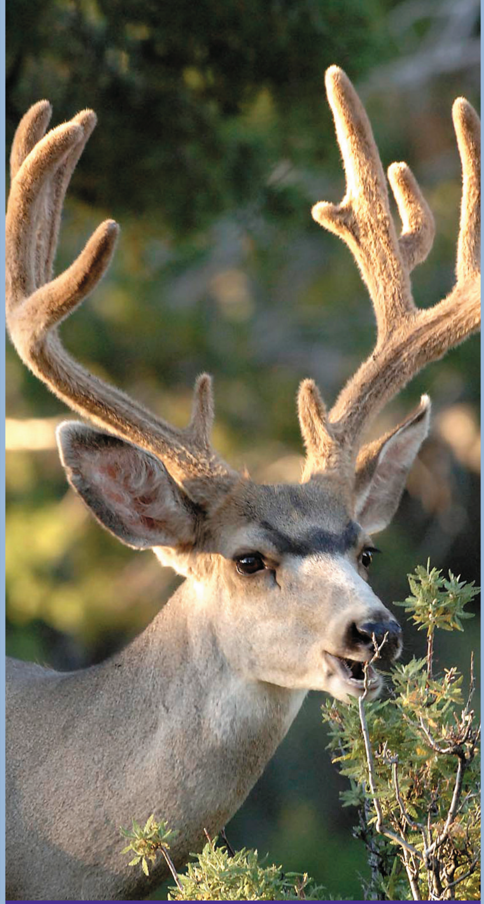

Methods For Monitoring Mule Deer Populations

A Product of the
Mule Deer Working Group

Sponsored by the
Western Association of Fish
and Wildlife Agencies
2011

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Cover photos courtesy of George Andrejko, Tom Keegan, Paul Spurling, Kevin Monteith, Tim Glenner, Jim Heffelfinger, and the Idaho Department of Fish and Game.

Suggested Citation: Keegan T. W., B. B. Ackerman, A. N. Aoude, L. C. Bender, T. Boudreau, L. H. Carpenter, B. B. Compton, M. Elmer, J. R. Heffelfinger, D. W. Lutz, B. D. Trindle, B. F. Wakeling, and B. E. Watkins. 2011. Methods for monitoring mule deer populations. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies, USA.

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ACKNOWLEDGMENTS

The Mule Deer Working Group thanks the Western Association of Fish and Wildlife Agencies (WAFWA) and the agency directors for supporting our efforts in compiling this handbook, particularly for allowing their staff time to work on this project. Thanks especially to Jim Karpowitz for his guidance as Director Sponsor. The final product benefitted from reviews by members of the Working Group as well as C. Bishop, L. Carpenter, J. Cook, R. Cook, O. Garton, J. Gude, A. Holland, M. Hurley, P. Lukacs, K. McCaffery, S. McCorquodale, A. Munig, W. Myers, J. Unsworth, and G. White.

PREFACE

Because of their popularity and wide distribution, mule and black-tailed deer (collectively referred to as 'mule deer,' *Odocoileus hemionus*) are one of the most economically and socially important animals in western North America. In a 2006 survey of outdoor activities, the U. S. Fish and Wildlife Service (USFWS) reported nearly 3 million people hunted in the 19 western states (USFWS 2007). Although this included hunters who pursued other species, mule deer have traditionally been one of the most important game animals in the West. In 2006 alone, hunters were afield for almost 50 million days and spent more than $7 billion in local communities across the West on lodging, food, fuel, and hunting-related equipment.

Hunters have contributed millions of dollars through license fees and excise taxes that finance wildlife management and benefit countless wildlife species. These funds support wildlife management agencies, which manage all wildlife species, not just those that are hunted. Mule deer have been an important component of this conservation paradigm and thus are responsible for supporting a wide variety of conservation activities valued by the public, including law enforcement, habitat management and acquisition, and wildlife population management.

