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The dentition of red deer *(Cervus elaphus)*: a scoring scheme to assess age from wear of the permanent molariform teeth

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(With 5 figures in the text)

Skulls of red deer *(Cervus elaphus)* of known age were examined. A scoring procedure devised for fallow deer *(Duma dama)* was used to relate tooth wear to a particular age (Brown & Chapman, 1990). The precise sequential nature of tooth wear as it appeared on the slopes and tips of cusps, on the marginal ridges and links between cusps was recorded. From these data a base has been provided from which estimates of age may be made of animals of unknown age. The variability for the scores are given for *95%* prediction intervals from the regression of age on total molar wear

Contents

Introduction

It is essential to have an accurate idea of an animal's age to manage effectively domestic livestock or interpret trends occurring among mammalian wildlife. Knowledge of the age of an animal is

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also an invaluable aid to archaeology, enabling indirect interpretations to be made of the socio-economic and ritual activities of the past.

Traditionally for cervids and other ungulates it is the number of teeth that have erupted or the extent that they are worn that has been used as an indication of age, but too often these estimates are in doubt because they have not been derived from animals of known age; and when animals of known age are used, the precise criteria for establishing wear status are not clear. Though the amount teeth may wear is known to be variable, the extent of the variability is rarely stated. Lowe (1967) evaluated different age indices from red deer of known age from Rhum, and acknowledged the usefulness of states of wear, but did not adequately describe how he recognized different levels of wear. **He** stated that the patterns of tooth wear of his red deer differed only slightly from those photographed from very different habitats in Germany. More recent publications about red deer continue to illustrate and describe the degrees of wear, but none of the authors, von Raesfeld (1971), Muller-Using (1971), Wagenknecht (1981), Drescher (1989) or Mitchell & Youngson (undated) has used a universally applicable scoring system to assess wear,

We reviewed the several approaches to ageing animals from different stages of occlusal wear, and found that the schemes described by Payne (1973) for goats *(Capra)* and Grant (1982) for cattle *(Bovis)* are ones most commonly used, but they are inappropriate for other species. Assessments of age from wear patterns are still frequently used, but because the accuracy of many of these assessments has been in doubt, we devised a detailed scoring system based on a clear understanding of the sequential nature of the tooth wear process on the individual cusps of the molariform teeth of fallow deer *(Dama dama)* (Brown & Chapman, 1990). Because the tooth wear characteristics for red deer *(Cervus elaphus)* are vey similar to those of fallow deer, we have used the same method for scoring the readily observable small changes in tooth wear for different age groups of 111 animals. We had found for fallow deer that the wear patterns observed on the premolars were less convincingly related to changes with age than the molars, and have excluded them from this study.

This paper analyses three approaches to ageing: the ages by which specific wear phenomena are found for the molars; the age by which a particular score may be expected; and lastly the predicted age from a derived tooth wear score, together with the 95% prediction intervals, obtained from a regression of age on total molar wear score.

Materials and methods

Sample

The sample was composed of 111 red deer, 59 male and 52 female of known age from 5 months old to 138 months (Table I). One of these animals was excluded, because there was serious doubt about its identity arising from the final preparation of its skull. Because the number of males and females in each group is uneven, with a preponderance of males in the younger ages and very few animals in the older groups, the sexes have been combined. The animals were at pasture in Richmond Park, Surrey, the vegetation of which has been described by Chapman & Chapman (1975). In May/June for 11 years calves were ear-tagged with plastic jumbo tags (Dalton Supplies Ltd.; Nettlebed, Oxon. RG9 5AB) within a few days of birth.

The tag in the left ear was numbered and colour coded for the year. The male and female halves of the right ear-tag gave a colour combination specific to an individual animal within a year group. Upon the death of marked animals the skulls with their mandibles were prepared by defleshing and then bleached with sodium perborate tetrahydrate (Chapman & Chapman, 1969). One hundred and one deer were killed within the appropriate legal seasons. (Males: mostly August and September, plus some calves taken during the female

TABLE I

*Red deer (**Cervus elaphus**) wear sample size, age and sex*

Age (months)	Males	Females	Totals
5-11	11	5	16
13-19	4	20	24
26-33	19	9	28
38-42	13	2	15
50-55	4	7	11
63-66	4	2	6
75-78	1	5	6
87-138	3	2	5
Total	59	52	111

cull. Females: mostly November, December and January). Ten deer died of natural or accidental causes. It should be noted that all the animals are born within a few weeks of each other and are culled at specially selected times of the year, leading to an uneven representation of animals for different ages.

Teeth examined

The dentitions of red deer are:

Deciduous i 0/3 c 1/1 pm 3/3
Permanent I 0/3 Cl/1 PM 3/3 M 3/3

Only the mandibular molars from the right side have been used in this study (Fig. 1). The first and second mandibular molars have a crown made up of mesial and distal pairs of cusps and 2 roots, one mesial and one distal. The third molar has an additional distal cusp and a root which is fused to the main distal root. The space that separates the paired mesial or distal cusps is the infundibulum (Fig. 2a). In life this is varyingly filled with chewed food and debris. On the buccal or cheek side the mesial cusp is the protoconid and the distal cusp the hypoconid, both being rounded and pillar-like with pointed tips. On the lingual side the mesial cusp is the paraconid and the distal the metaconid, both of which are flattened with a centrally located axial rounded ridge rising to a pointed cusp tip; the mesial cusp appears to overlap the distal. In the third molar the single distal additional cusp has been identified as the hypoconulid (Table II and Figs 2a & b), as defined in Brown & Chapman (1990).

Eruption

A consistent chronological eruption sequence is an essential condition if ageing from wear is to have any validity. Several authors have given tables for the ages the teeth erupt or the ages when the teeth become functional. Habermehl (1961), Mitchell (1967), Muller-Using (1971), von Raesfeld (1971), von Raesfeld & Vorreyer (1978), Wagenknecht (1981) and Drescher (1989) (Table III). The discrepancies that are apparent arise because it is not clear to what event the author is referring, development, eruption or the age when the teeth became functional. This sample is large enough to indicate by what age the teeth must have erupted and became functional.

