WHAT DO WE KNOW ABOUT NOCTURNAL ACTIVITY OF MOOSE?

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ABSTRACT: Study of activity and behavior of moose (*Alces alces*) has generally been undertaken during daylight hours because research at night is logistically complicated. However, some believe that moose are as or more active at night than day, thus, the amount and content of research about moose activity could be considered diurnally-biased. We conducted a review of the literature to determine what is known regarding nocturnal activity of moose and found that only 2.2% of all articles published about moose activity and behavior refer to nocturnal activity. Studies designed specifically to document nocturnal activity were mostly related to moose-vehicle collisions and use of mineral licks. Recent and increased use of GPS radio-collars will provide more and easier opportunities to distinguish and analyze diurnal and nocturnal activity of moose. Such information is important to understand better a variety of aspects of moose behavior and activity including predator-prey interactions, influence of human disturbances, relationships among habitat use, thermal stress, and climate change.

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There is extensive research and literature describing diurnal activity of moose (*Alces alces*) including foraging, movement, grooming, reproduction, and rearing (Franzmann & Schwartz 1998). Although certain studies have found that moose are most active during diurnal hours (Ericsson & Wallin 1996), it appears little is known about the 24-h activity patterns of moose (Bubenik 1998) because few studies have been designed to evaluate nocturnal behavior. One important management concern associated with nocturnal activity of moose is vehicle collisions in North America and Scandinavia (Oosenbrug et al. 1986, Child et al. 1991, Lavsund & Sandegren 1991, Belant 1995). These authors found that moose-vehicle collisions occurred mostly at twilight and night; traffic volume does not wholly account for this pattern (Dussault et al. 2006). Although reduced visibility likely contributes to increased moose-vehicle collisions at night, much nocturnal activity is unrelated to moose-vehicle collisions (Best et al. 1978, Leblond et al. 2007).

In New Hampshire, 3 times as many encounters between people and moose occurred at night than in daytime at roadside salt licks (Silverberg et al. 2002). Over the course of several years, Leblond et al. (2007) found increased nocturnal activity by moose at roadside salt pools in Quebec. Tankersley & Gasaway (1983) also observed that moose activity at mineral licks occurred predominately around midnight with little activity occurring midday. In British Columbia, Peterson (1955) also found that there was much more nocturnal than diurnal activity at salt licks, and moose had a tendency to feed at night. As in deer (*Odocoileus* spp.), the nocturnal habits of moose can be implied because they possess an eye shine or tapetum lucidum, a reflective surface on the retina that helps to amplify light in dark conditions (Bubenik 1998, VerCauteren & Pipas 2003).

Although certain aspects of nocturnal activity of moose have been addressed often, particularly moose-vehicle collisions that have important economic and human safety

concerns, most studies have not considered nocturnal activity of moose specifically. However, the importance of such is obvious when considering predation, thermal stress during summer (and in relation to climate change), and human influences on activity and security. In an effort to elucidate more clearly our current state of knowledge about nocturnal activity of moose, we reviewed the journal ALCES and conducted supplemental on-line searches of other peer-reviewed journals and monographs for articles pertaining to moose activity. Our primary objective was to identify the relative amount of research and knowledge concerning nocturnal activity of moose, and secondarily to identify and affirm the need for related behavioral studies.

METHODS

We searched the literature to determine the current state of understanding about nocturnal activity of moose. The primary sources of articles were hard copy volumes of ALCES to which we had access (Volumes 5, 8-41; 1968, 1971-2005); we manually scanned these articles. The exceptions were Volume 38 and Supplement 2 of ALCES that were available on-line (http://bolt.lakeheadu.ca/~alceswww/alces.html); pdf articles within were analyzed with keyword searches. Additionally, we searched literature in a variety of other relevant journals from an on-line source (i.e., ISI Web of Science). Finally, we reviewed the summary book "Ecology and Management of the North American Moose" (Franzmann & Schwartz 1998). Other monographs such as "The North American Moose" (Peterson 1955) were also checked and cross-referenced for reference to nocturnal activity. The on-line search and book reviews were done with keyword (Boolean) searches.

