Photo By: Mark Gocke

Moose Population Management Recommendations

Wyoming Game & Fish Department
Moose Working Group

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This work is a product of the Wyoming Game and Fish Department Moose Working Group, whose members include: Steve Kilpatrick, Chair; Brian Nesvik, Vice Chair; Doug Brimeyer; Joe Bohne; Herb Haley; Stan Harter; Jordan Kraft; Matt Lentsch; Ron Lockwood; and Tim Thomas.

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Introduction

The Wyoming Game and Fish Department (WGFD) has listed Shiras moose (*Alces alces shirasi*) as a species of greatest conservation need (WGFD 2005). Moose populations in Wyoming are delineated into 11 distinct herd units. These herd units are further divided into 43 hunt areas (appendix I). A post-season population objective has been established for each herd unit, with a statewide objective of 14,630 moose. Currently, (2007) four hunt areas are closed to moose hunting, and 14 hunt areas contain the minimum number of licenses (i.e. 5 any or antlered moose). Licenses are allocated in intervals of 5 since 20% go to non-resident hunters and 80% go to resident hunters.

Moose are likely the most difficult big game animal in Wyoming to manage. They are much less gregarious than other big game animals (Timmermann 1992), usually occur at low densities and occupy habitats that make visual observations difficult at best. Moose are a very desirable big game species and a favorite for wildlife viewing and photography. As such, their management receives considerable public scrutiny by both consumptive and non-consumptive users.

Successful moose management depends on adequate knowledge of population dynamics. Currently, managers do not have a reliable technique for estimating populations. Moose population estimates are considered unreliable or completely lacking in most herd units. The WGFD lacks the financial or manpower resources needed to collect sufficient data in most herd units to rigorously meet the assumptions of population simulation using POP-II. Even though we do not collect statistically sufficient data in most herd units, any survey data has value in providing at least minimum known population parameters and distribution data. A sightability model was developed based on habitat and topography features in northwestern Wyoming (Anderson 1994, Anderson and Lindzey 1996). This model works best in more open, flat habitats and is relatively expensive to conduct. Therefore it is not a realistic option for most moose herd units. Due to the lack of quality data upon which to make management decisions, managers have generally been conservative in their harvest management strategies for moose.

Historically, moose management has not been a high priority for the WGFD in most parts of Wyoming. This was due to a variety of reasons, including healthy populations, competing work demands, other Department or Regional priorities, lack of financial resources, limited manpower and/or inadequate techniques to collect meaningful data. In 2004, the WGFD created the Moose Working Group (MWG) – an internal committee of population biologists, habitat biologists and game wardens to review moose management in Wyoming. The WGFD (2005) identified the following problems associated with management of moose in Wyoming, only some of which are addressed by these recommendations.

- Moose populations are widely distributed at relatively low densities, making data collection difficult;
- Habitat prediction models and adequate monitoring programs have not been developed for herd units, leaving carrying capacities and habitat relationships unknown;
- Moose populations are experiencing significant declines in some areas of the state;
- Willow, aspen and mountain shrub habitats appear to be declining in both quality and quantity;
- Predation by large carnivores has the potential to reduce moose populations below desired levels in some areas of the state;

- Non-hunting mortality (e.g., vehicle collisions, poaching, mistaken identity during hunting season) may be contributing to reductions in populations in some areas;
- Reliable and economically feasible census techniques are lacking, making reliable population estimates and corresponding harvest strategies difficult;
- Impacts of diseases (e.g., West Nile virus, chronic wasting disease, keratoconjuctivitis) and parasites are largely unknown;
- Conflicts with winter recreation and urban expansion continue to increase habitat fragmentation and decrease habitat effectiveness; and
- The amounts of available forage may be limiting carrying capacities in some areas.

Effective management of moose populations requires on-going assessment of a number of parameters that indicate or enumerate their size, composition, growth rate, and productivity (Timmermann and Buss 1997). This paper will review some of the various parameters available to moose population managers and recommend management criteria for some of these parameters. Given the variation that can occur annually in specific parameters, it is essential that management of moose populations be based on as many reliable parameters as possible. The challenge is to develop a set of criteria for use by managers which will illustrate management is being conducted at the highest possible level (Crichton 1992a). Because of current and anticipated financial constraints, and in the interest of maintaining long term monitoring programs, the parameters measured should be simple, consistent and cost effective (Crichton 1992a).

Habitat concerns will be addressed in an additional document. The MWG will explore development of vegetation management criteria. Prior to that time, if compelling vegetation data and/or nutritional status suggests moose are negatively impacting their habitat, managers should consider implementing or increasing female harvest (Boertje et al. 2007).

Population Estimates

Population sizes can be assessed in three basic ways – total counts or census, sample estimates and indices (Timmermann and Buss 1997). Total counts are impractical and basically impossible to conduct on free-ranging moose populations. Sample estimates involve surveying a portion of the population and extrapolating that survey data, based on statistical methods, to a population estimate. Indices are indirect methods of monitoring populations, usually as a trend, and are discussed further below.

Conducting aerial surveys of moose on winter ranges is the most practical and efficient method for estimating moose numbers (Timmerman 1993, Timmerman and Buss 1997). The WGFD conducts aerial classification surveys in several moose herd units, using both fixed-wing aircraft and helicopters. Surveys are conducted annually in some herd units and less frequently in others. Adequate sample sizes desired for POP-II simulation modeling have been obtained in only one herd unit on a consistent basis – specifically the Sublette herd unit. Large survey samples have also been collected in the Jackson, Lincoln and Targhee herd units, although they are usually still below the desired level.

