J. Zool., Lond. (2005) 267, 233-247 © 2005 The Zoological Society of London Printed in the United Kingdom doi: 10.1017/S0952836905007405

Assessing the age of Reeves' muntjac *(Muntiacus reevesi)* by scoring wear of the mandibular molars

Norma G. Chapman[1] *, W. A. B. Brown[2] and P. Rothery[3]

[1] Larkmead, Barton Mills, Suffolk IP28 6AA, U.K.. *All correspondence to: ngchapman@btopenworld.com
[2] Red Wing, South Park, Sevenoaks, Kent TN 13 1EL, U.K.
[3] Centre for Ecology and Hydrology, Monks Wood, Abbots Ripton, Cambridgeshire PE28 2LS, U.K.

(Accepted 24 February 2005)

Abstract

The skulls and mandibles of 50 (28 male, 22 female) captive muntjac *Muntiacus reevesi* of exactly known age and four (two male, two female) of approximately known age were examined for their molar wear patterns. A procedure for scoring was based on earlier published work (Brown & Chapman, 1990, 1991) for fallow *Dama dama* and red deer *Cervus elaphus,* respectively. Specimens were also available from 17 male and 13 female wild muntjac whose approximate ages were known. The data show a curvilinear relationship between age and toothwear score, with increasing variability as the score increases. The predicted age and upper and lower limits of 95% prediction intervals are given for captive and wild muntjac deer. The range between upper and lower limits, though greater than was found for fallow and red deer, may still be a useful guide for assessing animals of unknown age.

Key words: muntjac, cervid, teeth wear, age, *Muntiacus reevesi*

INTRODUCTION

Reeves' muntjac *Muntiacus reevesi* is native to south-east China and Taiwan but is widely distributed in England following escapes and releases during the 20th century (N. Chapman, Harris & Stanford, 1994). The muntjac population in Britain was estimated to be around 52 000 in 1995 (Harris *et al.,* 1995) and many sources of information indicate a continuing increase in range and numbers. Serious impact on native flora by these deer has been reported (e.g. Cooke & Farrell, 2001). Consequently, culling of these small cervids has increased in recent years, and for effective management of a population, deer managers wish to estimate the ages of the deer that are shot, accidentally killed or found dead.

For young animals, several easily recognized parameters provide a guideline for age. Spots have faded from the natal pelage by about 2 months. Males begin to develop pedicles at 20—31 weeks, autumn-born males usually being precocious compared to those born at other seasons (N. G. Chapman, Furlong & Harris, 1997). An animal with velvet first antlers could be any age between 32 and 76 weeks (D. I. Chapman & Chapman, 1982; N. G. Chapman, 1991). Although muntjac are born throughout the year, the males do have a regular antler cycle, clocking into this cycle when they cast their first antlers, which may be as young as 51 weeks or as old as 112 weeks. Whole body weight correlates with age to some extent but season of birth has an influence. When a female has achieved a threshold weight of c. 10kg (around 8 months), she is capable of breeding and is categorized as being adult. Thereafter, increase in weight is relatively slight. In a sample of wild muntjac from southern England, for does over 2 years, including all stages of pregnancy, the mean weight was 12kg (range 9-15.8 kg, n= 124). The equivalent mean for males was 14.8kg («=105) but with a wider range (10.5-18.3kg) (N. G. Chapman, 1991).

The size of the mandible is also an indication of age for animals within their first year but after 46 weeks, when a length of 120 mm and a ramus height of 62 mm have been attained, further increase is slight.

The sequence of eruption of the teeth is a guide to age until the full permanent dentition is established by 2 years: individual variation is believed to be slight. The order of eruption is the same in both sexes with the exception of the permanent upper canine. In males this tooth emerges from the alveolus at about 21 weeks and rapidly develops into a small tusk, but in females the canine does not erupt until 53-57 weeks (D. I. Chapman, Chapman & Colles, 1985). The length of the tusk can indicate the probable age category of a buck but the breakage rate is high, e.g. 51% of bucks estimated as 3-5 years old had broken one or both tusks and only 29% of those over 5 years old had both tusks intact. If the tusk is extracted from the skull the degree of openness of the root (scored from 1 fully open to 5 for a pin-prick or smaller opening) can be a further guide to the age category. Progressive closure occurs after c. 3 years and the root is virtually closed after *c.* 5 years (N. G. Chapman, Furlong & Harris, 1997).

Whilst the above parameters, especially tooth eruption, may give an approximate indication of age, an easily applicable method, requiring no laboratory facilities or equipment, to assess the age of dead muntjac would be valuable. Mandibles are easily removed from a carcass and can be retained for examination later.

Hillson (1986) gives a comprehensive account of how the age of mammals may be assessed from their teeth, but most of these, except attrition of the teeth, involve destruction of the tooth and laboratory analysis. Assessment of age from toothwear patterns has been shown to be an effective non-destructive way of determining a close approximation of age in red and fallow deer of unknown age (Brown & Chapman, 1990, 1991; Dudley, 1999). This paper reports on a similar method for muntjac.

MATERIALS AND METHODS

Skulls and mandibles were available from 50 (28 male, 22 female) captive muntjac of exactly known age and 4 (2 of each sex) of approximately known ages between birth and 812 weeks. Specimens were also available from 17 male and 13 female wild muntjac of approximately known age. For a further 10 (5 male, 5 female), caught as adults, minimum ages were known. All specimens were thoroughly cleaned by the sodium perborate method (D. I. Chapman & Chapman, 1969) but wear was assessed only on the mandibular molars.

Captive muntjac

The animals, some of which were genetically related, were all from 1 source where they had been maintained within 1 of 3 paddocks (mean area 1050 m^2) covered by grasses and herbs and with numerous trees and shrubs. The diet of the deer was more or less the same throughout the years. For much of the year chopped carrots *Daucus carota* were the staple component, occasionally substituted by parsnips *Peucedanum sativum* or potatoes *Solarium tuberosum,* supplemented daily by browse. In winter this was mostly ivy *Hedera helix* and privet *Ligustrum vulgare* but in spring and summer a wide range of foliage was provided. According to season the roots and browse were supplemented by fruits, e.g. apples *Prunus malus* and horse chestnuts *Aesculus hippocastanum.* The latter were collected in the autumn and stored to provide a daily supply over the following months. Crushed oats *Avena sativa* or flaked maize *Zea mays* were sometimes provided. None of the animals was hand-reared and no pelleted concentrates were given. Each deer was marked with an individual identity ear-tag within a few days of birth.

