

## Morphological investigations of the winter coat in white-tailed deer: Differences in skin, glands and hair structure of various body regions

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Skin and hair samples taken from seven body areas of a winter hair coat of a male and a female yearling white-tailed deer *Odocoileus virginianus* Zimmerman, 1780 were investigated morphologically. The color, length, diameter, density and relative proportion of guard and wooly hair was determined from the histological sections. In addition, the epidermal thickness, and the shape, density, location and structure of sebaceous and sudoriferous glands were also determined. A reciprocal relationship was found between the insulation values of the pelage, the epidermal thickness and the amount of either gland. The areas known to provide the best insulation (the tail and the belly) exhibited the thinnest epidermis, the highest density of hair and the highest concentration of sebaceous glands. In reverse, the region with the lowest insulation capacity (the leg) exhibits the thickest epidermis, the lowest hair density and the highest amount of sudoriferous glands.

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### Introduction

Morphological investigation of deer skin and pelage has been reported in several cervid species, such as the red deer *Cervus elaphus* (Schäffer 1940, Ryder and Kay 1973, Ryder 1977, Kay and Ryder 1978), roe deer *Capreolus capreolus* (Johnson and Leask 1977, Adams and Johnson 1980), pudu *Pudu puda* (Feder and Arias 1992), musk deer *Moschus moschiferus* (Frädrieh 1966), white-tailed deer *Odocoileus virginianus* (Quay 1971), mule deer *Odocoileus hemionus hemionus* (Quay and Muller-Schwartz 1971), and reindeer and caribou *Rangifer tarandus* (Lewin and Stelfox 1967, Kallquist and Mossing 1978). Most of these studies were devoted either to the morphology of specialized skin glands (eg interdigital, tarsal, forehead, tail), as related to seasonal cycles or reported the histological picture of the seasonal coat change. Only rarely, were samples of skin taken from more than one specific area of the deer body (Kallquist and Mossing 1978). The present study

attempts to fill the gap in our knowledge of the deer hair coat by comparing the variability in the structure of hair and upper integument of the various body regions of white-tailed deer *Odocoileus virginianus* Zimmerman, 1780. The characteristics of the pelage (guard hair and wooly hair) and the parameters of the integument (arrectores pili, sebaceous and sudoriferous glands) were investigated in seven specific body areas of the winter coat of a white-tailed deer.

### Material and methods

Small rectangles of skin (approx.  $1 \times 3$  cm) were dissected from 7 body areas of healthy yearling white-tailed deer buck and doe, from roadkills found in December and February 1992/1993, respectively, around Guelph, southwest Ontario (latitude  $42^{\circ}\text{N}$ ). The following body regions were chosen for investigation: (1) midlateral neck area, (2) central interscapular area, (3) median lumbar area, (4) midlateral carpal region, (5) median abdominal area, (6) tail – mid superior section, (7) tail – mid inferior section (Fig. 1). The skin samples were first investigated macroscopically for the color and lengths of the guard and wooly hair and then microscopically for the hair diameter and shape. Fifty guard hair and fifty wooly hair chosen randomly from each region were measured and their average length was calculated. Small samples of the skin (approx.  $1 \text{ cm}^2$ ) were frozen to  $-20^{\circ}\text{C}$  and then cut longitudinally and transversally in a cryostat. The  $20 \mu$  sections were first stained with Hematoxylin-Eosin and then representative sections were photographed. An average wooly and guard hair diameters and the guard hair density per  $\text{mm}^2$  were established from corresponding cross sections by measuring 50 hairs. In addition, the histological sections were investigated for the position and structure of the sudoriferous and sebaceous glands, the number and size of arrectores pili, the amount of collagen in each region, the shape of the surface epithelium and the ratio of wooly to guard hair.