The first molar erupts shortly after birth, followed by the second and third. Once a tooth occludes against a tooth or teeth on the opposing jaw, wear commences and a tooth wear score can be derived.

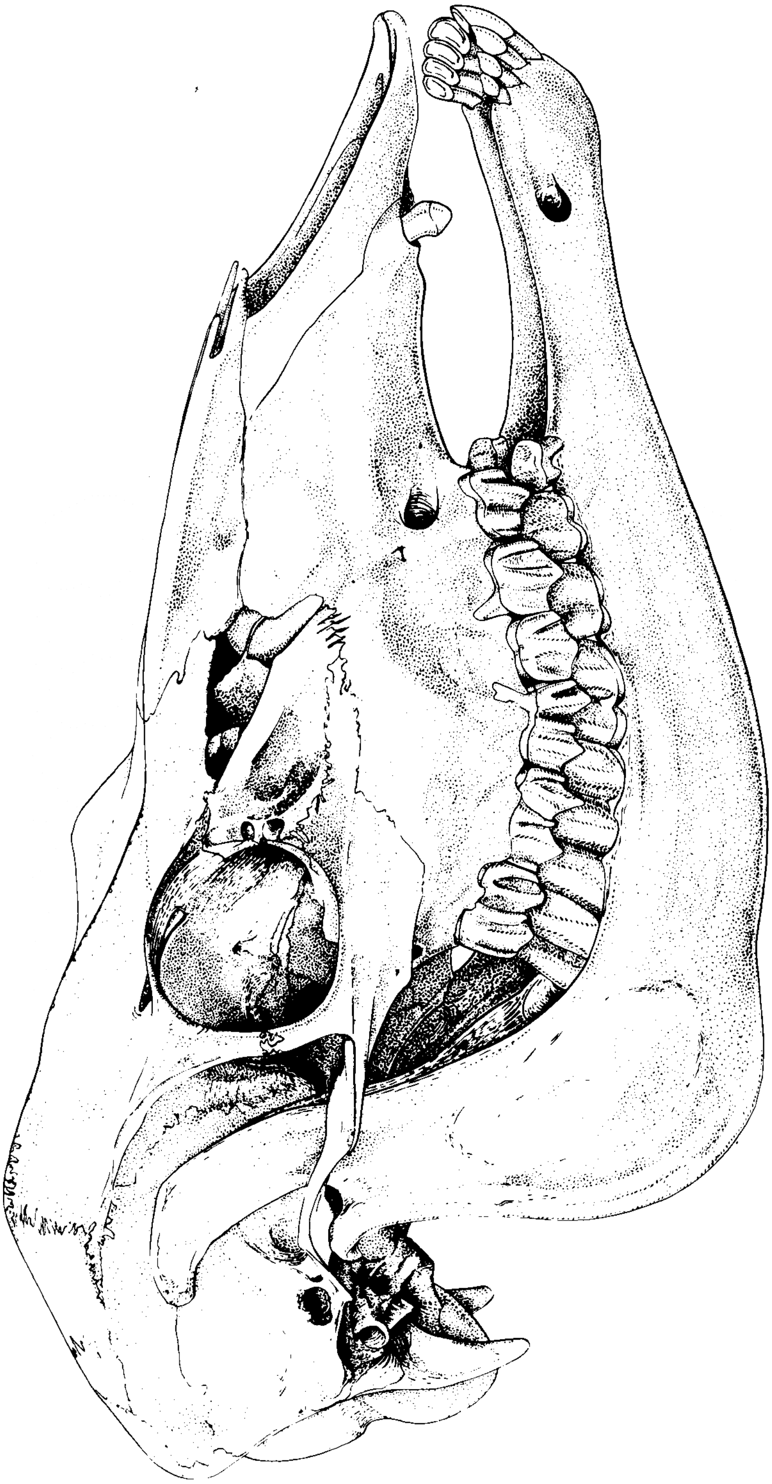


Fig. 1 The permanent dentition of red deer (*Cervus elaphus*). Epithelial covering of the premaxilla. The maxillary canine is isolated on its own and not subjected to wear. The mandibular incisors and canines occlude against a keratinised. Only the permanent molars of the right side have been analysed (2/3 size)