Wild muntjac

All the animals were from 1 locality, the King's Forest, Suffolk where a long-term study required individual recognition by ear-tags or tags plus radio-collars (Blakeley *et al.,* 1997; N. G. Chapman, Claydon *et al.,* 1985). For field observations non-adult animals were categorized as fawn (pelage still spotted), juvenile (2-5 months), sub-adult female (5-8 months) or sub-adult male (included those with pedicles or pedicles plus velvet first antlers). At the time of catching, the experienced handling team was able to make a closer estimate of age and because the study area (206 ha) was so intensively observed, the whereabouts of young animals was often known before they were caught. Subsequently the most experienced observer, K-. Claydon, estimated an approximate date of birth of the younger animals. Bucks were regarded as adult once they had cast their first antlers, which differ from later heads by the absence of a coronet. Any marked deer subsequently found dead (usually a road traffic accident, killed by dogs or shot) was examined and the skeleton cleaned.

Scoring the wear pattern

The mandibular molars have 4 cusps: a metaconid and paraconid on the lingual side, and a hypoconid and protoconid on the buccal side. An additional cusp, the hypoconulid, is present on the third molar, abutting the metaconid. A sheet was prepared with a stylized representation, generated on a computer keyboard, of each mandibular molar (Fig. 1). On this scores were written in the appropriate locations. Above the diagram were recorded the reference number, sex, age, left or right mandible, date and the scorer. Diagrams for 3 animals could be printed on 1 A4 sheet. The terms mesial and distal refer respectively to the anterior and posterior aspects of each molar. To assess each specimen the mandible was held in the left hand with the mesial end facing right.

Teeth, free of any adhering debris, were examined using a xlO hand lens in good light, e.g. strong sunlight or a 100 W lamp light. Any difference in wear between left and right sides was minimal and the right molars were chosen for examination except where teeth on that side were damaged.

As the outer layer, enamel, becomes worn on the occlusal surface and mesial and distal contact points, the underlying dentine is exposed to give a characteristic wear pattern of white enamel and darker dentine (Fig. 2). Scores were allotted according to the criteria shown in Table 1.

The maximum scores were 34 each for the first and second molars, and 32 plus 13 for the extra cusp, the hypoconulid, of the third molar giving a maximum total of ll3.

Each cusp was scored independently. No score was given when only the enamel showed abrasion. Exposure of dentine scored 1 point whatever the stage of exposure (Figs 2-7). There are 4 potential buccal-lingual dentine links, a link being formed when the enamel between

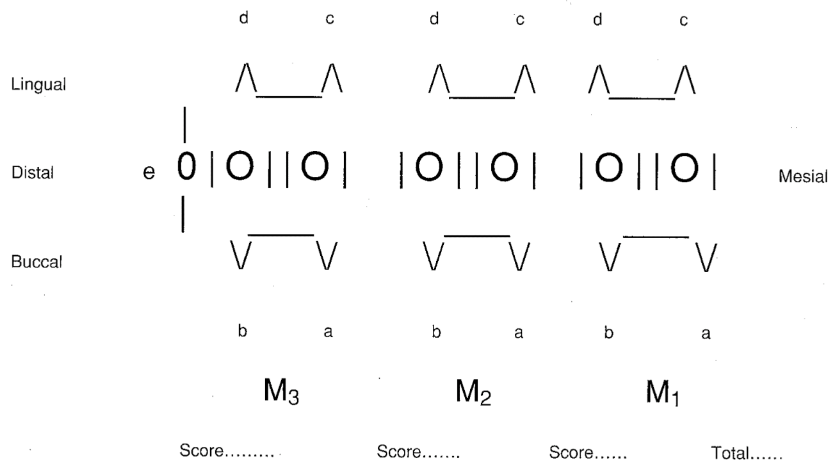

Fig. 1. Locations of tooth wear for Reeves' muntjac *Muntiacus reevesi* were identified and scored on a chart. Cusps: (a) protoconid; (b) hypoconid; (c) paraconid; (d) metaconid; (e) hypoconulid. O, infundibula and areas were dentine was exposed: (|) between the lingual and buccal cusps, also between the between the hypoconulid and hypoconid and metaconid; (—) between mesial and distal cusps.

Table 1. Criteria scored for each mandibular molar. See Figs 2–7

Wear feature	Score	Max. score per tooth
Dentine exposed–cream or brown	1 per cusp	4 (+1 on hypoconulid M_3)
Buccal–lingual links	1 per link	4
Mesial–distal links	3 per link	6
Link from hypoconulid to metaconid	3	3 on M_3 only
Link from hypoconulid to hypoconid	3	3 on M_3only
Infundibulum		
Open at one or both ends	0	0
Sealed by enamel at both ends	2	4
Reduced to $^1/_2$ or less of above stage	4	8
Reduced to pin-prick or obliterated	6	12 (+ 6 on hypoconulid of M_3)
Contact enamel lost against adjacent tooth	2 per site	4 for 1st & 2nd molars, 2 for 3rd molar
Lingual cusps: loss of triangular shape, more rounded, irregular or flattened	2 per cusp	4

2 cusps has abraded to reveal the underlying dentine. These links (a mesial, a distal and 2 between the infundibula) each scored 1 point. Of these, the mesial and distal links usually formed first (Fig. 2). The first central link established was sometimes diagonal (e.g. mesial buccal cusp to distal lingual cusps; Fig. 3) and sometimes to the adjacent cusp (e.g. mesial buccal cusp to mesial lingual cusp). The 2 mesial—distal links (between the 2 lingual cusps and between the 2 buccal cusps) each scored 3 points (Figs 4-7). On the third molar a dentine link from the hypoconulid to the hypoconid or to the metaconid each scored 3. When an infundibulum remained open at 1 or both ends, no score was given (Fig. 2). When an infundibulum was completely fenced by enamel without a break 2 points were added (e.g. Fig. 3). When, by attrition, the pit of the infundibulum was reduced in size to half or less of the previous score stage, 4 points were given. When the pit was as small as a pinprick or had been completely lost, 6 points were scored

(Figs 5 & 6). Where adjacent teeth abut, their enamel wears at the point of contact. Each of the 2 possible sites for the first and second molars and a single site for the third molar when this occurred scored 2 points. In the younger age classes this contact area was sometimes very small (Fig. 3) but was extensive (e.g. whole of mesial or distal side of crown) in older animals (Figs 6 & 7). The lingual cusps in a new fully developed molar viewed from the buccal side are distinctly triangular and this shape is maintained for years but with decreasing sharpness. When a cusp had lost that triangular shape and has become closer to a rounded outline, or a cusp had worn further to become irregular or flattened, 2 points were added (Figs 5-7). Throughout the scoring, if there was any ambiguity as to whether a stage had been reached it was not scored.