Various factors influence the quality of wildlife surveys, including: type of aircraft, experience of pilot, experience of observers, snow cover, time of survey, length of survey, intensity of survey, and weather conditions. Timmerman and Buss (1997) recommend the following criteria for conducting aerial surveys for moose:

- Surveys should be conducted within a short time frame (2 - 5 days) after a fresh snowfall;
- Clear or lightly overcast days preferred;
- Wind speeds less than 10 miles / hour;
- Counting restricted to short periods of 2 – 3 hours, ideally to coincide with the period of greatest moose activity – just after sunrise;
- Only an experienced primary observer and pilot be used (to increase effectiveness or to train inexperienced persons, a less experienced secondary observer can be used);
- Sufficient time allotted to search each area thoroughly;
- Accuracy is increased by using more than one observer and including animals observed by the pilot; and
- Maximum counts in most forested habitats can usually be obtained in December and January with adequate snow cover.

Data collected from classification surveys are used, along with harvest information, to estimate populations using a POP-II population simulation model. POP-II is a software program from Fossil Creek Software used primarily by wildlife biologists to simulate the dynamics of large mammal populations. Its use by wildlife managers is directed towards predicting the consequences of various harvest strategies and to assess ongoing data collection activities. According to Fossil Creek Software, the strength of POP-II is understanding past and present population parameters. When adequate sample sizes are collected, this can be a useful tool to model population dynamics of a herd unit. In 2003, recommended modeling parameters were standardizes statewide for POP-II, ver. 1.2.5 (appendix II). For some parameters, specific values were listed; for other parameters, a range of acceptable values were listed. These values were taken from the literature when available.

Currently, managers have little confidence in the developed population simulation models for most herds. In most herd units, managers do not collect adequate samples of population data for reliable population simulation. Due to small sample sizes, age and sex ratios can vary significantly between years with no apparent biological reason. Cohort specific age data is often missing or very limited. Age data based on harvested animals may not be reflective of the true population. Due to the relatively solitary nature of moose, managers likely over-sample female moose with calves and under-sample females without calves and/or males. In one case where moose are known to have telemetry collars, managers may observe 50-70% of collared moose during a trend flight but only model 20% of the trend collected.

Anderson (1994) developed a sightability model based on various habitat and topography features, primarily in two herd units in northwestern Wyoming. This survey technique can be expensive to conduct in more rugged terrain and in areas with low-density moose, and may not be suitable and/or affordable for many of the herd units in Wyoming. This technique can be used in the herd units where it was developed if survey protocol is rigorously followed. Moose population data obtained from application of this sightability model with the sampling protocols applied during model development should prove more reliable than trend data (Anderson and Lindzey 1996).

Management Recommendation:

1. Design and conduct annual classification surveys to collect adequate samples at the 80% confidence level in the Jackson, Lincoln, Targhee, and Sublette Herd Units. This should be a priority in work schedules and allocation of flight money. Prioritize and conduct classification surveys in other herd units as time and money allows.
2. Coordinate with the Idaho Fish and Game Department to conduct a concurrent sightability survey in the Targhee Herd Unit. This should occur every 3 years when possible. It should be made a priority in work schedules and flight money allocation.
3. The managers (wildlife biologists and/or game wardens) for the Jackson, Lincoln, Targhee, and Sublette Herd Units should work together to review and improve population modeling techniques. Others to include in this exercise may include WGFD Staff Biologist, University of Wyoming Coop Unit, and/or any of the wildlife management coordinators.

Antler Size

The size of antlers - usually expressed as the maximum width - of harvested male moose can be used as a management indicator of the number of adult males available for harvest in a population. Size and conformation of cervid antlers are influenced by age, nutrition and genetics (Goss 1983). When adult male moose obtain maximum body size, they put more energy into antler development, similar to other cervids. For Shiras moose, this seems to be at about age five (R.T. Bowyer, pers. comm.). This usually results in larger antler development by prime aged males compared to younger males who put proportionally more energy into body growth and maintenance than antler development.

Antler development varies between herd units and even hunt areas. All the moose in Wyoming are related and likely have not been separated long enough for genetics to play a major role in significant variations in antler development. Therefore, nutritional quality and quantity likely has the greatest influence on variation in antler development between similarly aged individuals in different locations. Nutritional quality and quantity can vary between locations and between years. The continuing drought in several parts of Wyoming has probably had an adverse effect on forage quality and/or quantity, and thus antler development, in recent years. Also, as populations approach carrying capacity, inter and intra-specific competition for limited resources likely influences antler development.

Antler width of hunter-harvested moose has been collected periodically from most hunt areas over the years by WGFD field personnel and through reports by hunters. There has been no known effort to standardize the measurement of this parameter and there is likely variation between WGFD personnel in how this parameter has been measured. It is also assumed that there is similar variation in reported hunters' measurements. Without standardized measurement protocol, it is difficult to judge the reliability of the data collected. For example, during the past 20 years, there are eight yearling moose with reported antler widths $\geq$ 35 inches and there are 17 2-year old moose with a reported antler width $\geq$ 39 inches, which is extremely unlikely. This could be due to incorrect aging or inaccurate antler measurements.

Table 1. Mean and median antler width (in inches) by age class of hunter harvested moose in Wyoming. Age is based on tooth cementum analysis of primary incisors. Antler width is collected by WGFD personnel and reported by hunters.