The social and economic effects of mule deer declines go far beyond hunters and wildlife management agencies. The mule deer is valued as an integral part of the western landscape by hunters and non-hunters alike. According to the 2006 USFWS survey, 25.6 million residents in 19 western states spent more than $15.5 billion that year "watching wildlife." The value of having abundant populations of such a charismatic species as mule deer cannot be overemphasized. Thus, social and economic impacts of mule deer declines are critical to all agencies that manage mule deer and the habitat they rely on.

To address the multitude of issues impacting recovery of mule deer populations, the Western Association of Fish and Wildlife Agencies (WAFWA) chartered the Mule Deer Working Group (MDWG). The MDWG, comprised of representatives of all WAFWA member agencies, was established to address 3 specific tasks:

1. Develop solutions to common mule deer management challenges;
2. Identify and prioritize cooperative research and management activities in the western states and provinces;
3. Increase communication between agencies and the public who are interested in mule deer, and among those in agencies, universities, and nongovernmental organizations who are interested in mule deer management.

Toward this end, the MDWG has developed strategies to improve mule deer management throughout western North America, and has effectively increased communication among mule deer managers, researchers, administrators, and the public. Increased communication among agency biologists will allow managers to face new resource challenges with the best available science and techniques. This ecoregional and range-wide approach to mule deer conservation will allow natural resource administrators to make science-based decisions and provide up-to-date and accurate information to their stakeholders.

At the first MDWG meeting, members identified issues considered important to mule deer management. These topics included short- and long-term changes to habitat, differences in mule deer ecology between ecoregions, changes to nutritional resources, effects of different hunting strategies, competition with elk (*Cervus elaphus*), inconsistent collection and analyses of data, deer-predator relationships, disease impacts, and interactions that occur among weather patterns and all these issues. The MDWG summarized these issues in a book entitled *Mule Deer Conservation: Issues and Management Strategies* in 2003 (deVos et al. 2003).

In 2004 the MDWG published the North American Mule Deer Conservation Plan (NAMDCP), with an accompanying MOU signed by state and federal agencies. The Plan provides goals, objectives, and strategies for implementing coordinated activities to benefit mule deer. The overall goal of the NAMDCP is *"Ecologically sustainable levels of black-tailed and mule deer throughout their range through habitat protection and management, improved communication, increased knowledge, and ecoregional-based decision making."*

Between 2006 and 2009 the MDWG published habitat management guidelines for all 7 North American ecoregions. These guidelines provide comprehensive recommendations to private, tribal, state, provincial, and federal land managers for maintaining and improving mule deer habitat.

The International Association of Fish and Wildlife Agencies (now the Association of Fish and Wildlife Agencies) joined with the Wildlife Management Institute, U. S. Geological Survey Cooperative Research Units Program, Nevada Department of Wildlife (NDOW), and the MDWG to conduct an Ungulate Survey and Data Management Workshop in 2005. One of the recommendations from that workshop was to develop a handbook of recommended methods for monitoring mule deer populations (Mason et al. 2006).

This handbook provides a comprehensive collection of population monitoring methods for mule deer. We recognize and emphasize that practical, political, and economic factors constrain the ability of wildlife agencies to make dramatic changes in their ongoing monitoring activities. However, when opportunities arise for evaluation or changes to mule deer population monitoring programs, this document should be used to guide that decision-making process.

All publications produced by the MDWG can be found at www.muledeerworkinggroup.com.

INTRODUCTION

This handbook has been prepared to aid mule deer managers and biologists in making better decisions and choices about their monitoring efforts, as well as understanding shortcomings of some commonly used data sets to avoid inappropriate inference. In today's world of escalating operating costs and reductions in human resources, it is absolutely necessary that practitioners select the most efficient monitoring techniques and implement them with the most effective strategies possible. Unfortunately, many monitoring programs simply repeat what has been done previously, with limited scholarly investigation into methods being used. Users of a technique should be aware of the weaknesses and assumptions and the likelihood of obtaining reliable knowledge, and realize the consequences of relying upon a poorly designed or executed method. Modern mule deer management must be based on monitoring methods that are statistically sound and designed to produce data necessary for decision makers.