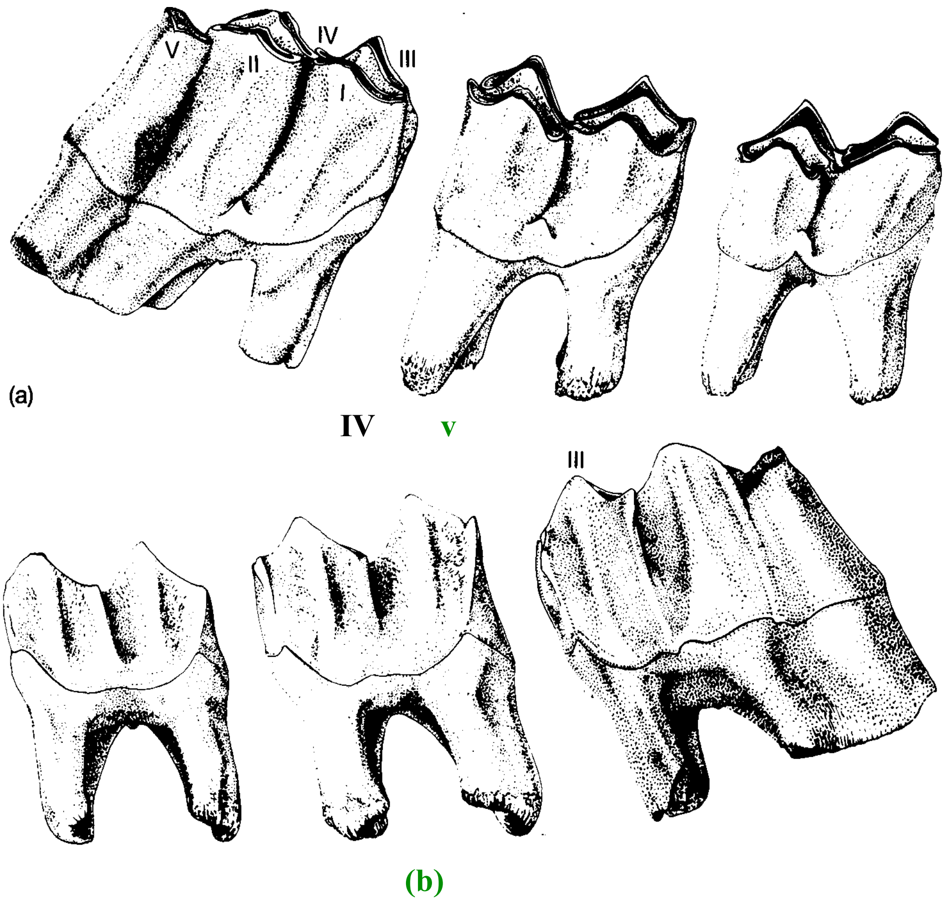


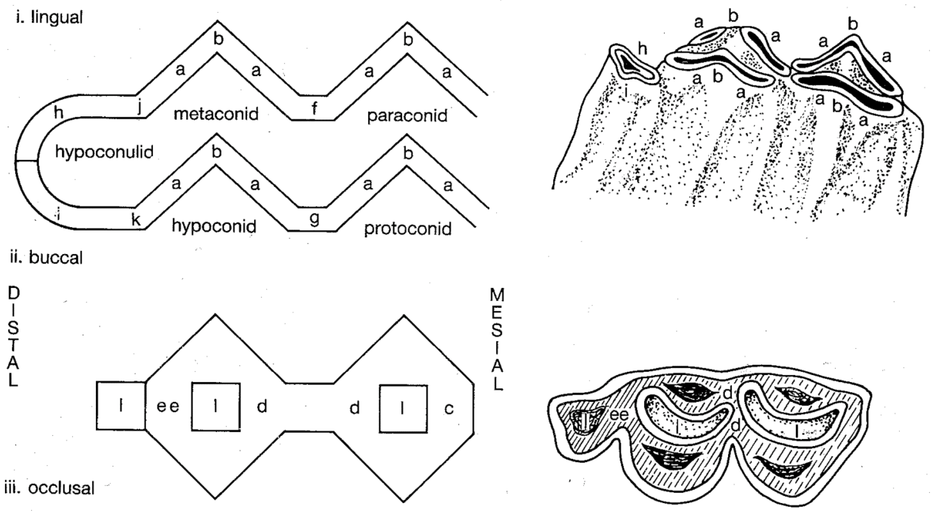
FIG. 2 (a) The buccal and (b) the lingual view of the molars from the right side of the mandible. The molars are selenodont with paired crescent-shaped cusps, which on the lingual side are flattened and on the buccal side rounded and pillar-like structures; the infundibula are located centrally between the lingual and buccal cusps. The teeth have a mesial and distal root, with the third molar having an additional cusp and a fused distal root. The cusps of the molars are as follows: I protoconid, II hypoconid. III paraconid, IV metaconid and V hypoconulid on the third molar only (II size).

Wear patterns

The distinctive characteristics of tooth wear and how they arise in red deer arc practically identical to those described in detail for fallow deer (Brown & Chapman, 1990). In the molar teeth the mesial slopes of the paired mesial cusps are the first to be worn, followed by wear on the distal cusp slopes. As opposing teeth come into contact, the covering enamel of the cusps is worn away revealing the underlying dentine. With time, more and more of the cusp is worn away and to prevent the central soft tissue pulp chamber of the cusp being exposed to the mouth's fluids, increments of secondary dentine are deposited by odontoblasts on the internal wall of the dentine. Because this secondary dentine is deposited incrementally, teeth have characteristic wear

TABLE II

The locations for scoring the third molar. The first and second molar are identical but without the distal hypoconulid. Though the representations of the cusps and other features are very diagrammatic, they proved to be a very effective way of recording the wear locations



Type of wear	Location	Score
Enamel wear on cusp slopes	a	1
Dentine wear on cusp slopes	a	2
"Central eye" between slopes	b	1
Dentine links between lingual and buccal cusps:		
i. mesial ridge	c	1
ii. between mesial and distal cusps	d	1
iii. distal ridge	e	1
Dentine links between mesial and buccal cusps:		
i. lingual aspect	f	1
ii. buccal aspect	g	1
Third molar hypoconulid dentine exposed:		
i. lingual aspect	h	1
ii. buccal aspect	i	1
iii. distal linking of i. and ii.	h&i	1
iv. link with lingual cusp	j	1
v. link with buccal cusp	k	1
vi. link between lingual and buccal cusps	e	1
All infundibulum worn away	l	1
Black staining of exposed dentine		1

TABLE **III**

*The ages for red deer **(Cervus elaphus)** by which the molars and permanent premolars come into wear. The ages (months) for the sample (n= 111) are compared with the findings of several authors*

	Molars			Premolars		
	1st	2nd	3rd	2nd	3rd	4th
Sample	0-5	13	26	26	26	26
Habermehl(1961)	5-12	12-24	23-27	27	27	27
Mitchell(1967)	5	12	33	24	24	24
von Raesfeld(1971)	5-11	12-14	30-31	28	28	28
Muller-Using (1971)	9	15	27-30	30	30	30
von Raesfeld & Vorreyer (1978)	4	12	21	25	25	25
Wagenknecht(1981)	4	12	21	25	25	25
Drescher(1989)	5-10	12-14	30-31	28	28	28

patterns, enabling an assessment of age to be made (Figs 3 & 4). As wear proceeds, the mesial and distal marginal ridge dentine and the dentine between the paired mesial and distal cusps becomes exposed. The ages by which these events are first observed and the age when they are always present have been determined (Tables IV, V, VI & VII).