Age Class	Sample Size	Mean Antler Size (inches)	Median Antler Size (inches)	Range (inches)
1	161	22.35	21	10 – 47.5
2	462	28.8	29	12 – 46
3	764	33.8	34	18 – 47.5
4	780	42.2	38	22 – 53.5
5	570	39.2	39.5	24 – 66
6	373	40.7	41	24 – 62
7	217	43.5	42	26 – 57
8	116	42.3	42	25 – 52
9	61	41.3	41	26 – 54
10	46	42	41	30.5 – 53
11	23	42.4	43	28 – 56
12	13	43.7	43	36 – 52
13	2	51.5	51.5	48 – 55
14	1	36	36	36
15	3	40.3	42	37 – 42
All	**3,592**	**37.1**	**37.0**	**10 – 66**

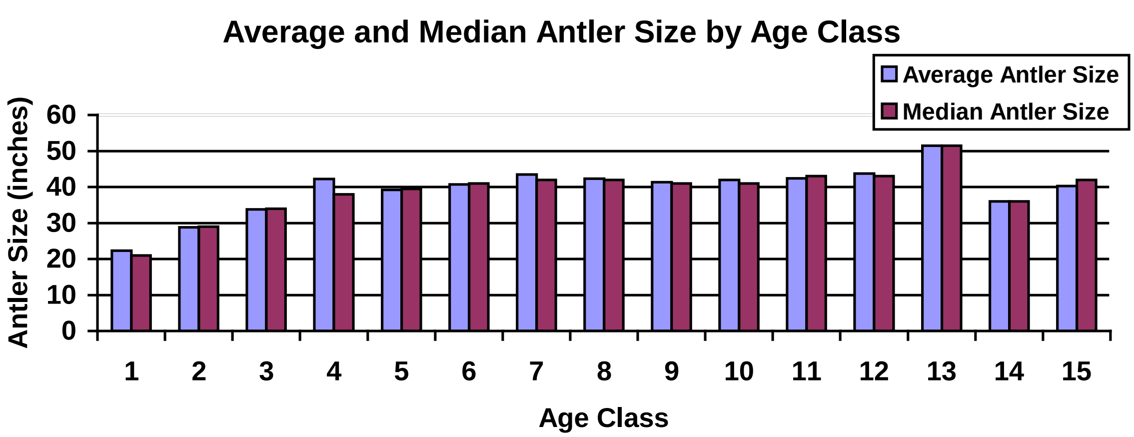

Figure 1. Average and median antler width (in inches) by age class of hunter harvested moose in Wyoming. Age based on tooth cementum analysis of primary incisors.

Based on data collected periodically since 1988 (Table 1), it appears that antler size of moose harvested in Wyoming continues to increase to about age four or five, at which time it seems to level off at an average width of about 41 inches for males $\geq$ 4 years old (median = 40 inches; n = 2,205; range = 22 – 66 inches). Based on the data set reviewed here, only 42 moose (1.9%) had reported antler widths of $\geq$ 50 inches and only 5 (0.2%) had reported antler widths of $\geq$ 60 inches.   Since antler development seems to correlate well with age of individuals, it was felt that it was not necessary to develop a management criteria for this parameter as it would essentially duplicate the age management criteria. It was thought that this information is of interest to managers and hunters so the MWG felt it as desirable to continue collecting antler size data.

Management Recommendation:

1. Develop standardized protocol for measuring and recording antler width in hunter harvested male moose.
2. Game wardens and wildlife biologists should collect antler width from all harvested moose encountered during field checks and at check stations.
3. Continue to collect hunter reported antler widths and compare these to the data collected by WGFD personnel for the same age animals. This will assess the quality of hunter reported data.

Hunter / Harvest Statistics

Currently, the WGFD surveys moose licenses holders by mail to collect harvest statistics, including age and sex of harvest, participation rate, success rate, and hunter effort (as measured by days hunted per animal harvested). This information can be useful to managers to monitor trends in harvest, which may be indicative of trends in populations (Timmerman and Buss 1997).

Hunter participation rate – the number of license holders who actually hunt – is very high in Wyoming. Almost all hunters with an any or antlered moose license hunt. Participation rates are slightly lower for antlerless moose hunters, but are still >95%. Realistically, a hunter may draw an any or antlered moose license only 2 or 3 times during their lifetime. Hunters may draw an antlerless license every 7-10 years in some hunt areas.

Hunter success and effort (mean days/animal harvested) are influenced by many factors, including, but not limited to: availability of moose to hunters, access to areas containing moose, moose density, timing of hunt, method of take (e.g. archery, rifle), weather, hunter objective (i.e. trophy vs. meat in the freezer), and the amount of effort hunters are willing to expend to find and harvest a moose. Hunter success and effort vary between years and between herd units / hunt areas and may not necessarily relate to changes in the population. Hunt areas with easy access to available moose will have higher success rates and lower effort rates than areas where moose are located in more backcountry locations. As such, management criteria should be specific to hunt area and/or herd unit based on historical data.

Management Recommendation:

1. Continue to obtain hunter harvest data through mail surveys conducted by WGFD Biological Services.
2. In order to provide the best possible data, after 2 unsuccessful attempts to solicit harvest information, WGFD Biological Services should provide a list of non-respondents to the responsible wildlife biologist who can coordinate with the responsible game warden(s) for conducting phone interviews with these non-respondent hunters. This recommendation will be at the discretion of the responsible wildlife biologist based on workload demands.