Attempts to score premolar and incisor wear and very advanced wear of the molars were unreliable. Signs of senescence included exposure of the root/crown junction, marked reduction in height of the crown, horizontal

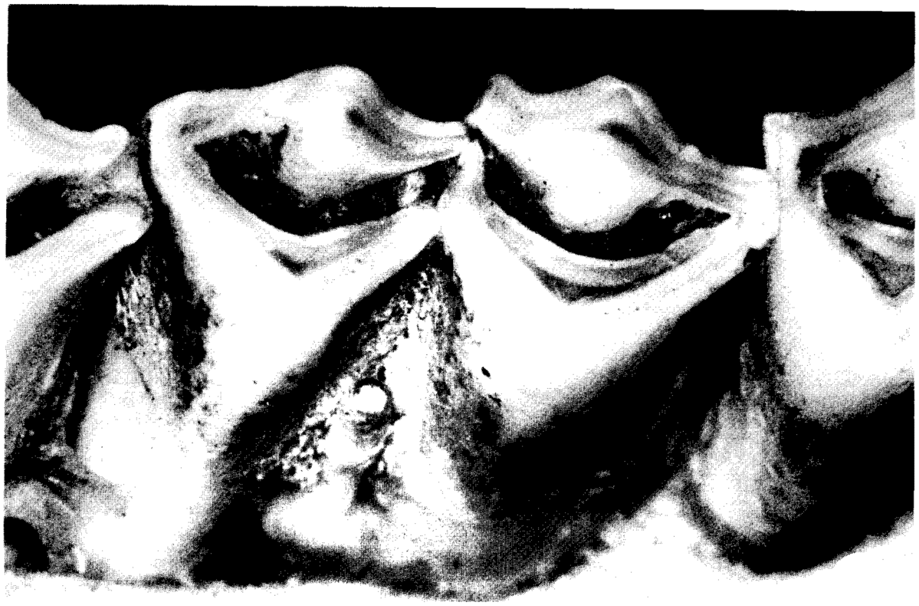

Fig. 2. *Muntiucus reevesi* DIC 250 M;, right jaw. Dentine exposed on all cusps (4); mesial and distal buccal-lingual links (2); infundibula both open at one end (0); mesial contact enamel lost (2). Numbers in parentheses, toothwear score.

Fig. 3. *Muntiacus reevesi* DIC 250 Mi, right jaw. Dentine exposed on all cusps (4): mesial and distal buccal-lingual links (2); one central buccal-lingual link (1); buccal mesial-distal link (3); distal infundibulum closed (2); contact enamel against premolar lost (2). Numbers in parentheses, toothwear score.

Fig. 4. *Muntiacus reevesi* DIC 762 M|, right jaw. Dentine exposed on all cusps (4); mesial, distal and 2 central buccal-lingual links (4); buccal and lingual mesial-distal links (6); infundibula both closed (4); mesial buccal cusp more rounded than triangular (2); mesial contact enamel lost (2). Numbers in parentheses, toothwear score.

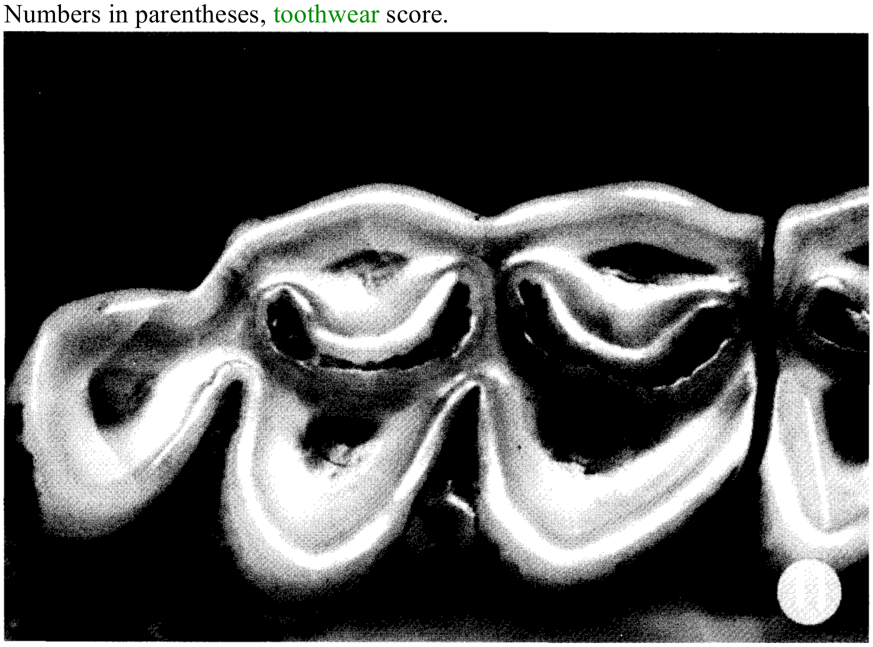

Fig. 5. *Muntiacus reevesi* DIC 1620 M3, right jaw. Dentine exposed on all cusps (5); all buccal-lingual links (4); both mesial-distal links (6); infundibula - mesial and distal closed (4) and gone on hypoconulid (6); hypoconulid link to metaconid (3) and to hypoconid (3); lingual cusps both rounded (4); contact enamel lost (2). Numbers in parentheses, toothwear score.

Fig. 6. *Muntiacus reevesi* DIC 1532 M,, right jaw. As for Fig. 5 but mesial and distal infundibula reduced to pin-pricks. Full score of 32 + 13. Occlusal surface horizontal. Numbers in parentheses, toothwear score.

Fig. 7. *Muntiacus reevesi* DIC 442 M| , right jaw. Dentine exposed on all cusps (4): all buccal-lingual links (4): both mesial-distal links (6): infundibula - mesial reduced to pin-prick (6) and distal gone (6): lingual cusps both rounded (4): contact enamel with premolar lost (2). Numbers in parentheses, toothwear score.