Wear scores and how they were recorded

The method for scoring wear was identical to that used for fallow deer (Brown & Chapman. 1990). Each slope of a molar cusp, that only had enamel worn with no exposed dentine, was given a score of 1. When the underlying dentine was exposed a score of 2 was given (Table **II,** location a). An additional score of one was given when:

1. The dentine between the mesial and distal slopes showed a central white 'eye' (Table II, location b), indicating the exposure of the secondary dentine that had formed in the pulp chamber.
2. The dentine was exposed to link the dentine of the lingual and buccal cusps (Table II, locations c, d & e).
3. The mesial and distal slopes were worn so that there was a continuous joining line of exposed dentine between the 2 cusps on either the lingual or buccal aspects of the tooth (Table II, locations f & g).
4. The exposed dentine linking the lingual and buccal cusps and the exposed dentine linking the mesial and distal cusps were stained dark brown.

The small size and the unique shape of the most distal cusp, the hypoconulid, of the third molar presented special problems. One point each was given for wear on the lingual and buccal aspects (Table II, locations h & i). A further point was given when the lingual or buccal dentine was linked with that of the metaconid or hypoconid (Table III, locations j & h). Finally, when the enamel that lines the infundibulum was worn away

FIG. 3. The occlusal view of the permanent mandibular teeth of a four-year-old red deer. All the molars are selenodont with crescent-shaped paired mesial and distal cusps with the third molar having an additional distal cusp. A progressive increase of wear is observed from the first to the third molar (I size).

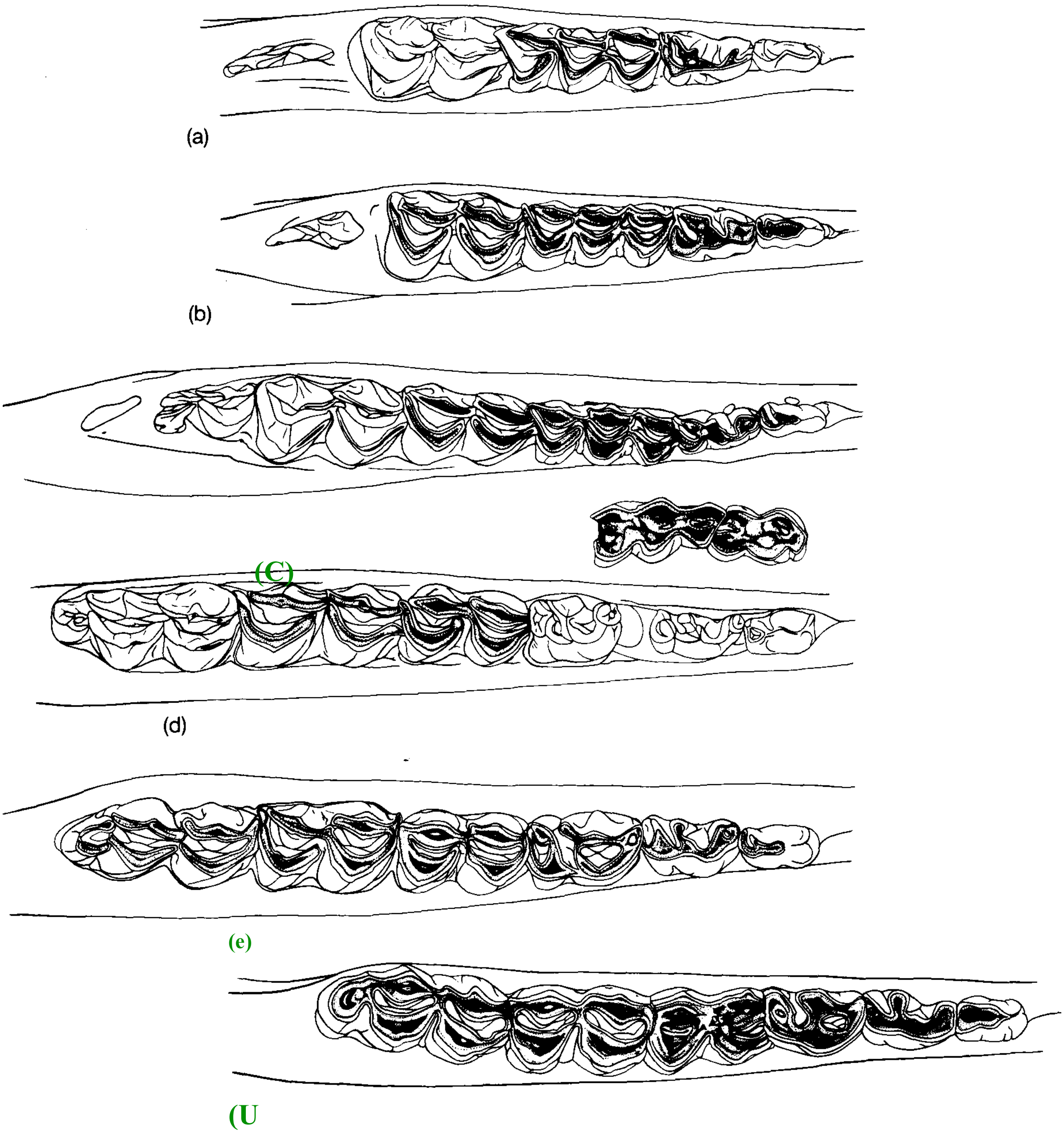


FIG. 4. Six stages to demonstrate sequential wear with age for red deer: (a) 5 months; (b) 10 months; (c) 18 months; (d) 27 months; (e) 50 months (f) 138 months. Note that in (a), (b) & (c) the deciduous premolars are still in place, while (d) shows well worn second and third deciduous premolars immediately after they have been shed and before the underlying premolars are functional (5/6 size).