3. Managers should develop average or “normal” harvest criteria specific to hunt areas and/or herd units that they manage. These should include desired success rates and effort specific to their location. These data should be averaged over 3 years to reduce the influence of annual variations. These shall be useful as guidelines to monitor harvest.

Sex and Age Structure of Populations

One parameter often used for management of big game populations is the age and sex ratio of the population. Moose population structure may be estimated by classification surveys, commonly using fixed-wing airplanes or helicopters. This works best when animals are in more open habitats and in larger groups, neither of which occurs regularly with moose in many parts of Wyoming. Sex and age composition estimates may vary widely due to survey type, survey intensity, scope of survey, experience of observer, time of day, length of survey, and weather conditions (Timmermann 1993). We rarely collect adequate sample sizes at the 80% confidence interval for most moose populations in Wyoming.

Unlike other cervids, Shiras moose generally do not collect harems or associate in large groups during the breeding season (Timmermann 1992). Males usually travel extensively during the rut to locate and breed receptive females. Males may tend an individual female for several days prior to successful breeding. The breeding season is relatively short, and females are receptive for only about 15-26 hours each estrous cycle (Schwartz 1992, 1997). Because of the short time frame for males to successfully breed females, males usually don’t breed more than a few females each year. As such, several moose biologists have advanced the theory that it is necessary to have a high proportion of adult males in the population to successfully impregnate the majority of receptive females. Crete et al (1981) suggested maintaining an adult bull:adult cow ratio of 67:100. Steinert et al (1993) suggested a healthy moose populations should contain at least 50-70 bulls:100 cows postseason. Vieira (2006), in updating the Laramie River moose management plan, recommended maintaining at least 65 bulls:100 cows to insure an adequate number of mature bulls for breeding, reduce the proportion of cows that cycle into second estrus, provide opportunity for hunters and non-consumptive users to observe mature bulls, and increase the potential for hunters to harvest mature males. Timmermann (1992) citied a study from Russia that reported a reduction in calf production when the adult sex ratio fell below 50 bulls:100 cows, and a study from Finland suggesting that maximum calf production occurred with a sex ratio no lower than 70 bulls:100 cows and a population with a mean age between 4.5 – 7.5 years. Crichton (1992b) also suggested concern is warranted when the average age of harvested bulls is < 4 years old. Populations with a high proportion of prime aged males tend to have highly synchronized breeding and thus parturition periods.

Moose are a polyestrous species, and females not bred during the first estrous will recycle approximately 24 days later (Schwartz 1992, 1997). If not successfully bred, moose may experience up to six recurrent estrous cycles extending into early March. But, successful breeding is uncommon after the second estrous cycle and has rarely been documented beyond the third cycle. With an average gestation length of approximately 231 days (Schwartz 1997), an extended breeding season could result in calves being born as late as mid-July. Calves born after the peak parturition period (May 15 – June 1) likely have a reduced chance of survival due to lower weights entering the following winter. With sufficient prime aged bulls in a population, up to 93% of receptive females will be bred during the first estrous cycle (Crichton 1992b, Schwartz 1992, 1997).

The ratio of adult cows to calves can be used as a measure of production and potential recruitment. Numerous factors influence cow:calf ratios, including age of first breeding by females, predation of neonates and observability of females with calves. This parameter can be highly variable between years and herd units, often with no apparent biological reason. Also, adequate classification samples are collected in only a few Wyoming herd units. As such, it would be difficult to establish management criteria for this parameter that would be useful in management decisions. While we have not developed a management criteria based on cow:calf ratios, collection of classification data during surveys is desired. This data can be viewed as trend data and significant or consistent changes over time can be indicative of population increases or decreases.

The WGFD routinely collects teeth from hunter-harvested moose to determine the age structure of the harvest. This information can be used to monitor age structure of the population, assuming that hunter harvested moose are representative of the population. Hunters are assumed to be non-selective when harvesting females, therefore it is believed that hunter harvested age data for females should be reasonably representative of the population. Some hunters are selective when targeting males, often selecting for matured aged animals with fully developed antlers. This selectivity can skew the data set so that it does not reasonably represent the true population. But looked at over time, it could be useful to monitor the relative abundance by age cohort and could be indicative of changes in the age structure of the populations.

Teeth are generally collected through voluntary submission by hunters. Hunters are provided with a tooth collection kit that includes instructions for collecting the primary incisors and a self-addressed, postage paid mailing box. The number of teeth collected varies between herd units and years. Teeth are submitted to the WGFD Laboratory at the University of Wyoming for preparation and analysis of cementum annuli. Several researchers have discussed the importance of maintaining prime age males and females in a population (Crichton 1992b, Schwartz 1997, Timmerman 1992). Cementum age data presented here was compiled from various years starting in 1988 to 2006 for moose harvested in Wyoming (Table 2). All age data was analyzed as whole years (i.e., 3 years, 4 years). The average age of males harvested was 4.0 years (n=5,100), the average age of females was 4.3 years (n=2,462) and the average age for all individuals was 4.1 years (n=7,562).

Table 2. Summary of age structure of harvested moose in Wyoming based on cementum analysis.