Previous authors have presented inclusive summaries of mule deer and elk monitoring efforts employed by the western states and provinces (Rupp et al. 2000, Rabe et al. 2002, Carpenter et al. 2003). Carpenter (1998) discussed several obstacles that make regional or landscape-scale research and monitoring difficult. One key obstacle identified was that inter- and intra-agency variation in data collection and monitoring methodologies often complicated and confounded our ability to make inferences about trends and underlying causes of ungulate population fluctuations.

Mason et al. (2006) thoroughly described the need for increased rigor and coordination of monitoring activities for mule deer management in western North America. The authors stated "*We believe there are substantial needs and opportunities to improve interagency and intra-agency coordination and collaboration in data-collection and analysis and to implement better communication and data-sharing strategies.*"

One of the best ways to meet these needs would be a handbook thoroughly describing monitoring methods and their advantages and disadvantages. Mason et al. (2006) called for a steering committee to "*focus on the development of a handbook of recommended field-sampling and statistical-analysis methods for elk and deer population and habitat monitoring.*" As discussed in the Preface, the MDWG, which has a history of developing important and useful documents for mule deer research and management, was the obvious entity to produce a handbook addressing monitoring methods for mule deer. In the following chapters, authors present a variety of monitoring techniques and strategies, including assumptions, advantages, and disadvantages of each.

Obviously, there are a wide range of techniques from which to choose and observers must rigorously select the most appropriate technique for the purpose intended. A call for standardization does not mean doing exactly the same thing in all places. One methodology will not work in all applications. Nor do we imply methods presented here are the only ones to consider. As Mason et al. (2006) explained "*by standardization we do not imply that all states use the same survey system but, rather, that all states should at least employ fundamental* *statistical aspects of random sampling and bias corrections when developing new or applying previously published survey techniques.*"

Nor should this publication constrain further advancements in survey and monitoring approaches. On the contrary, we should aggressively and diligently work toward improvements in accuracy and precision when estimating population parameters, while at the same time reducing excessive costs. Plainly, the need for continued and increased interagency collaboration on monitoring remains as essential today as when the MDWG was first established in 1998.

A key first step is to clearly state and understand management objectives. This will facilitate selection of appropriate monitoring techniques and intensity or frequency of measurement. Sampling all areas in all years may not be necessary. Perhaps focusing monitoring effort on fewer areas, but with greater sampling intensity, will produce more rigorous data on which to base management decisions.

Another important consideration involving standardization is the process of data storage and retrieval. In this era of computers and software packages, all data gathered should be collected and stored with standardized formats so data can be retrieved quickly. One very important advantage of this is cost savings. Human resources spent laboring over poorly stored data result in delays and inaccuracies. The ability to share data among other observers and agencies should also lead to new insights and strengthen our ability to analyze regional trends. Mason et al. (2006) addressed data collection by calling for peer-reviewed, standardized data-collection methods, including a searchable relational database.

Monitoring wildlife populations is one of the most basic elements of wildlife management. Because conducting a census of an entire population is rarely feasible, sampling is required and standard elements of statistical theory must be understood and followed. For the monitoring effort to be useful, resulting estimates should be both accurate and precise. Accuracy is how close an estimated value is to the actual (true) value. Precision is how close the measured values are to each other. However, in practice achieving adequate levels of accuracy and precision may be very difficult.

Among mule deer managers, there is often a strong desire to maintain consistent data-collection methods and parameter estimation techniques over time so estimates are consistent with previous measures. Maintaining data continuity is a worthy goal, but historic approaches may not be the best choice, and continued collection of inappropriate data streams does nothing to promote sound management. However, managers may be able to maintain data continuity when an improved technique is adopted by applying the traditional approach simultaneously for a year or 2 and identifying relationships of new estimates to traditional values. Unfortunately, because many monitoring efforts are poorly designed or implemented, users have no or poor measures of accuracy or precision of resulting estimates. Monitoring efforts must be scientifically sound and applied within an appropriate sampling framework to be useful.