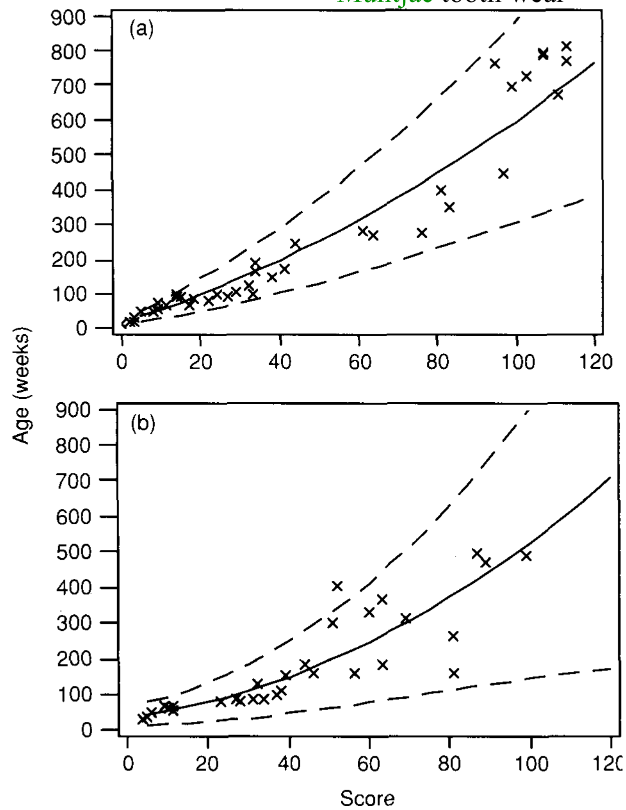

Fig. 8. Plot of age against toothwear score for Reeeves' muntjac *Muntiacus reevesi:* with predicted values (solid line) and 95% prediction intervals (broken line) calculated from a quadratic regression (see statistical methods): (a) captive animals; (b) wild animals.

occlusal surface (all cusps flattened), crown reduced to stumps and gaps between teeth. The exposure of dentine or complete wearing away of the cingulum also occurs at varying ages but this small accessory ridge, on the buccal side between the mesial and distal portions of the crown, shows considerable individual variation in prominence even before any wear occurs. The earliest age at which these features were observed were recorded, but their presence or absence thereafter was too variable to be useful in the scoring scheme.

To test for interobserver variation in scoring, two authors (WABB and NGC) scored independently on several occasions, including when the jaws were arranged in random sequence. Identical or very close scores were achieved.

Statistical analysis

Male and female animals were combined as there was no reason to suppose that wear and age differed between the sexes. The captives of unknown age and the wild animals for which only a minimum age was known were excluded from the analysis.

The data show a curvilinear relationship between age and toothwear score, with increasing variability in age as the score increases (Fig. 8). This suggests a model, developed for fallow and red deer (Brown & Chapman 1990, 1991), which describes the relationship as a quadratic regression of age on toothwear score, i.e.

$$\text{predicted age} = b_o + b_1 \text{ score} + b_2 \text{ score}^2$$

The coefficients in the model were estimated by a weighted regression with weights based on the assumption of standard deviation of age proportional to mean age. Examination of a plot of standardized residuals against the predicted values and a normal probability plot showed that the data were consistent with the model assumptions. The fitted model was also used to calculate 95% prediction intervals for the age of animals of given scores. Calculations were performed using the statistical package Minitab 13.

RESULTS

Chronology of wear

The first evidence of molar wear in the captive known age muntjac is at 20 weeks on the first molar, on the second molar at 46 weeks and the third molar at 69 weeks. The extra cusp on the third molar, the hypoconulid, comes in to wear at 98 weeks. A maximum score of 34 is achieved at 446 weeks for the first molar, 773 weeks for the second molar and 793 weeks for the third molar (Table 2). A very similar chronology of wear is apparent for the wild muntjac (Table 3). For captive animals, the earliest ages at which particular features were observed are shown in Table 4. Features that were unscored are shown in Table 5. The presence of these suggests a minimum age.

Statistical interpretations

The estimated coefficients in the fitted quadratic regressions relating age to toothwear scores are shown in Table 6. From the predicted age with the upper and lower limits of 95% prediction intervals for captive and wild muntjac deer using quadratic regression relating age to toothwear score, the predicted ages in the captive animals are higher than the wild animals (e.g. by 33% at score 30, decreasing steadily to 13% higher at score 100). The range between the upper and lower limits, however, is always greater and sometimes as much as a third greater for the wild animals (Table 7).

DISCUSSION

Chronology of tooth wear

Individual variation in the rate of wear may occur even within one deer population, because of differences in the hardness of enamel and dentine (Kierdorf& Becher, 1997) or physiological reasons such as fluoride intoxication

Table 2. Captive muntjac *Muntiacus reevesi*: individual scores for the three molars

		Scores				
Ref. no. DIC	Age (weeks)	1st molar	2nd molar	3rd molar	Plus hypoconulid	Total
415	12	0	0	0	0	0
356	13	0	0	0	0	0
1530	20	2	0	0	0	2
364	21	3	0	0	0	3
476	33	3	0	0	0	3
403	46	6	2	0	0	8
1214	47	5	0	0	0	5
466	56	5	4	0	0	9
346	66	7	4	0	0	11
353	69	11	4	2	0	17
946	73	5	4	0	0	9
250	82	14	6	2	0	22
661	83	12	4	2	0	18
1614	91	8	6	1	0	15
413	92	7	5	2	0	14
1623	92–98	6	5	3	0	14
1217	94	18	6	3	0	27
1583	98	22	6	4	1	33
351	100	14	5	5	0	24
762	107	20	5	4	0	29
833	120	18	9	5	0	32
169	*c.* 146	14	5	5	1	25
457	149	22	7	8	1	38
1236	168	15	11	7	1	34
834	173	22	11	7	1	41
1362	190	18	11	4	1	34
234	246	24	10	6	4	44
417	269	26	18	13	7	64
468	275	24	22	20	10	76
749	279	26	18	13	4	61
374	min. 311	24	24	9	7	64
358	min. 312	26	24	16	13	79
442	348	30	22	18	13	83
894	395	26	20	22	13	81
1586	446	34	24	26	13	97
1616	672	34	32	32	13	111
1604	695	34	28	24	13	99
1020	728	34	32	24	13	103
1620	767	34	24	22	13	95
1608	773	34	34	32	13	113
1594	789	34	34	26	13	107
1605	795	34	32	28	13	107
826	min.793	34	34	32	13	113
1532	812	34	34	32	13	113

