples from medieval sites in Belgium. Archaeofauna 6, 67–79.

Ervynck, A., Dobney, K., Hongo, H., Meadow, R., 2001. Born free? New evidence for the status of Sus scrofa at neolithic Çayönü Tepesi (Southeastern Anatolia, Turkey). Paléorient 27, 47–73.

Fandén, A., 2005. Ageing the beaver (*Castor fiber* L.): a skeletal development and life history calendar based on epiphyseal fusion. Archaeofauna 14, 199–213.

Grant, A., 1982. The use of tooth wear as a guide to the domestic ungulates. In: Wilson, B., Grigson, C., Payne, S. (Eds.), Ageing and Sexing Animal Bones from Archaeological Sites, BAR British Series, vol. 109, pp. 91–108.

Greenfield, H.J., Arnold, E.R., 2008. Absolute age and tooth eruption and wear sequences in sheep and goat: determining age-at-death in zooarchaeology using a modern control sample. J. Archaeol. Sci. 35, 836–849.

Habermehl, K.H., 1975. Die altersbestimmung bei hausund labortieren. Parey, Berlin & Hamburg.

Hesse, B., 1978. Evidence for Husbandry from the Early Neolithic Sites of Ganj Dareh in Western Iran (Ph.D. dissertation). Columbia University, New York: University Microfilms.

Hole, F., Flannery, K.V., Neely, J.A., 1969. Prehistory and Human Ecology on the Deh Luran Plain. In: Memoirs of the Museum of Anthropology. The University of Michigan Press, Ann Arbor.

Hongo, H., Meadow, R.H., 1998. Pig exploitation at Neolithic Cayönü Tepesi (Southeastern Anatolia). In: Nelson, S.M. (Ed.), Ancestors for the Pigs: Pigs in Prehistory. MASCA, Philadelphia, pp. 77–98.

Klein, R.G., 1982. Patterns of ungulate mortality and ungulate mortality profiles from Langebaanweg (Early Pliocene) and Elandsfontein (Middle Pleistocene), south-western Cape Province, South Africa. Ann. S. Afr. Mus. 90 (2), 49–64.

Laffer, J.P., 1983. The faunal remains from Banahilk. In: Braidwood, L., Braidwood, R.J., Howe, B., Reed, C.A., Watson, P.J. (Eds.), Prehistoric Archaeology Along the Zagros Flanks. The Oriental Institute, Chicago, pp. 629–647.

Legge, A.J., 2013. 'Practice with Science': molar tooth eruption ages in domestic, feral, and wild pigs (*Sus scrofa*). Int. J. Osteoarchaeol. (Online).

Matschke, G.H., 1967. Aging European wild hogs by dentition. J. Wildl. Manag. 31, 109–113.

Magnell, O., 2002. Tooth wear in wild boar (*Sus scrofa*). In: Rucillo, D. (Ed.), Recent Advances in Aging and Sexing Animal Bones. Durham: 9th ICAZ Conference, pp. 189–203.

Magnell, O., 2005. Harvesting wild boar—a study of prey choice by hunters during the Mesolithic in South Scandinavia by analysis of age and sex structures in faunal remains. Archaeofauna 14, 27–41.

Moran, N.C., O'Connor, T.P., 1994. Age attribution in domestic sheep be skeletal and dental maturation: A pilot study of available sources. J. Archaeol. Sci. 4, 267–285.

Munro, N.D., Bar-Oz, G., Stutz, A.J., 2009. Aging mountain gazelle (Gazella gazella): refining methods of tooth eruption and wear and bone fusion. J. Archaeol. Sci. 36, 752–763.

Munson, P.J., Garniewicz, R.C., 2003. Age-mediated survivorship of ungulate mandibles and teeth in canid-ravaged faunal assemblages. J. Archaeol. Sci. 30, 405–416.

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

Redding, R.W., 2005. Breaking the mold, a consideration of variation in the evolution of animal domestication. In: Vigne, J.-D., Helmer, D. (Eds.), The First Steps of Animal Domestication: New Zooarchaeological Approaches. Oxbow Books, Oxford, pp. 41–48.