TABLE IV

*Percentage of red deer (**Cervus elaphus**) in each age group with wear started on paired mesial and distal cusps of the permanent mandibular molars*

Age (months)	*n*	Wear		Molar M3	Molar M2	Molar M1
5–11	16	mesial cusps:	mesial slope	—	—	100
			distal slope	—	—	56
		distal cusps:	mesial slope	—	—	56
			distal slope	—	—	19
13–19	23	mesial cusps:	mesial slope	—	100	100
			distal slope	—	78	100
		distal cusps:	mesial slope	—	82	100
			distal slope	—	35	100
26–33	28	mesial cusps:	mesial slope	100	100	100
			distal slope	57	100	100
		distal cusps:	mesial slope	71	100	100
			distal slope	11	100	100
38–42	15	mesial cusps:	mesial slope	100	100	100
			distal slope	100	100	100
		distal cusps:	mesial slope	100	100	100
			distal slope	100	100	100

TABLE V

*Percentage of red deer (**Cervus elaphus**) in each age group in which the dentine of the lingual buccal cusps of the permanent mandibular molars is exposed and continuous on the mesial marginal ridge*

Age range (months)	Number	Molars 3rd	Molars 2nd	Molars 1st
5–11	16	0	0	0
13–19	23	0	0	8
26–33	28	7	43	71
38–42	15	40	73	87
50–55	11	73	91	100
63–66	6	100	100	100
75–78	6	67	83	100
87–138	5	100	100	100

revealing a continuous core of dentine (Table II, location 1), surrounded by the tooth's peripheral enamel, an additional point was given. The scores for each molar were arranged in the chronological age of the animal (Tables VIII & IX).

Statistical analysis

The data were analysed in 3 ways. The first identified in which age group for each molar a specific wear

TABLE VI

Percentage of red deer ***(Cervus elaphus)*** *in which the dentine of the paired lingual or buccal cusps is exposed and continuous and wear has commenced on the most distal cusp (hypoconulid) of the third molar*

Age (months)	*n*	Molar 3rd	2nd	1st	Hypoconulid
5-11	16				
13-19	23	—	—	—	—
26-33	28	—	4	11	7
38-42	15	—	—	13	93
50-55	11	—	27	45	90
63-66	6	33	100	100	100
75-78	6	17	83	83	100
87-138	5	60	80	100	100

TABLE VII

Ages (months) hy which specific wear characteristics are first observed and are always present in red deer ***(Cervus elaphus}***

Wear characteristic	3rd	2nd	1st
Mesial cusp wear begins	<26	<13	<5
Mesial cusp wear always present	<26	.<13	<5
Distal cusp wear begins	26-33	13-19	5-11
Distal cusp wear always present	38-42	26-33	13-19
Mesial marginal ridge wear begins	26-33	26-33	13-19
Mesial marginal ridge wear always present	87-138	87-138	50-55
Hypoconulid wear begins	26-33		
Hypoconulid wear always present	63-66		

characteristic was found (Tables IV, V, VI & VII). The second gave for the age groups the score each molar was likely to have (Tables VIII, IX & X). The last gave the predicted age together with 95% prediction intervals obtained from a regression of age on total molar scores as shown on the graph (Fig. 5). In addition, the total scores for each animal are plotted on the graph. The data revealed a curved relationship between age and total molar wear scores. The plot shows an ever increasing variability with age. For these reasons, a weighted multiple (i.e. curvilinear) regression of age on score and $(\text{score})^2$ was performed. The weights were based on the assumption that the residual standard deviation was proportional to the fitted line. The calculations were performed using GLIM (Payne, C,D., 1986) and the fitted regression was:

$$\text{Predicted age} = 4\text{-}6+0\text{-}36 \times (\text{score}) = 0\text{-}0035 \times (\text{score})^2$$

Similar calculations were done using a curvilinear regression of score against age which gave qualitatively similar results.

TABLE VIII

Wear scores for the molars of red deer **(Cervus elaphus),** arranged in order of age. n= 111. Note that the 18-month-old animal marked * has been excluded/rom any statistical analysis because of mistaken identity

Age (months)	M( )lar scoi 'es			Totals	Age (months)	Me)lar scoi res			Totals
	3rd	2nd	1st			3rd	2nd	1st	
5			1	1	28	8	22	28	58
5	—	—	2	2	28	7	19	27	53
5	—	—	7	2	29	4	16	22	42
6	—	—	8	8	30	4	22	27	53
6	—	—	6	6	30	3	17	22	42
6	—	—	2	2	30	10	20	24	54
6	—	—	4	4	30	4	23	23	50
6	—	—	6	6	30	9	20	23	52
6	—	—	6	6	30	16	22	25	63
6	—	—	6	6	30	8	20	26	54
6	—	—	2	2	31	10	21	22	53
6	—	—	4	4	31	11	23	22	56
6	—	—	4	4	33	11	21	25	57
9	—	—	12	12	38	18	19	26	63
10	—	—	17	17	39	20	20	26	66
11	—	—	14	14	39	19	21	22	62
13	—	1	16	17	39	22	24	27	73
14	—	1	16	17	39	17	25	25	67
15	—	2	22	24	39	22	21	26	69
15	—	1	16	17	39	17	21	26	64
18	—	8	16	24	40	20	21	22	63
18	—	10	21	31	40	13	16	20	59
18	—	12	17	29	40	16	23	36	75
18	—	9	20	29	40	17	20	23	60
18	—	10	16	26	40	17	16	22	55
18	—	6	20	26	41	18	25	31	74
18	—	10	20	30	42	20	28	29	77
18	—	10	20	30	50	25	24	29	78
18	—	9	23	32	50	31	28	36	95
18	—	7	16	23	51	26	26	29	81
18	—	7	17	24	51	24	25	32	81
18	—	7	16	23	54	20	29	23	72
18	—	9	19	28	54	25	25	33	83
18	—	8	19	27	54	28	27	26	81
18	—	11	16	27	54	30	35	35	100
18	—	8	20	28	54	23	23	24	70
18	—	14	16	30	54	25	26	29	80
18	—	8	20	28	55	31	26	29	86
18*	19	20	24	63	63	33	33	33	99
19	—	13	20	33	63	29	28	30	87
26	1	16	20	37	63	35	36	38	109
27	3	16	22	41	64	31	32	32	95
27	4	19	28	51	65	28	32	35	95
27	2	21	23	46	66	33	32	35	98
27	1	19	23	43	75	34	38	38	110
27	2	23	28	53	78	33	27	33	93
27	3	24	26	53	78	34	28	29	91
27	10	19	24	53	78	28	30	30	88
27	8	23	26	57	78	33	38	38	109
27	9	20	25	54	78	28	31	35	94
27	8	22	27	57	87	46	38	38	122
27	3	16	25	44	89	32	28	32	92
27	3	18	26	47	116	43	35	35	113
28	17	20	28	65	123	37	29	35	101
28	8	18	24	50	138	41	38	38	117