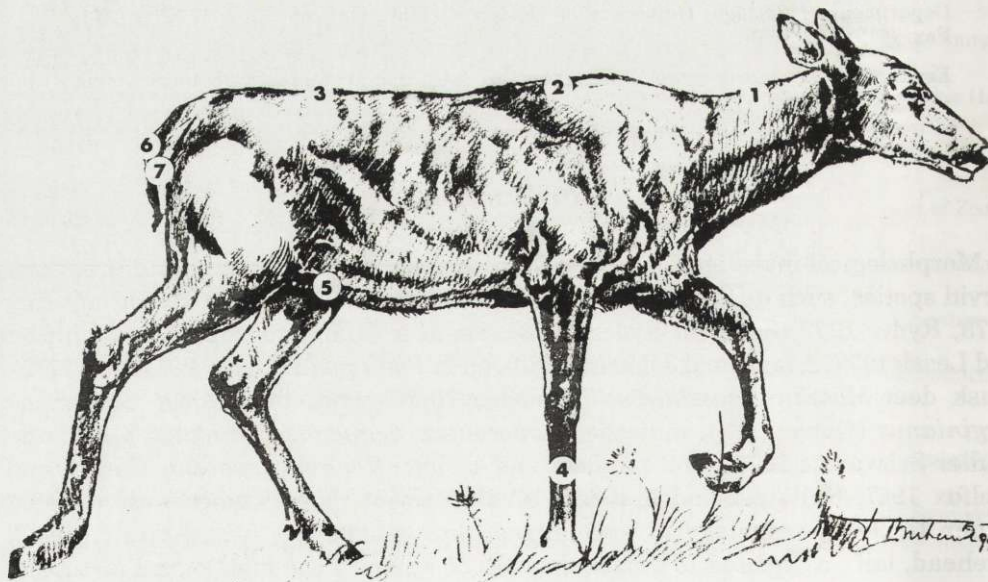


Fig. 1. Body regions investigated: (1) neck, (2) shoulder, (3) back, (4) leg, (5) belly, (6) upper tail, and (7) lower tail.



## Results

No substantial difference in coloration, diameter and density of hair was found between the sexes. However, the average length of the guard hair from various body areas was on average about 30% shorter in the buck than in the doe. As this was most probably due to the difference in the time of death (December versus February), it was decided to present tabulated data only in the female in which the coat was most fully developed.