Table 3. Wild muntjac *Muntiacus reevesi*: individual scores for the three molars

		Scores				
Ref. no. DIC	Age (weeks)	1st molar	2nd molar	3rd molar	Plus hypoconulid	Total
1396	33	4	0	0	0	4
1533	36	5	0	0	0	5
1306	30–43	6	0	0	0	6
816	52	6	1	0	0	7
880	54	6	5	0	0	11
1337	61	7	3	0	0	10
448	65	6	5	0	0	11
959	70	6	3	0	0	9
1363	80	22	5	2	0	29
431	79	12	7	4	0	23
1359	83	22	4	1	0	27
1526	83	22	5	4	0	31
758	88	20	10	4	0	34
1434	95	20	11	5	1	37
1439	108	20	12	5	1	38
577	128	20	6	5	1	32
1571	156	22	13	5	1	41
1216	157	28	22	18	13	81
1550	158	20	18	11	7	56
703	159	22	18	5	1	46
506	min. 162	20	10	10	1	41
1553	182	22	16	5	1	44
847	183	26	22	14	1	63
885	min. 255	24	18	9	4	55
778	263	34	22	18	7	81
843	min. 277	26	24	21	4	75
115	297	22	20	8	1	51
1351	312	24	22	14	9	69
1432	328	26	18	12	4	60
1600	368	26	14	10	13	63
1570	403	24	12	12	4	52
1590	min. 468	34	28	20	13	95
1548	471	26	26	24	13	89
1215	min. 477	34	26	22	13	95
1018	min. 457	34	26	22	13	95
1275	490	34	26	26	13	99
1577	493	30	24	20	13	87
1010	min. 515	34	26	22	13	85
1547	min. 520	34	24	22	13	93
1278	min. 543	34	24	22	13	93

The diet of the captive animals comprised natural foods with as much diversity as it was reasonable to provide, but

(Kierdorf, 1988), but generally the rate of attrition is primarily correlated with diet. Consequently the rate of wear of teeth of wild muntjac may differ among habitats but data from other localities were not available. A larger sample of exactly known age wild animals would have been desirable but it took 21 years to obtain the mandibles used in this study. Muntjac are aseasonal breeders (D. I. Chapman, Chapman & Dansie, 1984) so searching in the wild for cryptically coloured tiny neonates (mean birth weight 1.2kg: N. G. Chapman, 1991) in any month and subsequently recovering the bodies over a span of many years is not a realistic project.

The diet of the captive animals comprised natural foods with as much diversity as it was reasonable to provide, but inevitably differed from that of the wild animals, which are known to select a diversity of plants, e.g. 86 species were identified in the King's Forest study area (Harris & Forde, 1986). Despite the similarity of food ingested by all the captive muntjacs, variation in their rate of wear occurred. There is some degree of individual variation in the exact positions of adjacent teeth relative to each other that may affect the wear sequence, but this would apply to both wild and captive animals.

For young animals the sequence of eruption of the permanent teeth remains the more useful guide to assessing age than wear scores, which become appropriate from the time when all the molars are functional and subject to wear. This occurs at c. 100 weeks, approximately

Table 4. Summary of ages (weeks) at which certain events were observed in the captive muntjac *Muntiacus reevesi*

Event first seen	First molar	Second molar	Third molar	Hypoconulid of 3rd molar
Dentine exposed	20	46	69	98
Dentine exposed on all cusps	46 *et sq.*	56 *et seq.*	98 *et seq.*	149 onards
Buccal				
Lingual dentine links				Link to metaconid: first seen 246
Mesial	46	82	100	
Distal	69 (except one at 46)	82	275	Link to hypoconid: first seen 269
One central	69	149	246	
Two central	94	275	275	Both links 348 *et seq.*
All four links	94 *et seq.* except 3	275 *et seq.*	275 then 348 *et seq.*	
Mesial–distal dentine links				
Buccal	82	120	149	Not applicable
Buccal and lingual	83	275	275	
Both links on all specimens	94 *et seq.* (3 exceptions at 100, 120 and 168)	275 *et seq.*	348 *et seq.*	
Infundibula				
Closure of one	82	190	275	This stage not observed
Closure of two	94 *et seq.* (3 exceptions)	275 *et seq.*	275	Only one infundibulum
Both reduced to pin-prick	446 *et seq.*	773 *et seq.* (one exception)	672 then variable	275 then 348 *et seq.*
Loss of contact enamel				
Mesial	66 (on 7 spec. up to 173)	91 then 173	168 & 173	
On all specimens	246 *et seq.* (one exception)	672 *et seq.*	446 *et seq.* (one exception)	Not applicable
Distal	69 (on 4 specs. up to 173)	168 then 348	Distal: not applicable	
On all specimens	269 *et seq.* (one exception)	348 *et seq.* (4 exceptions)		
Loss of triangular shape on lingual cusps				Not applicable
On one cusp	98	269	269	
On both cusps	149	269	269 then 395	
On both cusps of all specimens	190 *et seq.* (one exception)	446	395	

Table 5. Earliest ages (weeks) at which unscored features were observed in muntjac *Muntiacus reevesi*. N/O, not observed

	Captive Known ages			Wild Estimated ages		
	M_1	M_2	M_3	M_1	M_2	M_3
Crown/root junction just visible	246	695	672	157	158	368
Occusal surface area distinctly greater than that of buccal aspect	279	279	348	260	260	365
Cingulum–dentine exposed	246	279	269	183	312	365
Cingulum–worn away	348	446	773	365	?, but > 244	N/O
Occlusal surface horizontal (all cusps flat)	446	N/O	N/O	? but > 244	N/O	N/O
Crowns reduced to stumps	773	773	N/O	N/O	N/O	N/O

the same time that the premolars, the last cheek teeth to erupt, have come into wear. The preliminary report on eruption (D. I. Chapman, Chapman & Colles, 1985) has now been supplemented by information from 13 additional animals.