	Sample Size	**Mean**	**Median**	**Range**
Males	5,100	4.0	4.0	1-18
Females	2,462	4.3	4.0	1-18
Total	7,562	4.1	4.0	1-18

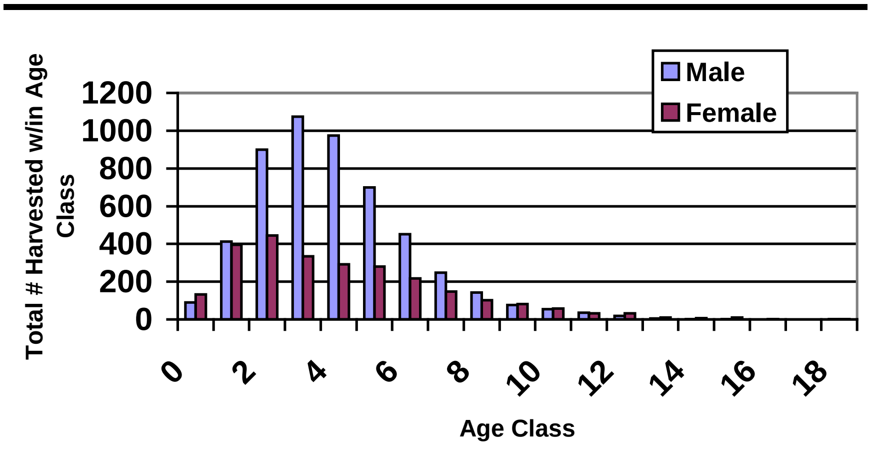

Figure 2. Age structure of male and female harvested moose in Wyoming.

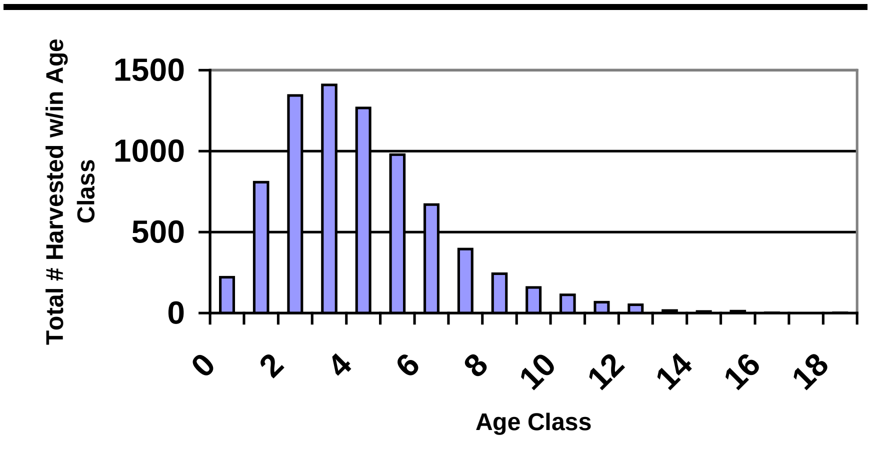

Figure 3. Age structure of harvested moose in Wyoming.

<u>Management Recommendation:</u>

1. Design and conduct classification surveys to collect adequate samples at the 80% confidence level in all herd units when feasible. Manpower and/or fiscal restraints may make it difficult to collect these data in most herd units.
2. Managers should strive to maintain a minimum postseason ratio of 50 adult males: 100 adult females to assure an adequate number of males are available to breed receptive females, to provide prime age males in the social structure of the population, and to provide quality recreational opportunity.
3. When managers have reasonable classification data and the postseason ratio of adult males is above 70:100 adult females, managers should consider increasing adult male harvest.

4. When sample sizes are below the desired level, managers should average classification data over 3 years to compare to these management criteria.
5. Age data should be reported and analyzed as whole years. That is, a moose is 3 years old from June 1 through May 31, at which time it becomes 4 years old. Age data will not be reported or analyzed in partial years (e.g. 3.2 years, 3.3 years, 3.4 years) for individual animals.
6. Managers should strive to maintain a median age of harvested males ≥ 4 years old at the herd unit level. In addition, managers should strive to maintain at least 40% of the harvested males at ≥ 5 years of age to assure an adequate number of males are available to breed receptive females, to provide prime age males in the social structure of the population, and to provide quality recreational opportunity.
7. Managers should also monitor the female age structure to assure representation in the prime ages classes (5 – 10 years old).

Tooth Age Data

Obtaining accurate age data is absolutely essential to monitor age structure of the harvest, and presumably, of the population. There are two generally accepted methods for aging large ungulates: tooth replacement and wear patterns; and analysis of cementum annulus. After age three, there is considerable variation in tooth wear patterns requiring subjective interpretation. Thus, obtaining consistently accurate ages with this method is extremely difficult.

Cementum annuli occur in most mammals and can be a reliable and accurate indicator of age for adult animals. Hamlin et al. (2000) showed a high accuracy rate for aging known-age elk (97%), mule deer (93%) and white-tailed deer (85%) by cementum analysis. The basis for cementum aging is the cyclic nature of cementum growth, which results in an annular pattern of "rings" in the tooth. In the northern hemisphere, a darkly stained ring or annulus is formed during winter. An abundant, lightly staining, cellular cementum layer is formed during the growth seasons of spring and summer.

Cementum annulus interpretation differs not only among species but also among different tooth types in the same individual. In order to develop a reliable tooth aging model, it is necessary to designate a species specific standardized tooth. The primary incisor (I1) of moose, and other ungulates, is the standard tooth collected and submitted for aging by cementum analysis (Dimmick and Pelton 1994, Matson 2007). The secondary incisor (I2), tertiary incisor (I3) or incisiform lower canine (LC) teeth will also work, but it must be noted if the tooth collected is different than the standard I1 tooth since a different aging model must be used.