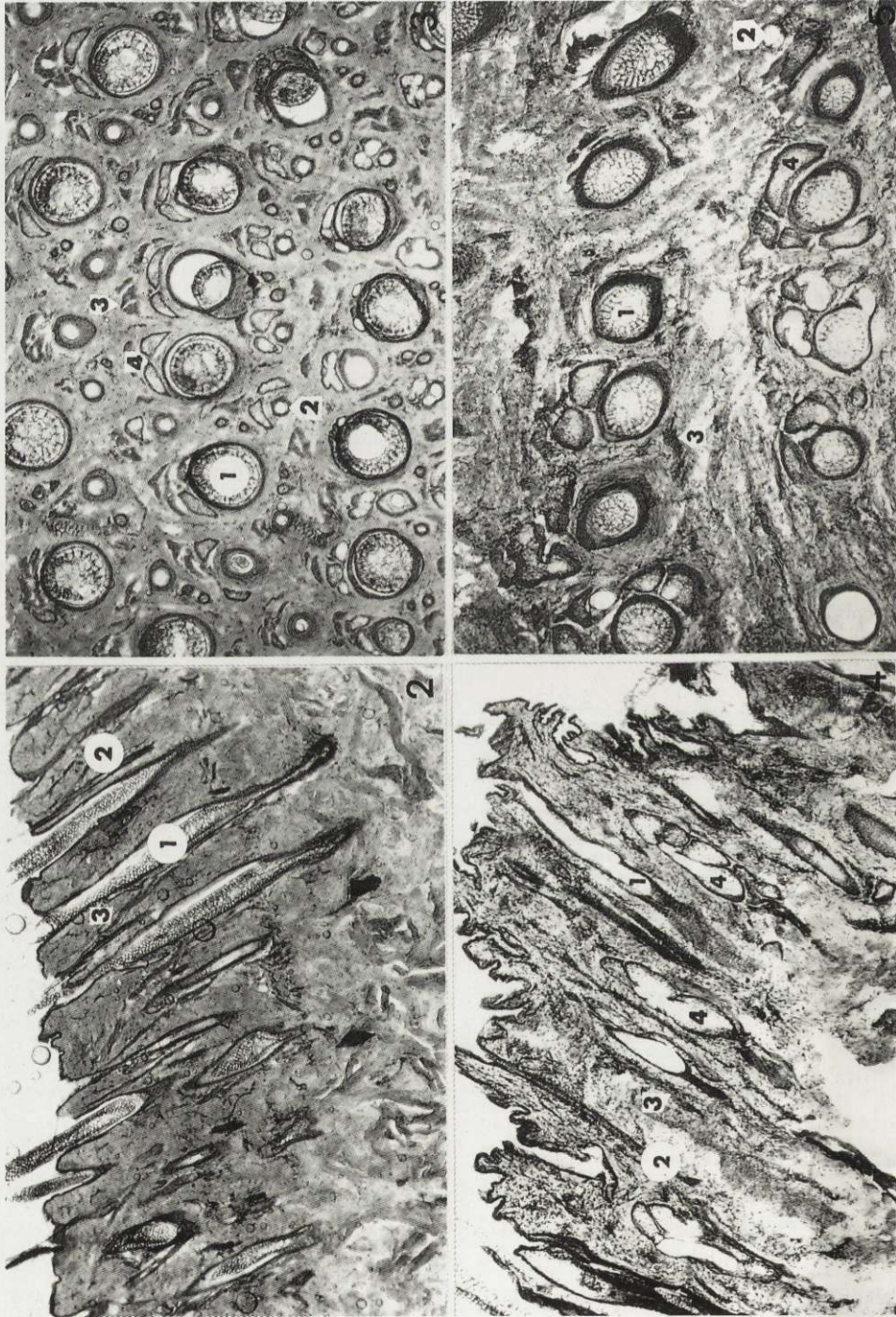
### Hair

**Color and structure:** The guard hair are mostly grey to brown with reddish or beige tips. Black tipped hair is found in the face area; the hair on the belly and the inferior part of the tail are purely white. Detail description of the color in various body regions is presented in Table 1. The guard hair are mostly straight with the largest amount of pigment located in the medulla, except on the underside of the tail and the belly areas, where the guard hair are curly and white. The wooly hair is thin, distinctly curly and are almost colorless, mostly appearing opaque white. The general ratio of guard hair to wooly hair in most body areas was approximately 1 : 2 except for the tail regions where fewer wooly hair were

Table 1. Morphological parameters of hair and skin in the winter coat of white-tailed deer.

Area	Hair color of guard hair	Guard hair			Wooly hair		Epidermis thickness (mm) (± SE)
		length (mm) (± SE)	diameter (mm) (± SE)	density (mm <sup>2</sup> ) (± SE)	length (mm) (± SE)	diameter (mm) (± SE)	
1 Neck	Mostly gray with light beige tips	63 (3.17)	0.20 (0.03)	4.30 (0.98)	31 (1.21)	0.020 (0.002)	0.02 (0.002)
2 Shoulder	Proximal half is mostly gray, the distal half is most- ly brown with beige tips	51 (2.46)	0.26 (0.03)	3.25 (0.76)	23 (1.15)	0.025 (0.003)	0.02 (0.003)
3 Back	Same as in the region 2	66 (3.22)	0.31 (0.03)	1.97 (0.46)	39 (1.26)	0.020 (0.002)	0.02 (0.003)
4 Leg	Proximal half is gray, the distal is brown with reddish-beige tips	17 (1.61)	0.13 (0.02)	2.30 (0.53)	8 (0.17)	0.015 (0.001)	0.03 (0.004)
5 Belly	Pure white	82 (4.03)	0.19 (0.09)	2.55 (0.51)	61 (2.34)	0.020 (0.002)	0.01 (0.001)
6 Tail up	Proximal part brown, distal reddish-beige	135 (5.32)	0.12 (0.06)	4.46 (1.03)	94 (2.76)	0.020 (0.002)	0.01 (0.001)
7 Tail down	Pure white, curly, like wooly hair	142 (6.65)	0.18 (0.05)	3.64 (0.72)	70 (2.14)	0.020 (0.002)	0.01 (0.001)