We developed a list of keywords based on words that could be used to identify literature pertaining to moose activity. The 14 keywords were activity, night, dark, dusk, dawn, daily, time, social, behavio(u)r, pattern, diurnal, nocturnal, morning, and evening. Using these keywords, we searched the entire text of each article in Volume 38 and Supplement 2 of ALCES with Adobe Reader 4.0 (Adobe Systems Incorporated, San Jose, CA). We recorded all relevant keyword hits. Each part of the article that contained the keyword was reviewed to determine if it related to nocturnal activity.

A visual scan of articles was conducted in each hard copy volume of ALCES. Each article title was scanned first after which we determined if that article, based on its title, was relevant to our search. If the title appeared relevant, we subsequently read the abstract; if the abstract contained relevant information, the methods section was read. Finally, we read the entire article and recorded any relevant information in point form. We became more experienced as we scanned more articles; hence, if a general theme originally led us to believe that it contained relevant information, but it failed on numerous accounts, it was considered irrelevant. The logistical process we used to conduct our review is illustrated in Figure 1.

The on-line search using the ISI Web of Science (http://isiknowledge.com; accessed November-December 2006, January 2007, and March 2007) consisted of using the previously mentioned keywords in conjunction with moose, ungulate, or cervid. We recorded the number of successful hits and scanned each article title. If the title appeared relevant to nocturnal activity, the abstract was scanned and we recorded relevant information; the entire article was not read. The working assumption was that if the activity patterns of moose were discussed in any great detail, it would appear within the abstract of the article. The total number of moose articles found was estimated by first searching 'moose' in all of the fields, and then randomly selecting the top article from each results page (10 articles/page) to determine the percentage of articles that were specifically related to moose and not other ungulates. We then applied this percentage