The difficulty of cementum analysis varies between species. Moose are among the most difficult of big game animals to age (Matson 1981). The most common causes of difficult analysis are unclear cementum patterns and/or indistinct dark bands. Accurate age analysis of cementum annulus requires standardized protocol for both preparation of slides as well as aging models based on known age animals.

In 2006, a sample of teeth prepared and aged at the WGFD Laboratory, Laramie, were sent to Matson's Lab, Milltown, MT for independent age analysis. A total of 143 teeth were analyzed (males = 110; female = 31; unknown = 2). Average age was the same from both labs for the total sample as well as by sex. Median age was the same for the total harvest and males, but there was a 1-year difference between the two labs for median age of females. There were some larger differences within individual hunt areas. Ages agreed or were within ± 1 year 79% of time (Table 3). Agreement was greatest for younger age classes: 64% agreement for ages 1 – 3 years; 22.6% agreement for older ages classes (Table 4). Ages of male were in agreement more often than ages of females (Table 3), but the sample size was 3:1 males to females – the female sample size may be too small for meaningful comparison.

Table 3. Comparison of cementum age analysis by WGFD Lab and Matson's Lab.

	Total (n = 143)		Male (n = 110)		Females (n = 31)	
	# in agreement	%	# M in agreement	%	# F in agreement	%
Agree	66	46.2	54	49.1	10	32.3
+ / - 1	47	32.9	36	32.7	11	35.5
+ / - 2	12	8.4	8	7.3	4	12.9
+ / - 3	11	7.7	8	7.3	3	9.7
+ / - 4	4	2.8	2	1.8	2	6.5
+ / - 5	1	0.7	1	0.9	0	0.0
+ / - 6	1	0.7	0	0.0	1	3.2
+ / - 7	1	0.7	1	0.9	0	0.0

Table 4. Agreement of cementum age analysis by age class.

Age Class	Agree / N	%	
1	16 / 22	72.7%	
2	19 / 23	82.6%	64.2%
3	17 / 36	47.2%	
4	7 / 22	31.8%	
5	2 / 12	16.7%	
6	3 / 10	30.0%	
7	1 / 4	25.0%	
8	0 / 3	0.0%	22.6%
9	0 / 4	0.0%	
10	1 / 2	50.0%	
11	0 / 1	0.0%	
12	0 / 3	0.0%	
Total	**59 / 127**	**45.7%**	

Management Recommendation:

1. Continue to collect teeth for cementum age analysis by providing moose license holders with a tooth collection kit.
2. Have game wardens and wildlife biologists collect both I1 teeth from any harvested moose checked in the field or at check stations. This should increase the number of teeth available for age analysis as well as increase the likelihood of collecting intact teeth. Also, teeth should be collected from other moose mortalities.

3. Initiate a study to compare the preparation and analysis of moose teeth by the WGFD Lab, Laramie and Matson's Lab, Milltown, MT. Solicit funding for this study from the Wyoming Governor's Big Game License Coalition.

Mandatory Reporting of Hunter Harvested Moose

Much of the management data collected on moose involves data collected from hunter-harvested moose. We collect hunter success, hunter effort (as measured by days hunted per animals harvested), age and sex structure of harvest, biological samples for disease monitoring, and antler size from hunter-harvested animals. In order to obtain adequate and accurate data sets, the MWG discussed the option of mandatory reporting by moose hunters. While there are several options to implement this idea, the basic concept is that any licensed hunter must report a harvested moose within an established time frame.

The MWG decided that this could create significant workload demands for field personnel and could unnecessarily inconvenience moose hunters. Instead of mandatory reporting, it was decided to educate licensed moose hunters on the importance of voluntarily providing harvest information through existing efforts. If these efforts are unsuccessful, the MWG will reconsider the option of recommending mandatory moose harvest reporting.

Management Recommendation:

1. Continue to provide moose license holders with a letter from Biological Services encouraging compliance with collection of tooth samples and harvest reporting, whether successful or not.
2. Continue to provide moose license holders with a tooth collection kit.
3. Continue to obtain hunter harvest data through mail surveys conducted by Biological Services.
4. After 2 unsuccessful attempts to solicit harvest information, Biological Services should provide a list of non-respondents to the responsible wildlife biologist who can coordinate with the responsible game warden(s) for conducting phone interviews with these licensed hunters. This recommendation will be at the discretion of the responsible wildlife biologist based on workload demands.

Funding for Moose Management

The WGFD collected an average $249,305 in moose license revenue during 2001-2005, while management costs averaged $758,342 during the same period (Table 5). Even with an additional annual average of $284,706 in Department revenue - from application fees, conservation stamp revenues, federal grants and other sources - having been attributed to the moose program budget during these same years, the moose management program runs a significant deficit. Additional funding sources are necessary to address identified management and research needs. This emphasizes the importance of identifying management partners to cost share moose management costs.

Table 5. Moose management summary from 2001 – 2005. Harvest data and licenses issued are by calendar year. Revenue and management costs are by fiscal year (July 1 – June 30).