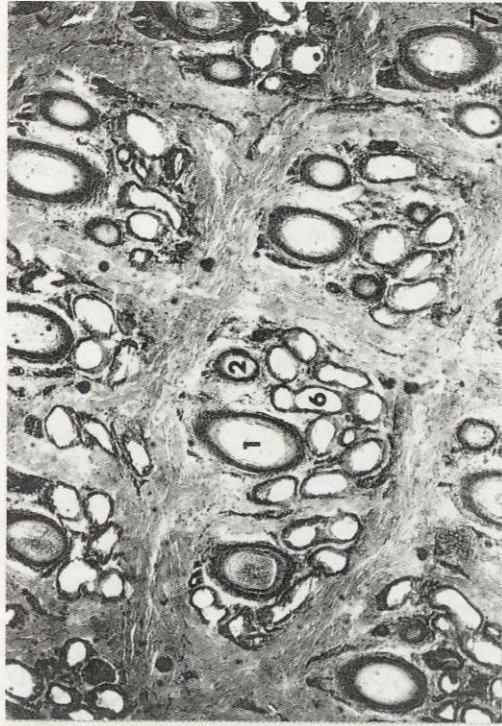


Fig. 2. Skin of the neck area (longitudinal section). (1) shaft of the guard hair, (2) woolly hair, (3) arrector pili. Magnification of all longitudinal sections is 15X.

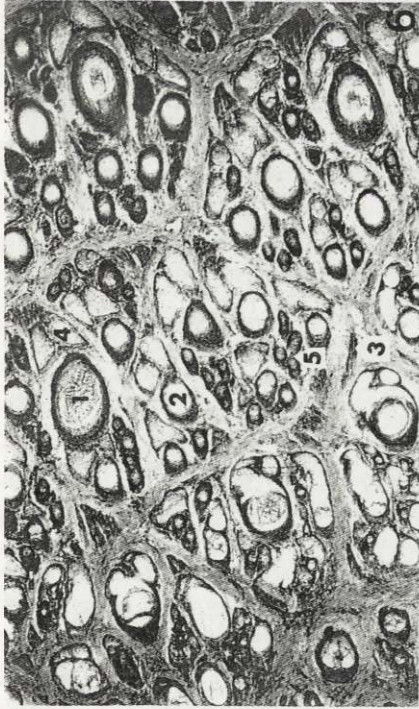


Fig. 3. Skin of the neck area (cross section). (1-3) same as in Fig. 2, (4) Sebaceous glands. Note the rows of guard hair. Magnification of all cross sections is 50X.

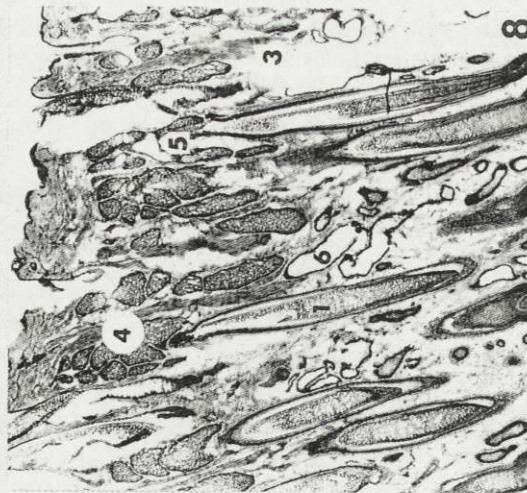


Fig. 4. Skin of the abdominal area (longitudinal section). (1-4) same as in Fig. 3. Note the large sebaceous glands.

Fig. 5. Skin of the abdominal area (cross section). (1-4) as in previous figures. Note the low hair density.

Fig. 6. Skin of the front leg area (cross section of the upper dermis). (1-4) as previously, (5) group of ducts of sudoriferous glands.

Fig. 7. Skin of the front leg area (cross section of the lower dermis). (1-5) as previously, (6) secretory tubules of the sudoriferous glands.

Fig. 8. Skin of the upper tail area. Note the high concentration of sebaceous and sudoriferous glands as well as prominent arrectores pili. (1-6) as previously.



detected. In most body regions the length of the wooly hair is about 50% of the length of the guard hair. The hair grows in distinct rows (Fig. 3) with wooly hair sandwiched between the guard hair. The most distinct arrangement of hair in rows was found in the belly region.

Density: The highest density of hair per  $\text{mm}^2$  was detected in the upper tail area (4.5), followed closely by the neck (4.3). The lowest density (2.0) was found in the back region followed by the leg area (2.3). Additional data are presented in the Table 1.