TABLE IX

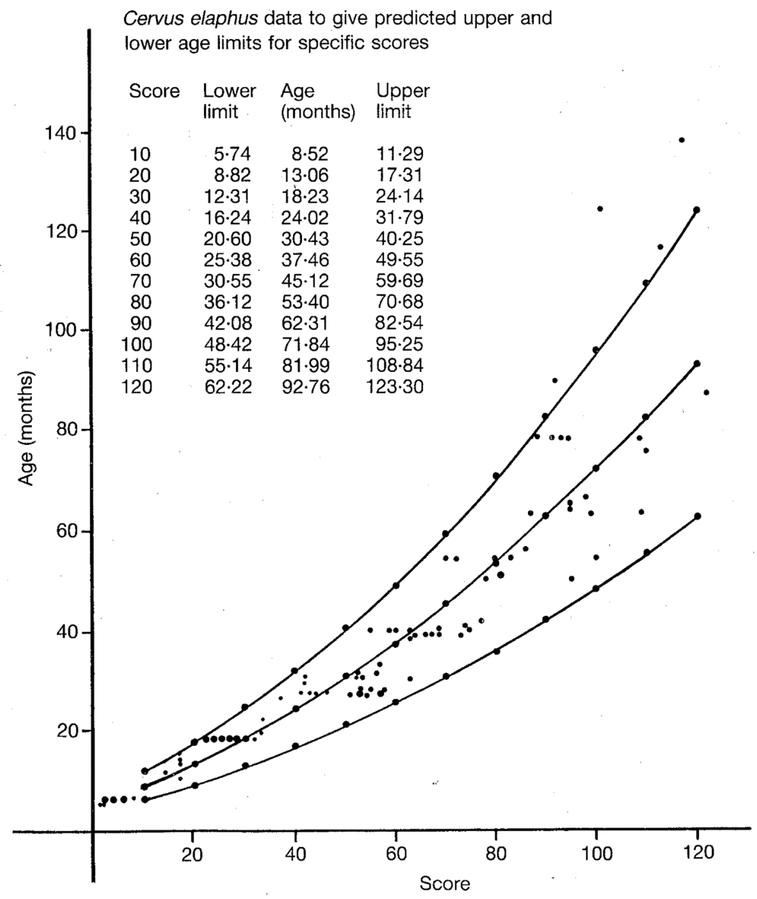
*Scores for individual molar wear for different age groups of red deer (**Cervus elaphus**)*

Age (months)															
5–11		13–19		26–33		38–42		50–55		63–66		75–78		87–138	
Score	*n*	Score	*n*	Score	*n*	Score	*n*	Score	*n*	Score	*n*	Score	*n*	Score	*n*
First molar															
1	1	16	9	20	1	20	1	23	1	30	1	29	1	32	1
2	4	17	2	22	5	22	3	24	1	32	1	30	1	35	2
4	3	19	2	23	4	23	1	26	1	33	1	33	1	38	2
6	4	20	7	24	3	25	1	29	4	35	2	35	1		
8	1	21	1	25	4	26	4	32	1	38	1	38	2		
12	1	22	1	26	4	27	1								
14	1	23	1	27	3	29	2								
17	1			28	4	31	1								
						36	1								
Second molar															
		1	3	16	4	16	2	23	1	28	1	27	1	28	1
		2	1	17	1	19	1	24	1	30	1	28	1	29	1
		6	1	18	2	20	2	25	2	32	2	30	1	35	1
		7	3	19	4	21	4	26	3	33	1	31	1	38	2
		8	4	20	5	23	2	27	1	36	1	38	2		
		9	3	21	3	24	1	28	1						
		10	4	22	4	25	2	29	1						
		11	1	23	4	28	1	35	1						
		12	1	24	1										
		13	1												
		14	1												
Third molar															
				1	2	13	1	20	1	28	1	28	2	32	1
				2	2	16	1	23	1	29	1	33	2	37	1
				3	5	17	5	24	1	31	1	34	2	41	1
				4	4	18	2	25	3	33	2			43	1
				7	1	19	1	26	1	35	1			46	1
				8	5	20	3	28	1						
				9	2	22	2	31	2						
				10	3										
				11	2										
				16	1										
				17	1										

TABLE X

*Age by which a particular score will be achieved for red deer (**Cervus elaphus**)*

Age (months)	Molar scores 3rd	2nd	1st	Total scores
5–11	zero	zero	1–17	1–17
13–19	zero	1–14	16–23	17–33
26–33	1–17	16–24	20–28	37–65
38–42	overlap	overlap	overlap	overlap



Cervus elaphus data to give predicted upper and lower age limits for specific scores

Score	Lower limit	Age (months)	Upper limit
10	5·74	8·52	11·29
20	8·82	13·06	17·31
30	12·31	18·23	24·14
40	16·24	24·02	31·79
50	20·60	30·43	40·25
60	25·38	37·46	49·55
70	30·55	45·12	59·69
80	36·12	53·40	70·68
90	42·08	62·31	82·54
100	48·42	71·84	95·25
110	55·14	81·99	108·84
120	62·22	92·76	123·30

FIG. 5. A scatterplot of the data, together with age (months) and 95% prediction intervals obtained from a regression of age on total molar score for red deer, $n = 110$. The inset table gives the age with upper and lower limits for scores at intervals of 10 points.