Too frequently, users discover data they worked hard to obtain are not suitable for rigorous statistical analyses. The best way to prevent this situation is to include an assessment of statistical needs in the design phase of the monitoring effort. Consultation with a statistician is an important first step. One key question to address early in a monitoring effort is "what is the power of the test?" The power of the test allows the observer to anticipate the level of sampling necessary to detect a desired difference. In other words, if a management action is designed to reduce the population by 10%, will your sampling intensity allow you to detect this amount of change if it actually occurs? If variability among samples is high, the number of samples required to detect the difference may be quite large.

In some situations, observers may conclude the number of samples required to detect a difference is too large for available resources. The observer then must decide to either increase the difference to be detected or wait until adequate resources are available to appropriately conduct monitoring. Either choice is better than going ahead with measurements only to conclude that, given substantial variability in the data, you cannot possibly determine whether the management action was successful.

This handbook is presented with the intent information contained within is pertinent to many monitoring tasks. The authors all worked under a common vision:

"*Collecting and disseminating scientifically defensible and comparable mule deer population information to increase interagency coordination, collaboration, and management capabilities.*"

We hope you agree we hit the mark.

DEFINITIONS

Accuracy – How closely a sample-based estimate represents the true population.

Bias – A systematic difference between a sample-based estimate and true value.

Census – A complete count of all members of a population in a given area.

Count – Simple tabulation of deer observed in a given area. Counts do not include members of the population that occur in the area but are not detected.

Database – A usually large collection of logically related data organized so one can rapidly search and retrieve desired data.

Database, relational – A relational database contains multiple data tables consisting of different data with a shared attribute. Relationships between records in various tables are strictly defined; data can be accessed or reassembled in many ways without having to reorganize database tables.

Detectability – Probability that a member of a population in a given area will be observed.

Deterministic model - A mathematical representation based on known relationships among items or events with no randomness incorporated into input or output values. A particular model input will produce the same fixed output every time the model is run. See stochastic model.

Metadata – "Data about data." A description or documentation of other data managed within a database. May include descriptive information about the context, quality, condition, or characteristics of the data.

Online analytical processing (OLAP) – Procedure that uses a multidimensional data model ("multidimensional cube") to allow rapid execution of complex analytical and ad hoc queries (typically displayed as a new table on a web site) along any combination of dimensions.

Natality – Ratio of total live births to total population in a specific area and time frame; typically expressed as young/adult female/year.

Precision – Variability associated with an estimate (i.e., how much do estimates deviate from true values). Confidence intervals are a common way of expressing precision of an estimate.

Process variation – Inherent biological fluctuations in a characteristic or process. E.g., the variation in the unknown annual survival rate of a population.

Query – A request for information from a database. Database queries allow users to interactively interrogate a database, analyze data, and update the database. Many database systems require users to make requests for information in the form of stylized queries written in a specific language.

Sample bias – The tendency of a sample to exclude some members of the population and over-represent others.

Sampling frame – A mutually exclusive and all-inclusive list of members of the population to be sampled. E.g., all geographic subunits within a management zone, all wildlife agencies in WAFWA.

Sampling variation – Variability in an estimate due entirely to the way a parameter is sampled (how many and which units). May be measured by quantifying variation between different samples of the same size taken from the same population.

Sightability – Probability that a deer within an observer's field of view will be detected by the observer. Functional synonym of detectability.

Sightability model – Probability functions built from empirical data (typically aerial surveys) that provide an estimated probability of detection of a deer within the observer's field of view for any combination of environmental covariates included in a model. Covariates typically include group size, deer activity, snow cover, and vegetation cover. Sightability correction factors are usually developed based on detectability of radiomarked deer.

Simple random sampling – Drawing a subset of items from a population such that each item has an equal chance of being selected.

Spatially balanced random sampling – Method using hierarchical randomization whereby samples are approximately evenly spread across the spatial sampling frame to prevent clumping.