Length: The average length of the guard hair ranges from 17 mm, detected in the frontal leg region, to 142 mm, found on the superior section of the tail. The shortest wooly hair (8 mm) were registered on the leg, the longest (94 mm) in the superior section of the tail (Table 1).

Diameter: Guard hair diameter varied from 0.13 mm in the leg region to 0.31 mm in the back area. Wooly hair diameter varied from 0.015 mm in the frontal leg region to 0.025 mm in the shoulder area. The greatest variability in the hair diameters was found in both tail areas (Table 1).

#### Skin

Epidermis: The thinnest epidermis was detected in both tail areas and the belly region (0.01 mm), the thickest epidermis was found in the leg skin (0.03 mm). The rest of the body exhibits epidermis of approximately 0.02 mm. Whereas the thickness of the epidermis was more or less uniform in all regions investigated, the shape of the surface varies greatly. In the belly region (Fig. 4) the surface is extremely convoluted with deep invaginations into the dermis. Similar structure was also found in the superior region of the tail. However in the neck, shoulder or back areas the surface formed relatively low, regularly spaced undulations. The underside of the tail (Fig. 8) is almost uniformly flat.

Sudoriferous glands (SUG): The bulk of these glands is located almost twice as deep (as measured from the epidermis) as most sebaceous glands (SBG). The highest concentration of SUG was detected in the skin of the front leg (Figs 6 and 7), where they are located in the deep areas of the dermis (Fig. 7) which is infiltrated with a massive amount of collagen fibers. The neck, shoulder and back areas exhibit approximately the same moderate amount of SUG. These glands usually have a wider lumen, especially in the shoulder area and are embedded in a small amount of collagen fibers. In the tail regions (Figs 7 and 8), the SUG are more common than in the neck, shoulder or back areas. Here they are located closer to the surface, right under the SBG, especially in upper tail region. Only few collagen fibers were found in the dermis of the tail skin but unlike in the other body areas, small islets of fat cells were found interspersed between and just below the hair follicles. The lowest number of SUG was observed in the belly area (Fig. 4) which exhibits a heavy lymphatic infiltration and a moderate amount of collagen in the dermis.

**Sebaceous glands:** The highest amount of SBG was located in the inferior and superior parts of the tail (Figs 7 and 8), where the glands are large, multilobulated and located very close to the surface. In the tail regions the SBG form almost an uninterrupted layer of glandular tissue. The second highest concentration was found in the belly area (Figs 4 and 5) where SBG are also large, multilobulated but located slightly deeper than in the tail section. The SBG of all other areas are mostly simpler structures of highly tubular form (Fig. 3). Very few SBG were detected in the skin of the front leg where they are located in the most superficial areas of the dermis (Fig. 6).

**Arrectores pili:** Only rudimentary arrectores pili (AP) were located in the belly region (Figs 4 and 5). A moderate to more substantial amount was found in the leg, neck, shoulder and back regions (Figs 2 and 3). The highest amount of smooth muscles was found in both areas of the tail where thick strands surrounded the SBG and filled almost half of the spaces between hair shafts (Fig. 8). These smooth muscles were much thicker than the regular AP found in other skin regions.

### Discussion

Pelage is a unique product of the mammalian skin which is best suited to protect each individual species. The main functions of the pelage is to maintain an integrity of an internal environment, provide camouflage, help in thermo-regulation and foster intraspecific communication. Besides hair, the other skin derivatives such as the skin glands and skin muscles help deer to survive the impact of climatic changes. In all cervids, the pelage characteristics vary considerably between individual body areas. Because of its protective function, and its role in intersexual communication, the differences are more pronounced in the winter coat than in the summer coat. The generally darker color (grey, brown or black) found on the external surface of white-tailed deer serve as camouflage. The pure white color of the abdominal hair may counteract the shadow cast by the body and thus help the deer to blend with their environment (Dobie 1990).