Year	Harvest	Rec. Days	Success	Days/ Animal	Lic. Sold	Lic. Rev.	Mgmt. Costs
2001	1,215	7,592	89%	6.2	1,406	$ 297,850	$ 594,652
2002	1,160	9,048	86%	7.8	1,386	$ 263,800	$ 617,427
2003	999	7,530	87%	7.5	1,189	$ 252,323	$ 646,341
2004	770	5,026	84%	6.5	927	$ 218,524	$ 1,004,466
2005	682	4,673	88%	6.9	798	$ 214,029	$ 928,822

By state statute, the Governor of Wyoming can allocate up to 20 big licenses, with no more than five valid for bighorn sheep and five valid for moose. In 2003, Governor Freudenthal broke with longstanding tradition and allocated the Governor licenses to the Wyoming Governor's Big Game License Coalition, a coalition of conservation groups comprised of the Wildlife Heritage Foundation of Wyoming (program administrator), Wyoming Chapter of Foundation for North America Wild Sheep, Rocky Mountain Elk Foundation, Mule Deer Foundation and North American Moose Foundation. Through 2007, 123 projects were funded and $1,289,135 has been spent or committed for on-the-ground projects. Through 2007, the sale of moose licenses generated $332,500, of which 70% ($232,750) has gone to the moose account to directly benefit moose management in Wyoming. A total of 29 moose projects have been funded with these proceeds through 2007. The WGBGLC is an annual program and can be discontinued at any time by the current or future governors.

Management Recommendation:

1. Continue to work with the Wyoming Governor's Big Game License Coalition to market the 5 Governor's Moose Licenses annually.
2. Prioritize research and management needs and submit applications for funding to the WGBGLC to support moose management and research in Wyoming.
3. Continue to pursue other funding avenues to address identified moose research and management needs.

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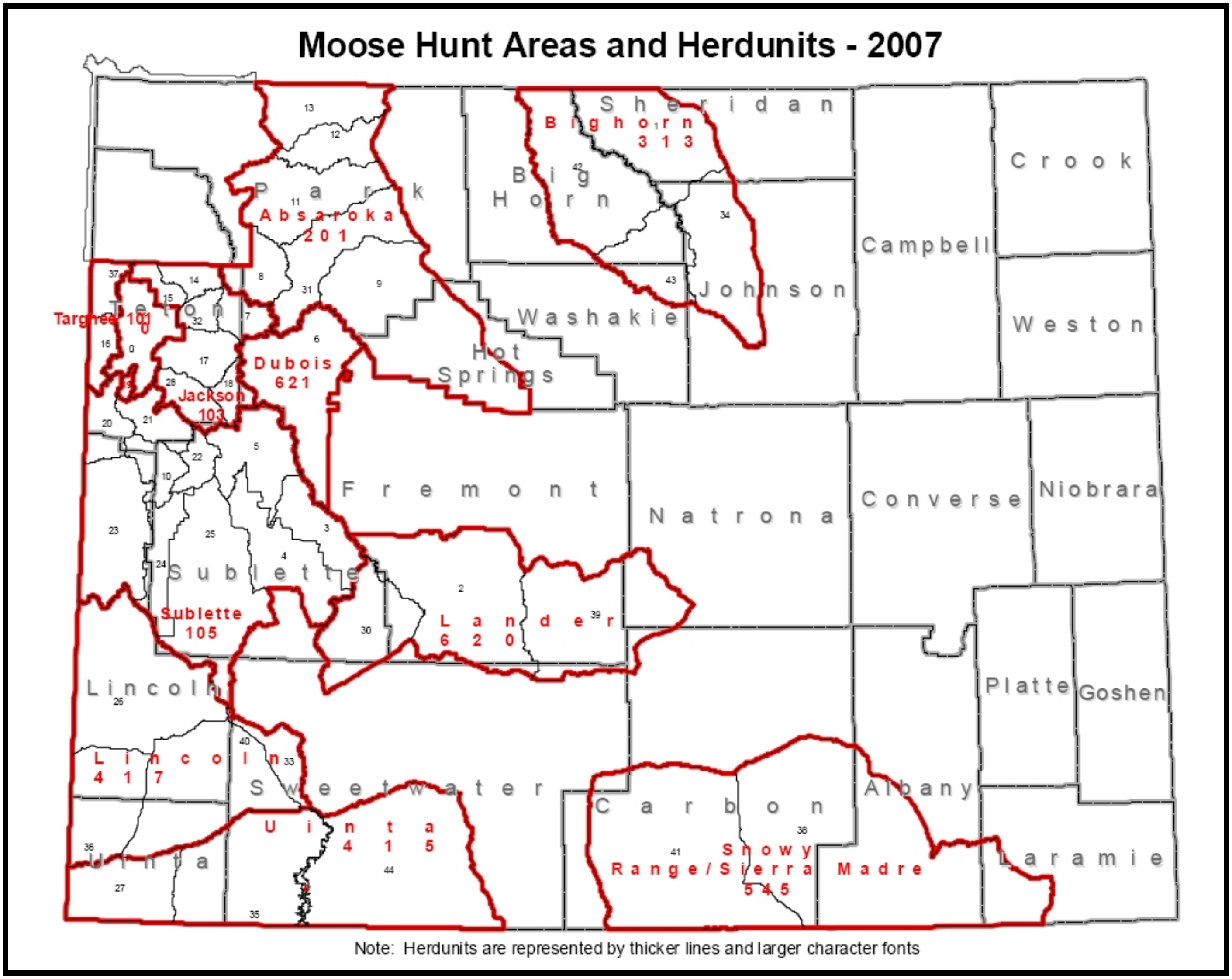
Appendix I.