Spreadsheet – Computer application for data storage and manipulation. Information (data in text or numeric form, formulas, functions) are entered in cells in a row-column matrix and can be manipulated, analyzed, and displayed graphically.

Stochastic model – A mathematical representation which incorporates randomness in some input or output values such that model output is a probability distribution of potential values. See deterministic model.

Stratification – Separation of a population into more homogeneous (similar) sub-populations. Appropriate stratified sampling should reduce sampling variance, improve precision of estimates, and increase efficiency. To be valid, stratification needs to occur prior to data collection (i.e., not after collecting and summarizing observations).

Structured Query Language (SQL) – Database computer language designed for managing data in relational database management systems.

Survey design – A system used to select samples from a sampling frame (population). The design typically invokes a series of formal sampling constructs for the data collection scheme.

Visibility bias – Failure to observe all deer present (in a sampled area) during a survey.

MANAGEMENT OBJECTIVES

Mule deer are managed through a variety of hunt structures designed to attain one or more management objectives. Management objectives can be very simple (e.g., provide for a stated number of hunter days each year) or complex (e.g., provide for a specific buck:doe [B:D] ratio, a specific age structure in the harvest, or a specific level of hunter success). Management objectives are often not simply biological in nature, but rather are generally designed to attain a desired outcome for a specific customer segment. It is overly simplistic to state "hunters only want to hunt." Human dimensions research has demonstrated different segments of the hunting public pursue a wide range of experiences, including simply going afield, spending time with friends and family, seeing wildlife, or harvesting an older age class buck that meets some personal standard.

Management objectives adopted by wildlife management agencies are generally established through a public process that considers desires of hunters and other interested publics, biological limitations, and social values. Social values (best determined via human dimensions research) may include diverse aspects ranging from watchable wildlife interests to tolerance for agricultural damage. Many states and provinces establish broad objectives such as number of hunters afield and number of days they expect hunters to spend hunting. These are important considerations because objectives also factor into expected revenue projections agencies depend on for funding wildlife management activities. Beyond those considerations, hunting opportunity within management units is generally adjusted based on more specific management objectives that may include

1. Population trend.
2. Population abundance objectives (e.g., a specific estimated population with accompanying sex and age structure).
3. Buck:doe ratios (before or after the hunt, or both).
4. Estimated age structure of bucks in the population or age composition of bucks in the harvest.
5. Antler size or conformation of harvested bucks.
6. Number of deer harvested (by sex or age class).
7. Hunter effort or harvest rates (e.g., days afield, success rates, days/harvested deer); or
8. Fawn:doe (F:D) ratios.
9. Habitat condition.
10. Incidence of agricultural depredations or other conflicts.

Harvest and hunting opportunity objectives may be further subdivided among user groups (weapon types or hunter demographics such as youth hunts). Agencies routinely use multiple management objectives (Appendix A) to guide their season structures (which often incorporate multiple hunting seasons).

MONITORING STANDARDS

Monitoring of harvested populations is arguably one of the most important management activities conducted by agencies, but limited revenues preclude intensive monitoring for all or even a majority of populations within each state or province. Depending on intensity, harvest has the potential to influence most mule deer population parameters, including sex ratios, age structure, and abundance (Erickson et al. 2003). Not all populations of mule deer are managed in the same way, and certain population management strategies require more intensive monitoring of population demographics than others. Similarly, different components of the population have differing effects on population trends. For example, buck harvest has little effect on overall population trend, whereas even small changes in doe survival can greatly influence population trend (Bowden et al. 2000, Gaillard et al. 2000). However, adult doe survival shows much less annual variation than does production and survival of juveniles. Because of the high annual variation due to varying environmental influences, production and survival of juveniles accounts for the majority of the annual variation in population size (Gaillard et al. 2000). Consequently, juvenile:adult female ratios are the most common population demographic collected by agencies along with overall population trend. Conversely, despite high sensitivity of population trend to changes in adult female survival (Bowden et al. 2000, Gaillard et al. 2000), high costs of telemetry-based studies, limited agency budgets, and lack of annual variation relative to production and survival of juveniles and hence proportional contribution to population trend, monitoring of adult doe survival is usually undertaken only when needed, as when a decline in population size is indicated.