The primary (guard) hair are generally coarse and long, and their medulla contain melanin. The secondary (wooly) hair (or underfur) are thinner, highly convoluted, generally 50% shorter than the guard hair, contain no medulla and reach high density (Ryder 1977, Kay and Ryder 1978). The length of the hair in deer not only correlates with the requirement to insulate and protect the skin but also with other factors, such as the capacity to hold on snow and ice in the exposed areas. Therefore, the shortest guard and wooly hair are found on extremities and the longest hair on the underside of the tail. The long, pure white, curly filaments of the tail hair can significantly protect the relatively exposed circumanal area. However, its main function is probably in communication; like a white flag, an elevated tail signals danger to conspecifics. The diameter of guard hair and wooly hair filaments is fairly uniform across the main body cover. That the thinnest hair



(guard as well as woolly) are located in the leg area indicates that this region either does not require any special thermal protection or that the need to prevent accumulation of frozen snow on leg hair supersedes the need for insulation. The longest hair, providing the best thermal protection was detected in the belly area; However, unlike in the other regions, the woolly hair there reached around 75% of the length of the guard hair.

The sudoriferous glands (sweat glands) in cervids were earlier called apocrine glands. Although the larger diameter and the deeper location in some skin regions may resemble the apocrine glands, they nevertheless open to the skin surface instead of to the hair shaft as true apocrine glands do. Furthermore, there is no clear scientific evidence, that most of these glands produce any pheromones (Quay and Muller-Schwartz 1971). Finally, the physiological function of the SUG is to produce sweat. However, to my knowledge no study has attempted to investigate the role of sweat production in cervid thermoregulation. However, the large number of SUG in the leg area would support some role in evaporative cooling suggested by Kallquist and Mossing (1978), as this region is the most exposed to the effect of convection.

The sebaceous glands are most prominent in the underside of the tail area where they might be involved in the impregnation of the long white hair covering the exposed circumanal region. However, as a large concentration of SBG was also found in the upper tail areas it may be speculated that perhaps these glands are producing signal pheromones. These would be released during the period of alarm when the deer's tail is moving up. The thick bundles of smooth muscles which surround the SBG, might be able to squeeze the pheromones out of the superficially located glands. The thick strands of muscles enveloping SBG resemble the smooth muscles surrounding the secretory glands of the prostate which cause the release of the prostatic secretion during ejaculation. The thin, but relatively dense hair in the tail areas (especially in the white underside) would serve as an ideal dispenser of pheromones released from SBG. Generally distributed SG are probably not significant in olfactory communication, however, some specialized SG are important source of pheromones (Quay 1977). The possibility of pheromone-secreting caudal glands was already discussed by Quay and Muller-Schwartz (1971) who also speculated that arrectores pili muscles may be used for ejection of sebum in response to emotion. Similarly to white-tailed deer, enlarged caudal glands were also reported in red deer (Schäffer 1940), mule deer (Quay and Muller-Schwartz 1971), woodland caribou (Lewin and Stelfox 1967), and musk deer (Frädlich 1966).

The second highest density of SBG was found in the belly area, which is another location associated with the long, white guard hair. The massive production of water-repellent sebum in the abdominal area may prevent moisture from reaching the skin in the laying deer. Surprisingly low density of SBG was detected in the main areas of the body covering and the region of the leg. This may indicate that



the thick undercoat (wooly hair) combined with the tough guard hair does not require any great amount of repellent to insulate the skin from the effect of water.

The epidermis of the body skin is approximately 5–15× thinner than the epidermis of the antler velvet skin (Bubenik 1993). That indicates that the body skin but not the velvet skin is involved in thermoregulation by thermal convection. Therefore, the areas with the longest hair (tail and belly) exhibited the thinnest epidermis. On the other hand, in the leg region the priority is the protection from abrasion and thermoregulation by evaporative cooling. Therefore, this area has the thickest epithelium, the greatest amount of sudoriferous glands and the lowest hair density.

It can be concluded, that a reciprocal relationship exists between the insulation values of the pelage, the epidermal thickness and the amount of either glands. The areas providing the best insulation (tail and belly) have the thinnest epidermis, the highest density of hair and the highest concentration of sebaceous glands. In reverse, the region with the lowest insulation values (the leg) exhibits the thickest epidermis, the lowest hair density and the highest amount of the sudoriferous glands.

Acknowledgments: This paper is dedicated to the memory of my father, a retired deer biologist, A. B. Bubenik, who died suddenly in February of 1995. He provided valuable comments on the text of this manuscript and made the drawing of the Fig. 1.

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