Results

Eruption

By five months of age the first of the permanent molars was erupted and functional, by 13 months the second molar and by 26 months the third molar (Table III).

Wear patterns

The consistent sequential nature of eruption assures a sequential pattern of tooth wear. The mesial slopes of the paired mesial cusps of all the molars started to wear before the slopes of the paired distal cusps. The first observed wear was of the comparatively thin white enamel followed by exposure of the underlying lightly brown stained dentine, which as it became progressively worn revealed the white 'eye' of the secondary dentine.

(a) *Wear of the mesial and distal slopes of the paired mesial and distal cusps* (Table IV).
Among the 13 animals that were five or six months old whose *first molars* were functional, all had wear on their mesial cusps; five of these animals had early wear on the mesial slopes of the distal cusps as well. The distal slopes were in wear from nine months. All the 23 animals in the 13-19 months age group had all their cuspal slopes in wear. For all but two of the 13 five- and six-month-old animals only the enamel had worn, but from 10 months onwards the underlying dentine was exposed and in wear. The white 'eye' of secondary dentine was first in evidence at 10 months, but not consistently present on all four cusps until 26 months. The *second molar* was functional from 13 months with enamel wear only on the mesial buccal cusp. Of the 18 animals aged 18 months, all had enamel or dentine wear on their mesial cusps, but usually only enamel wear on the distal cusp. Though all the animals were the same age, there were minor variations in the extent of the wear and how far it had progressed. There was no wear on the distal slopes of either the hypoconid or metaconid of 11 animals. **By** 26 months all four slopes of the mesial and distal cusps were in wear. The white 'eye' ofpulpal dentine was present on at least one of the cusps of 23 out of the 28 animals who were in the 26-33 month age group. The *third molar* was erupted and functional, with enamel wear only, by 26 months. **By** 38 months the paired mesial and distal cusps had dentine consistently exposed for the mesial and distal cusps. The most distal cusp, the hypoconulid, first showed enamel wear on a single 28-month-old animal, but not until 33 months was wear consistently present. The white 'eye' of dentine was first evident among 39-month-old animals and consistently so from 50 months.

(b) *The dentine of the lingual and buccal cusps exposed continuously across the mesial or distal marginal ridges or between the paired mesial and distal cusps*

The earliest age by which they??-.?? *molar* mesial marginal ridge had exposed dentine linking the lingual and buccal cusps was 15 months, and by 27 months a link between lingual and buccal aspects was consistently present (Fig. 4d). By 27 months the mesial marginal ridge of the *second molar* had exposed dentine, but it was not until 87 months that the mesial marginal ridge dentine was consistently found exposed. The earliest buccal/lingual link of exposed dentine for the *third molar* was found at 31 months, but the link between the buccal and lingual cusps was not a consistent findng until 87 months (Table V).

The dentine of the paired lingual or buccal cusps at first becomes exposed as a continuous link with the exposed dentine of the slopes, between 26-33 months for *the first* and *second molars,* but not until 50 or more months for the *third molar.* The most distal cusp, the hypoconulid, of the third molar was consistently in wear from 63 months (Table VI).

Wear scores

The animals are arranged chronologically with their wear scores (Table VIII). The totalled scores for the molars reflect the larger scores to be expected as the second and third molars became functional.

The scores for *the first molar* showed the overlaps between the different age groups. There was no overlap of scores for the *second molar* between deer, younger than 19 months and older than 26 months, but overlap occurred for the older groups. There was score overlap for the *third molar* in all the age groups and the dispersion of the overlap increased with age (Table IX).

Regression analysis of age on wear scores

The curved regression line was derived by plotting the total molar scores against individual known age (Fig. 5). As the scores increased with age, there was an ever increasing range of predictable age at the 95% prediction intervals. With a score of 10 there was a predicted age of 8-5 months ± 2-77 months, with a score of 50 a predicted age of 30-43 months ±9-83 months and with a score of 100, there is a predicted age of 71-84 months ±23-42 months.

Discussion

Eruption

A precise age of eruption for individual teeth cannot be given for this sample because of the narrow spread of ages in any one year (Table I). This arises because all the animals were born within a short time of each other, and were culled at regular times of the year, the males in August and September, the females in November, December or January. It can only be said that, within a certain age group, particular teeth will have erupted and become functional. Nevertheless, in spite of these reservations, the ages at which the teeth become functional in this sample of red deer are in broad agreement with various authors (Table III).

It should be remembered that the rate of wear may vary with the nature of the nutrition, as has been reported for domesticated animals, Ludwig, Healey & Cuttress (1966) and Deniz & Payne (1982), but what effect variations of nutrition have on wild or semi-wild animals is uncertain. Mitchell & Youngson (undated) noted from their Scottish red deer that it may be that most, if not all, red deer populations show much the same rates of tooth eruption and wear.

Wear patterns

The use of wear patterns as a means of assessing ages is dependent upon certain specific features being worn by a certain age (Figs 3 & 4): they are the ages at which each cusp and slope of the cusp comes into wear, with first the outer enamel being worn, then the underlying dentine being exposed and lastly the appearance of white 'eye' of secondary dentine. Assessments of age can be made by knowing by what age wear of the paired mesial and distal cusps has taken place, the age when there is a link of exposed dentine between the buccal and lingual sides of a tooth and the age when the dentine is continuously exposed to join the exposed dentine of the mesial and buccal cusps on the lingual or buccal sides. For all of these different events, there is for each pair of cusps and each molar two to three ways the link may be made; and it is for this reason that scoring a level of wear is particularly valuable as it will reflect a level of overall wear, without being dependent on a strict chronology of a wearing pattern. The absence of a particular wear pattern, as for instance unexposed dentine between the paired lingual or buccal cusps, indicated that the animal was over 55 months old (Table VI). However, it was found that the presence of a worn mesial marginal ridge on the 2nd molar, which was first observed in a 26-month-old animal, was not consistently present until after 78 months, a range of over four years (Table V). It is the large range of ages by which a particular wear pattern appears in the older animals that makes wear patterns by themselves an insufficiently reliable means of assessing age.