Redding, R.W., Rosenberg, M., 1998. Ancestral pigs: a new (Guinea) model for pig domestication. In: Nelson, S.M. (Ed.), Ancestors for the Pigs: Pigs in Prehistory. MASCA, Philadelphia, pp. 65–76.

Redding, R.W., Rosenberg, M., 2000. Hallan Çemi and early village organization in Eastern Anatolia. In: Kuijt, Ian (Ed.), Life in Neolithic Farming Communities. Plenum Publishers, New York, pp. 39–52.

Rolett, B.V., Chiu, M., 1994. Age estimation of prehistoric pigs (*Sus scrofa*) by molar eruption and attrition. J. Archaeol. Sci. 21, 377–386.

Rosenberg, M., Nesbitt, R., Redding, R.W., Peasnall, B.L., 1998. Hallan Çemi, pig husbandry, and post-Pleistocene adaptations along the Taurus-Zagros Arc (Turkey). Paléorient 24, 25–41.

Rufolo, S.J., 2011. Specialized Pastorlaism and Urban Process in Third Millennium BC Northern Mesopotamia (Ph.D. dissertation). John Hopkins University, Baltimore: University Microfilms.

Silver, I.A., 1969. The ageing of domestic animals. In: Brothwell, D., Higgs, E.S. (Eds.), Science in Archaeology. Thames and Hudson, London, pp. 283–302.

Starkovich, B.M., Stiner, M.C., 2009. Hallan Çemi Tepesi: high-ranked game exploitation alongside intensive seed processing at the Epipaleolithic-Neolithic transition in southeastern Turkey. Anthropozoologica 44, 41–61.

Stiner, M.C., 1990. The use of mortality patterns in archaeological studies of Hominid predatory adaptations. J. Anthropol. Archaeol., 305–351.

Tucker, A.L., Widowski, T.M., 2009. Normal profiles for deciduous dental eruption in domestic piglets: effect of sow, litter, and piglet characteristics. J. Anim. Sci. 87, 2274–2281.

Watson, P.J., 1983. The soundings at Banahilk. In: Braidwood, L., Braidwood, R.J., Howe, B., Reed, C.A., Watson, P.J. (Eds.), Prehistoric Archaeology along the Zagros Flanks. The Oriental Institute, Chicago, pp. 545–613.

Weiss, H., 1990. Third millennium urbanization: a perspective from Tell Leilan. In: Eichler, S., Wäfler, M., Warburton, D.A. (Eds.), Tall al-Hamidiya 2: Symposion Recent Excavations in the Upper Khabur Region. Universitätsverlag Freiburg/Vandenhoeck and Ruprecht, Fribourg, Switzerland/Göttingen, Germany, pp. 159–166.

Zeder, M.A., 1991. Feeding Cities: Specialized Animal Economy in the Ancient Near East. Smithsonian Institution Press, Washington, DC.

Zeder, M.A., Hesse, B., 2000. The initial domestication of goats (Capra hircus) in the Zagros Mountains 10,000 years ago. Science 287, 2254–2257.

Zeder, M.A., 2001. A metrical analysis of a collection of modern goats (Capra hircus aegargus and C. h. hircus) from Iran and Iraq: implications for the study of caprine domestication. J. Archaeol. Sci. 28, 61–79.

Zeder, M.A., 2003. Food provisioning in urban societies: a view from northern Mesopotamia. In: The Social Construction of Ancient Cities. Smithsonian Institution Press, Washington D.C., pp. 156–183.

Zeder, M.A., 2006a. Central questions in the domestication of plants and animals. Evol. Arch. 15, 105–117.

Zeder, M.A., 2006b. Archaeological approaches to Documenting Animal Domestication. In: Zeder, M.A., Decker-Walters, D., Bradley, D., Smith, B.D. (Eds.), Documenting Domestication: New Genetic and Archaeological Paradigms. University of California Press, Berkeley, pp. 209–227.

Zeder, M.A., 2006c. Reconciling rates of long bone fusion and tooth eruption and wear in sheep (Ovis) and goat (Capra). In: Rucillo, D. (Ed.), Recent Advances in Aging and Sexing Animal Bones. Durham: 9th ICAZ Conference, pp. 87–118.