Table 6. Estimated coefficients in the fitted quadratic regressions relating age to toothwear score (see statistical methods) for muntjac *Muntiacus reevesi*

		Estimated regression coefficients (se)			
Group	n	Intercept (b_0)	Linear (b_1)	Quadratic (b_2)	R^2 (%)
Captive	40	14.8 (2.05)	3.69 (0.39)	0.0212 (0.0063)	94
Wild	30	36.4 (10.2)	1.37 (1.00)	0.0353 (0.0154)	75

To assist in estimating ages of young muntjac, information on eruption, lengths of tooth row and mandible are included in the Appendix, together with other parameters (body weight, pedicle/antler development) that show a range within an age class.

The model for a given score gave a wider range between the lower and upper limits for the predicted age than had been hoped. For animals up to 2 years, however, the upper and lower limits can be ruled out from observation of the eruption of the teeth and other parameters from which a closer approximation to true age can be made. For example, in Table 7, a score of 30 gives a predicted age of 109 weeks with 34 and 185 weeks as the lower and upper limits. A 109-week-old muntjac would recently have attained a fully established permanent dentition with

Table 7. Predicted age and upper and lower limits of 95% prediction intervals for captive and wild Muntjac deer using quadratic regression relating age to toothwear score

Captive Wild

Lower Age Upper Score limit (weeks) limit

Lower Age Upper limit (weeks) limit

5	17	34	50	12	44	77	
10	28	54	80	16	54	91	
15	39	75	111	20	65	110	
20	50	97	144	24	78	132	
25	62	120	178	28	93	157	
30	75	145	214	34	109	185	
35	88	170	252	40	127	215	
40	102	196	291	46	148	249	
45	117	224	331	54	169	285	
50	131	252	373	62	193	324	
55	147	282	417	70	218	367	
60	163	313	462	78	246	413	
65	179	344	510	86	274	463	
70	196	377	558	95	305	515	
75	213	411	609	103	338	572	
80	231	446	661	112	372	632	
85	248	482	715	120	408	696	
90	267	519	771	128	445	763	
95	286	557	828	136	485	834	
100	305	596	887	144	526	908	(900)
105	324	636	948	152	569	987	(900)
110	344	677	1011	159	614	1069	(900)
115	364	720	1076	166	661	1155	(900)
120	384	763	1142 (900)	174	709	1244	(900)

recent exposure of dentine on the premolars. A 34-week-old would not yet have M; fully functional and no M3. A male's cranial appendages would be no more than pedicles and tiny velvet antlers: in a female the permanent upper canine would not have erupted. On a 185-week-old animal, wear on the last premolar would be conspicuous. Therefore both ends of the prediction can be dismissed. If a skull is also available, observation of the third molar is a further guide: the distal half of the crown is not completely clear of the maxilla until 149-173 weeks.

In older deer there is a greater opportunity for individual variation to be expressed. Muntjac are potentially long-lived, often reaching teenage in captivity where 20 years 11 months has been recorded (B. Buckingham, pers. comm.), but wild populations are probably composed mostly of young and middle ages. Consequently the problem of increasing variability and unreliability of age estimation with increasing age affects relatively few of the deer likely to be encountered.

Demographic data from several sites showed that mortality by 3 years was 75% and by 7 years was 95% (Harris *et al.,* 1995). For the purpose of that analysis, less detailed criteria of tooth wear were used to categorize animals into age classes, i.e. < 2 years, 2-3 years, 3-5 years, > 5 years as has been done in other studies (N. G. Chapman & Harris, 1991; N. G. Chapman, Furlong & Harris, 1997). Very few wild muntjac are likely to reach their late teens. In Table 7 for scores above 100, the calculated theoretical upper limits are best disregarded and a maximum of 900 weeks substituted.

The scores for those muntjac (w= 14) excluded from the statistical analysis fell within the ranges appropriate for their respective approximate or minimum ages.

In the present study ages have been expressed in weeks, but wildlife managers would not expect to estimate ages to such a precise unit: apart from young animals an estimate within 12 months for older animals would have been desirable. Although a score gives a predicted age, the upper and lower limits show that there is a wide range at all levels, being, for instance, as much as five years for captive deer for a toothwear score of 60. It is even larger in wild muntjac (Table 7). Cohort analysis, summarized by Mayle, Peace & Gill (1999), which is recommended to managers of populations of seasonally breeding species of deer, is not a valid proposition for muntjac because of their precocious and aseasonal breeding. For most managers of muntjac, the priority is to reduce the population without concern for age structure or the desire for sustainability. Nevertheless, a simple method of estimating age of dead muntjac is helpful. The method reported here uses the minimum number of features to obtain an assessment and the only requirements are thoroughly clean (not necessarily bleached) mandibles, a hand lens and good light. With a little practice the method can be applied quickly, the names of the cusps need not be memorized, and whilst consistency is desirable, a difference of a couple of points will not seriously influence the predicted age.

Examination of incremental lines in cementum has been widely used in estimating ages of other cervids but whether a vertical section is prepared as a histological slide or a hemi-section is polished, the methodology and interpretation are fraught with problems, and the method is inappropriate for bleached specimens (Dudley, 1999). Using M] extracted from four mandibles used in the present study, P. Revington (pers. comm.) prepared polished sections through the bifurcation of the root that were examined microscopically using reflected light. The exact ages of these animals are shown below, with Revington's estimates in parentheses:

3 years 17 weeks (1 year+); 5 years 15 weeks (3 years);

7 years 31 weeks (4 years); 5 years 19 weeks (6 years);

and one wild muntjac believed to be about 5 years 3 weeks was estimated as 5 years. Revington (1996) stated that interpretation of incremental lines is more difficult from the small teeth of muntjac and roe deer *Capreolus capreolus* than from larger deer, but reported a correct estimate in 50% of a sample and plus or minus 1 year for the remainder. The size and source of the sample were not given. Attempts to count incremental lines in wild muntjac from Thetford Forest (a few km from the King's Forest) were unsuccessful (T. Banham, pers. comm.).

SUMMARY

The skulls and mandibles of 50 captive muntjac of known age, plus four of approximate age, and 30 wild muntjac of approximately known age were examined. A scoring scheme devised from the earlier work of Brown & Chapman (1990, 1991) was used to assess wear of the mandibular molars. Statistical analysis of the data gives predicted age with upper and lower limits of 95% prediction intervals. Although the range for any predicted age is wider in muntjac than fallow or red deer, the results indicate that the scoring system is an easily applied means of assessing muntjac of unknown age.