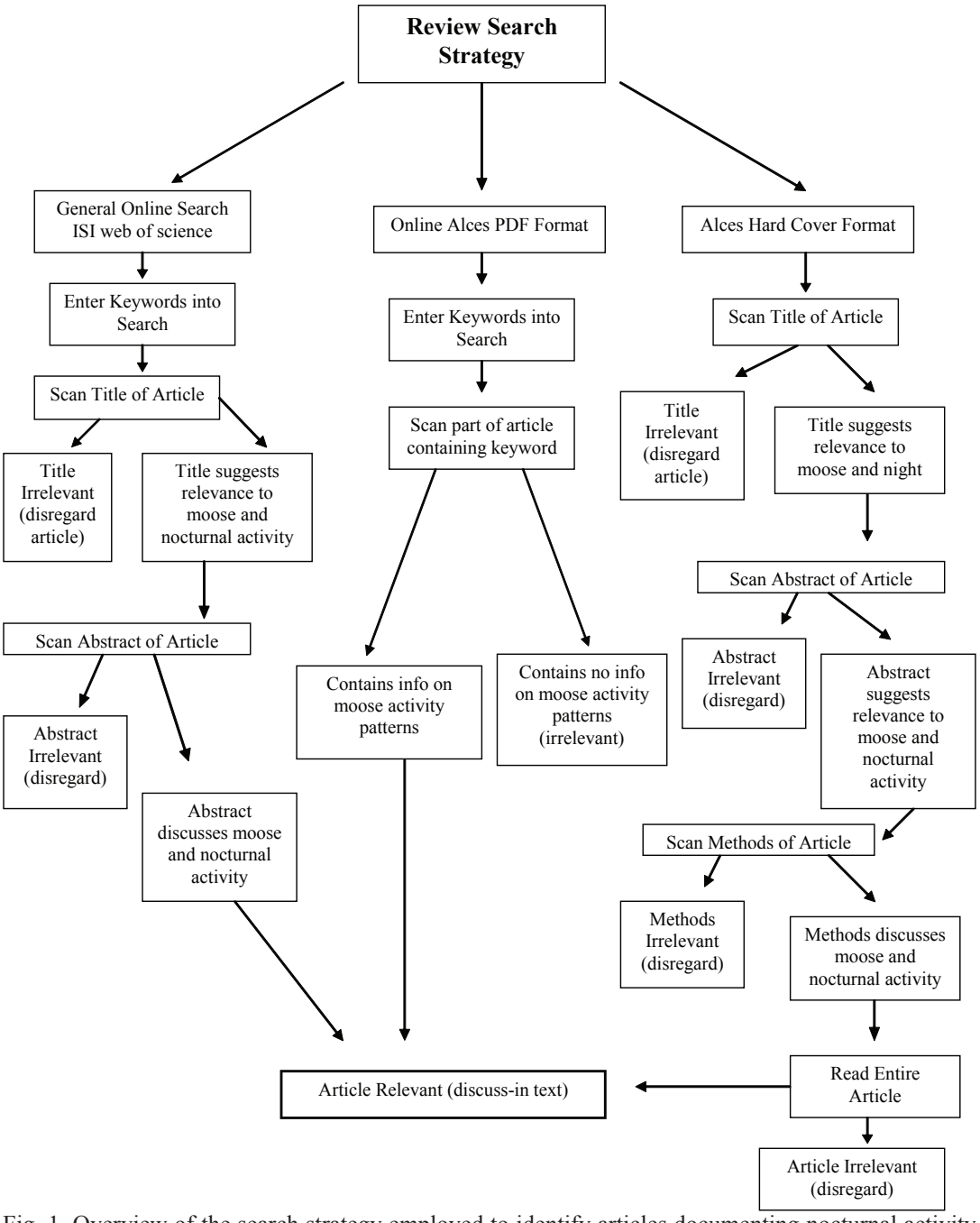

Fig. 1. Overview of the search strategy employed to identify articles documenting nocturnal activity of moose.

as a correction factor to determine the total number of moose-related articles on the ISI Web of Science. We were unconcerned about overlap with our search in ALCES because the ISI Web of Science did not search ALCES.

Finally, we reviewed "The Ecology and Management of the North American Moose" (Franzmann & Schwartz 1998) and "The North American Moose" (Peterson 1955). The indices of these books were searched using the previously mentioned keywords. We scanned the chapter topics and read specific

chapters (i.e., Behavior, Ecology) based on their relationship to our objective.

RESULTS

In total, only 41 articles were identified that related to nocturnal activity of moose. We grouped the 41 articles into 5 general categories; vehicle collisions, mineral lick use, daily activity, human disturbance, and reproduction (Table 1). Articles addressing vehicle collisions, daily activity, and human disturbance spanned the range of moose; articles about reproduction were from Eurasia and those about use of mineral licks were from North America. The 2 most common categories were daily activity (n = 17) and vehicle collisions (n = 11) (Table 1), although many "daily activity" articles referred to activity at dusk and dawn, not nocturnal activity specifically.

The keyword search of the 47 pdf articles in ALCES yielded 4 relevant articles about nocturnal activity, an 8.5% rate of relevancy. Of 726 articles in the hard copy volumes of ALCES searched with the keywords, 20 were relevant to nocturnal/evening/morning moose activity, a 2.7% rate of relevancy. Using moose as the primary keyword was the most successful method of finding relevant articles in the ISI Web of Science search. The estimated number of moose-related articles was 1067 of which only 16 pertained to moose activity, a 1.5% rate of relevancy.

Using the keyword list to search the index and table of contents of "The Ecology and Management of the North American Moose" yielded no relevant information about nocturnal activity of moose. Scanning chapters considered relevant to moose activity also failed to identify any discussion about nocturnal activity patterns of moose. The chapter "Incidental Mortality" (Child 1998) indicated that moose-vehicle collisions occurred most often in low light conditions, and the chapter "Behavior" (Bubenik 1998) stated that the position of the sun in the sky influences activity patterns of moose.

DISCUSSION

Despite the evidence that moose are commonly active at night, and that nocturnal activity in winter is necessarily high due to the short diurnal period in far northern latitudes, the amount of literature we found delineating nocturnal and diurnal activity was limited. Specifically, the percentage of relevant articles about nocturnal activity in ALCES was <10%, and the Boolean search also uncovered few (16) relevant articles. When all data were averaged, the percentage of articles relevant to nocturnal activity of moose was very low, only 2.2% of all articles searched.