Moose Hunt Areas and Herdunits - 2007
Sheridan
Bighorn 313
Big Horn
Park
Absaroka 201
Campbell
Crook
Teton
Targhee 101
Washakie
Johnson
Weston
Dubois 621
Hot Springs
Jackson 103
Fremont
Natrona
Converse
Niobrara
Sublette
Sublette 105
Lander 620
Lincoln
Lincoln 417
Sweetwater
Platte
Goshen
Uinta 415
Carbon
Albany
Uinta
Snowy Range/Sierra Madre 545
Laramie
Note: Herdunits are represented by thicker lines and larger character fonts

Appendix II. Standard ranges of parameters recommended for modeling big game herds in Wyoming.[1]

4/1/03

	Mule Deer	Pronghorn	Elk	**Moose**	Bighorn Sheep
Wounding Loss Rate [2]	10%	10%	10%	**10%**	25% rams, 10% other
Number of Age Classes [3]	12-15	12-15	15-20	**15-18**	12-15
Fecundity Rates: Age Classes (No/100 ♀s)	1: 0; 2→max.: 170	1: 0; 2→max.: 180	1: 0; 2: 0-30; 3→max.: 90	**1: 0; 2: 0; 3→max.: 90**	1: 0; 2: 0; 3→max.: 90
Sex ratio at Birth [4]	50:50	50:50	50:50	**50:50**	50:50
Juvenile Mortality Rate (pre-season) [5]	50%	50%	40%	**40%**	40%
Juvenile Mortality Rate (post-season) [6]	30-55%	30-55%	10-20%	**15-25%**	20-35%
Adult Mortality Rate (pre-season) [7]	2%	2%	1%	**1%**	2%
Prime-age Adult Mortality Rate (post-season) [8]	3-10% for age classes 2-5	3-10% for age classes 2-5	3-10% for age classes 2-6	**3-10% for age classes 2-6**	3-10% for age classes 2-6
Post-prime Adult Mortality Rate (post-season) [9]	Increases incrementally after age class 5, reaching 100% in oldest age classes	Increases incrementally after age class 5, reaching 100% in oldest age classes	Increases incrementally after age class 6, reaching 100% in oldest age classes	**Increases incrementally after age class 6, reaching 100% in oldest age classes**	Increases incrementally after age class 6, reaching 100% in oldest age classes
Sex-Based Differential Mortality (post-hunt) [9]	♂ mortality > ♀ mortality after class 5	♂ mortality > ♀ mortality after class 5	♂ mortality > ♀ mortality after class 6	**♂ mortality > ♀ mortality after class 6**	♂ mortality > ♀ mortality after class 6
MSI (pre-season) [10]	1.0 = normal summer	1.0 = normal summer	1.0 = normal summer	**1.0 = normal summer**	1.0 = normal summer
MSI (post-season) [11]	1.0 = normal winter	1.0 = normal winter	1.0 = normal winter	**1.0 = normal winter**	1.0 = normal winter

[1] All model parameters are recommended for use with POP II, Version 1.2.5 by Fossil Creek Software. Ranges of "acceptable" values are provided for several modeling parameters, however biologists and coordinators should strive to use consistent parameter values among models unless data or other information support alternative values in specific herd models.

[2] Use of wounding rates other than those listed and use of age- or sex-based, differential wounding rates must be justified with data or studies applicable to the herd being modeled.

[3] The number of age classes is based on tooth data and recoveries or observations of known-age, marked animals. Generally, the number of age classes will be within the recommended ranges unless data or observations indicate otherwise. By convention, Age Class 1 represents young of the year, Age Class 2 represents yearlings, and Age Classes 3 and higher represents adults.

[4] Always assume 50:50 sex ratio at birth.

[5] Pre-season (summer) juvenile mortality rates are fixed. Alignment of fall fawn:doe ratios is achieved by adjusting the pre-season MSIs.

[6] Post-season juvenile mortality rates may be adjusted within the recommended ranges to align modeled ratios or population estimates consistently with observed values. Post-season mortality rates of juvenile males may be up to 10-20% higher than for females, based upon Wyoming data for pronghorn, and based upon findings of Unsworth et al. (1999) and Conolly (1981) for mule deer. However, mortality rates outside the recommended ranges must be documented with data or studies that are applicable to the herd being modeled.

[7] Pre-season adult mortality rates are fixed. These are modified by the pre-season MSI needed to align fawn:doe ratios, so it is assumed changes in fawn mortality are also reflected in the adult segment.

[8] Post-season mortality rates of prime adults may be adjusted within the recommended ranges to align modeled ratios or population estimates consistently with observed values. However, mortality rates outside the recommended ranges must be documented with data or studies that are applicable to the herd being modeled.

[9] Post-season mortality rates of post-prime adults increase incrementally to reach 100% by the oldest female age classes. Mortality rates of post-prime adult males generally increase at a faster rate, reaching 100% several years before the oldest female age class. The rates of increase and magnitude of differential should be determined from the best data or information that is available for each herd being modeled. These parameters may be developed through iterative modeling exercises until modeled sex or age ratios, or population estimates align consistently with observed values.

[10] Pre-season MSIs are adjusted as needed to align simulated ratios of juveniles to age 1+ females, with the ratios observed in pre- or post-season classifications.

[11] An MSI of 1 is assumed to represent "normal" conditions. The linear MSI option should be used unless there is good justification for use of a curvilinear model. Post-season MSIs should be adjusted based upon either environmental data, for example weather severity indices, or alignment of modeled parameters. When post-season MSIs are adjusted through iterative modeling exercises, the modeler should evaluate whether the resulting MSIs are a reasonable representation of environmental or biological factors such as severe weather, drought, habitat condition, disease, or population density.