Acknowledgements

Many people participated in the King's Forest study. Without their support and the permission of the Forestry Commission to undertake the long-term project, no wild individually marked muntjac would have been available.

Our thanks are extended to everyone who was involved. The studies of both the wild population and the captives were initiated by the late Donald Chapman. Henrietta Price measured the mandibles and we also thank Dr P. A. Morris for valuable comments on a draft of the paper and for testing the scoring system on a sub-sample.

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Appendix. Reeves' muntjac *Muntiacus reevesi*: tooth eruption and other parameters to assist in estimating ages up to 2 years

Ref. DIC or name	Age (weeks)	Sex	Mandibular teeth	Maxillary teeth	Length of mandibular tooth row (mm)	Length of mandible (mm)	Pedicles/antlers	Body weight (kg)
441	0.14	M	Premolars all erupting: p_2 tip < 1 mm, p_3 3 mm and p_4 (all 3 cusps) 5 mm below bone M_1 alveolus opening Incisors: all fully erupted (and in all other animals)	Premolars all erupting: p^2 3 mm, p^3 5 mm and p^4 4 mm below the bone. M^1 alveolus opening Canine tip 1 mm below premaxilla	24	64		0.86
730	0.57	F	p_2 just through bone, p_3 and p_4 all cusps 4–5 mm above bone M_1 tips of cusps visible within alveolus	p^2 4 mm, p^3 and mesial cusp of p^4 6 mm below bone, distal cusp slightly shorter. M^1 tips level with alveolus rim. Canine: tip 2 mm below premaxilla	25	72		1.15
698	0.5–1	F	p_2 2 mm above bone, p_3 more advanced, p_4 5 mm above bone M_1 alveolus opening	Premolars erupting: p^2 shorter than p^3 and p^4 which are 5 mm below bone Canine: tip 2 mm below premaxilla	23	68		1.07
282	1.14	F	p_2 tip 2 mm, p_3 and p_4 5 mm below bone M_1 tips of mesial and distal cusps just visible	Premolars all 6–7 mm below the bone Canine 1.5 mm below the premaxilla	24	72		1.1
199	3	F	p_2 ht. $^3/_3$ of p_3 and p_4 M_1 alveolus opening	Premolars as for 1.14 weeks M^1 tip of buccal side mesial cusp emerging from alveolus Canine: 2 mm below premaxilla	27	71		1.42
1589	3.7	M	p_2 almost fully erupted, p_3 not quite clear of bone, p_4 crown clear of bone M_1 mesial cusp just emerged from alveolus	Not available	25	74		2.13
1595	9	F	p_2, p_3 and p_4: all crowns clear of bone (and in all older animals) M_1 mesial cusps 2 mm emerged	p^4 crown clear of bone M^1 cusps $^1/_2$ ht. of p^4 canine not available	34	81		4.75
Rg[a] Breeze	9	M	M_1 mesial cusp well above bone, distal cusp just visible	Premolars:all crowns clear of bone and in all older animals M^1 tips of mesial cusp clear of bone			No pedicles	4.5
415	12.5	F	M_1 mesial cusp *c.* $^1/_2$ ht. of p_4, distal cusp shorter; no wear	Premolars: all crowns clear of bone M^1 mesial cusp $^1/_2$ ht. of p^4, distal cusp shorter Canine protrudes 2 mm below premaxilla	33	89		4.75

356	12.5	M	As above but M_1 cusps *c.* 1 mm taller	As above but tip of permanent canine emerging from alveolus above deciduous canine	35	98.5		5.5
Rg Sunny	17	M	M_1 mesial and distal cusps same ht. as p_4, crown not clear of bone M_2 just erupting	M^1 distal cusp less advanced than M_1 Canine (deciduous) still present	–	–	No pedicles	7.0
1530	20	F	M_1 both prs. cusps = ht. of p_4, dentine just visible on mesial cusp, crown not clear of bone	M^1 tips of mesial and distal cusps level with tips of p^4, crown not clear of bone Canine not available	34	93		–
364	21	M	M_1 crown clear of bone M_2 tips of mesial cusp just above bone (2 mm on lingual side, 1 mm on buccal)	M^1 mesial cusps same ht. as p^4, crown not quite clear of bone Canine protrudes 5 mm below premaxilla	35	107	Pedicle bumps	7.5
Rg Eddy	24	M	M_2 mesial cusps just visible	M^2 mesial cusps just visible Canine (deciduous) present	–	–	Pedicles *c.* 15 mm	7.5
Rg Snowy	27	M	M_2 mesial cusps $\frac{1}{2}$ ht. of M_1, distal cusps (particularly buccal) only just visible	M^2 lightly less advanced than M_2 Canine: deciduous still present, permanent erupting above it	–	–	Pedicles *c.* 25 mm	9.0
1257	29	M	M_1 crown clear of bone M_2 tip of mesial cusp just above bone	M^1 crown clear of bone M^2 within alveolus, 1 mm of mesial cusp below bone Canine: deciduous protrudes 4 mm and permanent 1 mm below premaxilla	34	102	Pedicle bumps	7.0
Rg Johny	32	M	M_1 crown clear of bone M_2 mesial cusps 2/3 ht. of M_1, distal cusps $\frac{1}{2}$ ht. of mesial cusps	M^1 crown clear of bone M^2 mesial cusps 2/3 ht. of M^1, distal cusps just visible Canine (deciduous) shed	–	–	Pedicles: slight bump	10.5
476	33	M	M_2 mesial cusp $\frac{1}{2}$ ht. of M_1, distal cusp shorter	M^1 crown almost clear of bone M^2 mesial cusp $\frac{1}{2}$ ht. of M^1, distal buccal cusp shorter, lingual cusp within alveolus Canines: decid. still present, perm. tip 4 mm below premaxilla	41	102	Pedicles 8 mm	7.0
Rg Peaty	39	M	M_2 crown not clear of bone M_3 not erupted	M^3 not erupted Canine: permanent protrudes *c.* 12 mm below premaxilla	–	–	Pedicles + early stage of velvet antlers	11.8
403	46	M	M_2 crown almost clear of bone, ht. equal to M_1 M_3 alveolus apparent	M^1 crown clear of bone M^2 crown almost clear of bone M^3 alveolus opening Canine: permanent protrudes *c.* 8 mm below premaxilla	41	120	Pedicles 56 mm Antlers, velvet 14 mm	10.5
1214	47	F	M_2 mesial cusp 1–2 mm shorter than M_1, distal cusp shorter M_3 alveolus apparent Incisiforms: all still deciduous	M^2 less advanced than 46-week animal, distal cusp only $\frac{1}{2}$ ht. M^1 Canines: permanent emerging from alveolus above deciduous	46	112		9.0

Appendix. Continued.