Most assuredly, we did not identify all published information about nocturnal activity of moose because our search of ALCES ended with the 2005 volume, and not all relevant M. Sc. theses and Ph. D. dissertations were searched. However, the proportion of literature delineating nocturnal activity within our search is likely representative of the broader body of literature on moose behavior and activity patterns, because we were just as likely to have missed articles on general activity as those on specific nocturnal activity.

In the book "The Ecology and Management of the North American Moose" we found only limited information regarding nocturnal activity. Mention was made of moose being struck most often by vehicles at dusk and dawn (Child 1998), which appears to be a common occurrence (Fig. 2), and has received obvious attention because of the economic and human safety concerns. For our purposes, we included articles outlining activity at dawn and dusk as nocturnal activity. Subsequently, the relative amount of information about true nocturnal activity of moose could be less than we report.

Bubenik (1998) identified the need to understand better how endogenous rhythms of moose change seasonally. The recent, increased use of GPS radio-collars on moose should provide related information if researchers analyze data to differentiate nocturnal

Table 1. Summary of research category, location, and authors of articles identified in a general literature search of the nocturnal activity of moose.

Category	No. Articles	Location	Author
Vehicle collisions	11	Sweden	Eriksson et al. 1985
		Newfoundland	Oosenbrug et al. 1986
		British Columbia	Child et al. 1991
		Alaska	Del Frate and Spraker 1991
		Sweden	Lavsund and Sandegren 1991
		Minnesota	Belant 1995
		New England	Farrell et al. 1996
		United States	Hughes et al. 1996
		Alaska	Garrett and Conway 1999
		Newfoundland	Joyce and Mahoney 2001
		Quebec	Dussault et al. 2006
Mineral licks	6	Alaska	Tankersley and Gasaway 1983
		Quebec	Couturier and Barrette 1988
		New Hampshire	Silverberg et al. 2002, 2003
		British Columbia	Rea et al. 2004
		Quebec	Leblond et al. 2007
Daily activity	17	Ontario	deVos 1958
		Ontario	Simkin 1963
		Ontario	Cobus 1972
		Quebec	Joyal and Sherrer 1974
		Alberta	Best et al. 1978
		Alaska	Risenhoover 1986
		Sweden	Cederlund 1989
		Alaska	Gillingham and Klein 1992
		Worldwide	Timmerman 1992
		British Columbia	Demarchi and Bunnell 1995
		Alaska	Moen et al. 1996
		Russia	Roshchevsky et al. 1999
		Minnesota	Moen et al. 2001
		Russia	Zaitsev 2002
		Sweden	Dettki et al. 2004
		Quebec	Dussault et al. 2004
		Norway	Eriksen 2006
Human disturbance	5	Alberta	Lynch 1978
		Norway	Anderson et al. 1996
		Sweden	Ericsson and Wallin 1996
		Wyoming	Colescott and Gillingham 1998
		Manitoba	Crichton 2002
Reproduction	2	Northern Asia	Zheleznov and Fox 2001
		Russia	Bogomolova and Kurochkin 2002

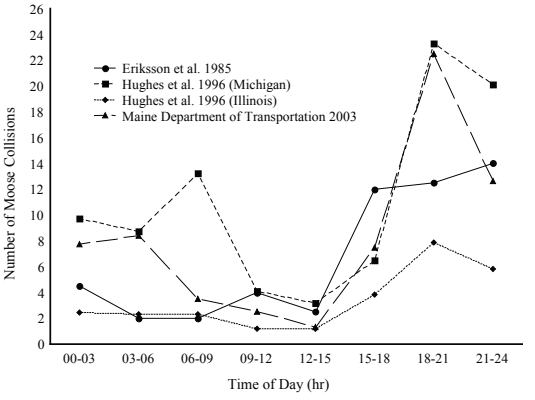

Fig. 2. Distribution of moose-vehicle collisions by 3-h intervals over a 24-h period using data reported in Scandinavia and North America (modified from Eriksson et al. 1985, Hughes et al. 1996, and Maine Department of Transportation 2003). The number of collisions indicated on the Y axis for Eriksson et al. (1985) is x 1, for the Maine Department of Transportation (2003) is x 100, and for Hughes et al. (1996) is x 1000.