It was noted too that there were minor variations in the wear patterns of the red deer that had not been found in fallow deer. In the latter, the mesial marginal ridge was always worn before the exposure of the dentine linking the distal slopes of the paraconid and protoconid or between the distal slope of protoconid with the mesial slope of the metaconid, as may be seen for the first molar (Fig. 4d).

The complete wearing away of an infundibulum would be a distinctive and useful stage for assigning a minimum age for very old animals. Even the oldest animal of this sample, 138 months, still had evidence of its infundibula.

Animals that were close in age to each other have very similar wear characteristics. The 13 six-month-old animals showed preponderantly enamel wear only on their first molars. All the 18-month-old deer had dentine exposed on their paired first molar's mesial and distal cusps, while their distal cusps showed only enamel wear.

Wear scores

Establishing a precise means of scoring for wear, as distinct from recording a description of wear patterns, as Payne (1973) and Grant (1982) did, increases the objectivity of the assessment; the determination of age by scoring for all aspects of the wearing phenomenon, in contrast to an analysis of an overall pattern is a useful refinement. Not relating the score to a particular pattern, but rather to the accumulation of increased and readily identifiable wear locations and degrees of wear, allows for a steady progression of wear to be recorded. Tests for repeatability of the technique were undertaken and a very high level of accord was found. Quantifying scores enables the data to be handled on computers, a need recognized by Payne (1987). It is apparent from a comparison of the wear scores of animals of identical age that though the wear patterns may be variable in a number of ways, the scores are very close. The 18 animals of 18 months had a mean total molar wear score of 27-5 ±2-7, which is a useful confirmation of the reliability of the scoring technique. Though Lowe (1967) was the first to report on a known aged sample of red deer, comparing mandibles for animals of unknown age, it is not clear how he selected his wear comparisons. Mitchell & Youngson (undated) arranged jaws by sex, age and place of origin and from the photographs an overall picture of wear with age can be seen, but it is difficult to say that these changes are more than visual impressions. By defining the cuspal details of wear by scoring for each readily visible event, a more accurate evaluation of age can be made than by relying on a wear pattern. A particular wear pattern event may not have occurred, but overall wearing of the molars would have continued and a score would therefore reflect more accurately the age of the animals. This can best be appreciated by reference to the regression graph with its 95% intervals and the scatter of the individual scores (Fig. 5).

Regression analysis of age on wear scores

The curves from the regression analysis gave the most readily usable means for estimating age of an animal with no record of age. The prediction intervals indicating the range between which the estimate fell demonstrated how with higher scores the range of age increased, and emphasizing that with older animals wear, by whatever means it is recorded, can only be a guide to age. The plots of the individual animal's wear scores on to the regression graph show greater scatter with increasing age and higher scores. A score of 70 will give an estimated age of 45 months ± 15 months, whereas a score of 100 gives a predicted age of 72 months±23 months (Fig. 5).

A comparison of the regression lines of the scores and ages with those of the fallow deer in our earlier paper (Brown & Chapman, 1990), reveal the similarities of the shape of the curves and the difference of the ages for particular scores. A score of 70 for fallow deer gave an estimated age of 48 months + 13 months and for a score of 100 an estimated age of 77 months+22 months. These older ages for the fallow deer confirmed the need to establish the databases of wear scores with age for the different species of animals. It was not thought to be legitimate, because of age and number differences, to make other comparisons between the two species on the age their wear patterns were reached or individual scores achieved. It is interesting to reflect on why fallow deer's teeth appear to wear more slowly and it may be because fallow deer teeth erupt marginally later than teeth of red deer.

The data presented here are derived from a single enclosed park-managed, free-range herd of deer. The question remains how applicable these results are to red deer living in other parks or environments? What effect on the tooth wear rates the different pasture conditions that exist on Scottish moors will have is unknown though, as already stated, Mitchell & Youngson (undated) found their wear rates for these animals very similar to the German red deer of Miiller-Using (1971). Variations in wear rates have been reported for domestic animals under variable management and grazing conditions by Ludwig *et al.* (1966) for sheep and Deniz & Payne (1982) for goats. In contrast comparisons made of wear patterns of fallow deer from Richmond Park and from Essex, Chaplin & White (1969) found only minimal differences in matched age groups up to the age of 48 months. Morris (1980, pers. comm.) examining the same known-aged red deer as our sample found no correlation between the area of exposed dentine and the age of the animal, adding to the evidence for the inherent variability within the species. A localized occlusal factor was identified in impala *(Aepyceros melampus)* by Spinage (1971). He found that there was a greater rate of wear on the first molars than the second and third molars and suggested this was due to the angle of occlusion which the mandible makes with the maxilla. More recent evidence from the comparison of wild West African buffalo *(Syncerus caffer brachyceros}* with *(Syncerus caffer* caffer), in which the rates of attrition were similar in both populations (Spinage & Brown, 1988), suggests that though there may be differences in the speed of attrition between the same species of domesticated animals living under man-controlled environments, these differences may not be so marked among wild animals.

Summary

The teeth of 111 red deer mandibles from animals of known age have been examined. The ages by whch particular wear characteristics were established are given. **By** using a scoring system devised for fallow deer, the age was established at which, for each molar, a particular score could be expected. Deriving a score from detailed wear phenomena was found to be more reliable than assessing age from wear patterns. The linear regression of age on total molar scores gives the predicted age, together with the 95% prediction intervals associated with any particular score. The data can be used to make an assessment of age of an animal of unknown age.

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