Ref. DIC or name	Age (weeks)	Sex	Mandibular teeth	Maxillary teeth	Length of mandibular tooth row (mm)	Length of mandible (mm)	Pedicles/antlers	Body weight (kg)
Rg Andy	53	M	I_1 about to erupt M_3 tips of mesial and distal cusps erupted	M^3 not erupted Canine: permanent protrudes below premaxilla	–	–	Antlers hard 1st head	10.5
466	56	F	M_2 cusp hts. equal to M_1 M_3 mesial cusp 2/3 ht. of M_2, distal cusp shorter I_1 fully erupted	M^2 crown not clear of bone, cusp hts. equal to M^1 M^3 tip of mesial cusp emerging Canines: deciduous shed, tip of permanent just below premaxilla	54	121		11.5
Rg Peaty	57	M	M_2 crown clear of bone M_3 mesial and distal cusps same ht. as M_2, hypoconulid tip visible on buccal side I_1 not erupted but developing within bone	M^2 crown clear of bone M^3 mesial cusps 2/3 ht. of M^2, distal lingual tip just through Canine: permanent protrudes below premaxilla	–	–	Antlers hard Ist head	12.5
Rg Eddy	62	M	I_1 not erupted but lies within bone	Canine protrudes *c.* 20 mm below premaxilla	–	–	Antlers hard Ist head	11.0
346	66	M	M_3 mesial and distal cusps almost equal to ht. of M_2, hypoconulid 2 mm above bone I_1 and I_2 fully erupted, I_3 erupting Canine: deciduous still present	M^2 not quite clear of bone M^3 mesial cusp 2/3 ht. of M^3, distal cusp shorter Canine: permanent 15 mm below premaxilla	53	123	Pedicles 46 mm Antlers hard, 19 mm, 1st head	11.5
353	69	M	M_3 mesial and distal cusps equal hts. to M_2. Hypoconulid 3 mm above bone, I_1 fully established but I_2, I_3 and c_1 present	M^2 crown clear of bone M^3 mesial cusp ht. equal to M^2, distal cusp shorter Canine: 20 mm below premaxilla	56	123	Pedicles 50 mm Antlers velvet, 45 mm, 2nd head	10.5
946	73	F	M^3 mesial and distal cusps almost equal to ht. of M_2, hypoconulid 1 mm above bone Incisors and canine: all fully established	M^3 mesial cusp reaches $^3/_4$ way down M^2, distal cusp shorter Canine: protrudes 5 mm below premaxilla	58	122		12.0
Rg Eddy	78	M	p_2 shed, p_3 and p_4 pieces still remain I_1, I_2, I_3 and canine all fully established	All deciduous premolars still present Canine:permanent (tusk), prominent	–	–	Antlers hard, *c.* 30 mm, Ist head	10.5
250	82	F	M_3 hypoconulid 2 mm above bone P_2 half erupted, P_3 erupted, P_4 visible on lingual side under p_4 I_1 and I_2 fully established, I_3 erupting, c_1 present	M^3 mesial; cusp ht. $^1/_2$ ht. of M^2, distal cusp tip only below bone (less advanced than 69-week and 73-week animals) Canine: protrudes 5 mm below premaxilla	59	126		9.0

661	83	M	Premolars: all permanent, fully established, no dentine yet visible i.e.virtually unworn M_3 hypoconulid 5 mm, well clear of angle of the jaw. Incisors and canine: all permanent	M^3 distal cusp almost same ht, as mesial, crown not quite clear of bone P^2 and P^3 fully established (no dentine exposed yet) P^4 erupting, 4 mm below bone Canine: 21 mm below premaxilla	61	122	Pedicles 50 mm Antlers hard, 38 mm, 1st head	10.5
Rg Peaty	83	M	i_3 and canine shed, I_3 and canine erupted on one side Permanent premolars well erupted, p_3 shed, p_2 and p_4 pieces remain M_3 hypoconulid clear of angle of the jaw	p^2 shed on one side M^3 partly erupted, tips only of distal cusps below the bone Canine: permanent, prominent	–	–	Antlers velvet, 2nd head	13.5
1614	91	M	All teeth are fully established permanent Dentine not yet exposed on premolars	M^3 distal cusp almost same ht. as mesial cusp, crown not clear of bone Premolars; all permanent, dentine not exposed Canine: 22 mm below premaxilla	57	123	Pedicles 42 mm Antlers hard, 40 mm 2nd head,	8.5
413	92	M	All teeth are fully erupted Slight exposure of pale cream dentine on p_3 and p_4	All teeth are permanent M^3 distal cusp slightly shorter than mesial cusp Premolars:pale cream dentine just apparent on p^3 and p^4 Canine: 22 mm below premaxilla	51	122	Pedicles 45 mm Antlers hard, 52 mm 2nd head	12.0
Rg Herby	92	M	All teeth are fully established	Canine *c.* 20 mm	–	–	Antlers hard, *c.* 25 mm, Ist head	11.5
1217	94	M	Slight exposure of pale cream dentine on p_4	Premolars: very slight exposure of pale cream dentine in some places Canine: 12 mm below premaxilla	56	125	Pedicles 49 mm Antlers velvet, 10 mm Ist head)	12.0
1583	98	M	Slight exposure of cream dentine on p_2 and p_3 and distinct exposure on whole occlusal surface of p_4	Dentine exposed on all premolars Canine: 25 mm below premaxilla	58	128	Pedicles 36 mm Antlers hard, 35 mm, 1st head	12.1
351	100	M	Dentine exposed on p_3 and p_4	Premolars: dentine exposed on all Canine: 23 mm below maxilla	58	128	Pedicle 42 mm Antlers velvet, 48 mm 2nd head	11.5
762	107	F	Dentine now exposed on all three premolars	Crown of M^3 not fully clear of maxilla Premolars: brown dentine exposed on all Canine: 4 mm below the premaxilla	56	124.5		9.0

[a] Rg, radiographs.