activity. Cederlund (1989) and Ericksen (2006) have used GPS data to illustrate quite clearly that moose are active at night. Nocturnal activity changed seasonally, with change probably attributable to seasonal shifts in foraging strategies and rumination requirements (Cederlund 1989).

The 2 specific research topics related directly to nocturnal activity that were most prevalent in the literature were moose-vehicle collisions and use of mineral licks (Table 1, Fig. 2 and 3). Peaks in nocturnal collisions are presumably related to moose being more difficult to see at night, but also reflect that nocturnal activity is common and relatively high (Oosenbrug et al. 1986, Child et al. 1991, Lavsund and Sandgren 1991, Belant 1995, Dussault et al. 2006, Leblond et al. 2007). The high frequency of nocturnal visits to mineral licks could indicate a general activity pattern unrelated to human interactions. Further, there is a relationship between moose-vehicle collisions and use of roadside salt licks in many areas (e.g., New Hampshire, Silverberg et al. 2002, 2003).

Presumably, the inconvenience and difficulty of studying moose at night is partly responsible for the paucity of studies about nocturnal activity in the literature. Despite these logistical constraints, it is evident that an important segment of moose ecology and behavior is not well researched or understood. However, it is also evident that certain nocturnal activity and behavior is similar across moose range. For example, use of mineral licks in North America and moose-vehicle collisions in both North America and Scandinavia peak around midnight (Fig. 2 and 3), but is this similar activity and behavior due to similar influences?

There is much basic information related to nocturnal activity that has important consequences in moose management. For example, does thermal stress in summer increase nocturnal activity of moose (Dussault et al. 2004), and does proximity of thermal cover and foraging areas affect energy budgets and productivity? Will climate change and global warming influence diurnal and nocturnal activity patterns of moose? Does human hunting alter moose behavior and increase their nocturnal movements and activity (Andersen et al. 1996, Eriksen 2006)? Do moose populations affected by large predators (e.g., Alaska) have different activity patterns than populations without large predators (e.g., northeastern United States)? Will newly arrived predators affect daily activity patterns of previously non-predated moose populations (e.g., Norway; Eriksen 2006)? Does darkness

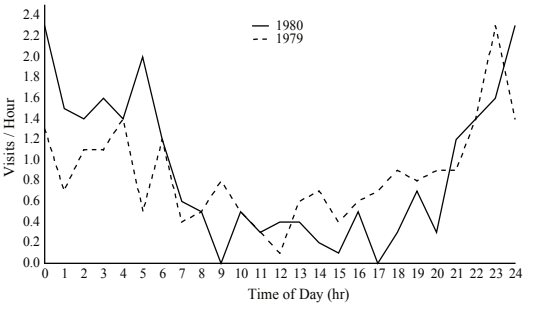

Fig. 3. The diel pattern of mineral lick visits per observation hour (reproduced from Tankersley & Gasaway 1983).

serve the function of protective cover against such predators (Mysterud and Ostbye 1999)? Finally, do lunar cycles, seasonal changes in daylength, and latitude influence behaviour of moose populations?

We recommend that more emphasis be placed on elucidating nocturnal activity and behavior of moose. The recent use of GPS technology in radio-collars should provide the opportunity to analyze data from varied locations and moose populations. Fine-tuning GPS radio-collars to record detailed temporal and activity patterns, and observing moose with infrared technologies should aid in gathering such information. Monitoring captive moose in zoos, wildlife rehabilitation centers, and research facilities could also provide useful insights. Such efforts are of practical importance to understand better and predict nocturnal activity, such as moose-vehicle collisions with human safety and economic concerns, as well as to document important behavioral adaptations and responses of moose related to predation, human disturbance, and climate change.

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