Monitoring intensity may be driven by both biological and socio-political needs. From a biological standpoint, greater monitoring effort is typically associated with management objectives that maximize buck harvest rates, or control populations with substantial female harvest. In these cases, managers need more information to avoid unintended consequences such as undesired population declines or very low B:D ratios. Conversely, conservative management approaches (e.g., light buck harvest rates used to achieve greater proportions of older age class bucks in the harvest) can be monitored less frequently or with less intensive methods because there is much less risk of creating those undesirable changes in the deer population. For example, in a situation where a management objective calls for a B:D ratio of 40:100, there is no meaningful biological consequence whether the ratio is 30:100 or 50:100. However, periodic assessment of population trend or size should be conducted because populations may be affected by factors other than harvest. Paradoxically, socio-political influences may override this logic and very intensive monitoring may be required to demonstrate a particular strategy is achieving conservative management objectives.

Population status also influences monitoring needs. Populations of small size and uncertain viability require more intensive monitoring than do larger populations under similar harvesting strategies because overharvest or environmental variation can quickly lead to extirpation of small populations. Conversely, populations near or above carrying capacity (*K*) because of inadequate female harvest may also require intensive monitoring (e.g., of deer health, body condition, or recruitment) to measure or demonstrate effects of overpopulation. Because harvesting is essentially a landscape-scale management manipulation for which demographic outcomes are not always known, harvest strategy is another criterion that influences monitoring decisions. Impacts of harvest strategies which are less understood require more intensive monitoring to provide rigorous data on impacts on abundance, sex ratios, and age structure. When possible, agencies should endeavor to understand impacts of harvest strategies through large-scale, experimental manipulation of harvest regulations over multiple areas. Such approaches have greatly clarified the critical components of population dynamics that need to be monitored (Gaillard et al. 2000).

Ideally, harvest strategies and monitoring intensity are linked with agency management objectives and corresponding population demographic variables or controlling processes (e.g., a certain population size will be controlled by female harvest, B:D ratio is controlled by both male and female harvest, and population age structure is controlled by both male and female harvest). Because each management objective helps define an appropriate harvest strategy, the more intensive the management objectives (in terms of population impacts), the more rigorous the degree of monitoring needed to assess responses of the population. Moreover, some harvest strategies may require intensive monitoring for certain objectives (e.g., abundance) but not others (e.g., buck age structure). The following outlines the most common types of harvest strategies employed by agencies and minimum recommended levels of monitoring (see also Table 1).

Doe Harvest Strategies

Independent of buck harvest strategy, does may be harvested at intensities ranging from no harvest to open-entry harvest (most often with some constraint such as primitive weapons, reduced season length or area, or participation limited to youth or senior hunters).

No or light antlerless harvest.— Minimal harvest of antlerless deer limits concerns for population size unless populations are small initially. Lack of substantial antlerless harvest usually assumes populations are well below ecological (i.e., resource-limited) carrying capacity, and thus deer health and antler development are not limited by intra-specific competition. However, if antlerless harvest is low or nonexistent because of socio-political influences, those assumptions may be invalid.

- Requires periodic trend assessment even with little anticipated impact on adult females because populations may change independent of female harvest rates.
- If female harvest is low, but populations are high relative to K, more frequent monitoring of trend or abundance, population productivity or recruitment, or body condition may be needed to demonstrate whether populations are performing poorly and increased female harvest may be beneficial.

Moderate to heavy antlerless harvest.— Includes increased harvest of adult females to control population size or provide increased recreational opportunities.

- Requires annual monitoring of population trend or periodic monitoring of population size to determine impacts of antlerless harvest.
- Requires annual monitoring of population productivity or recruitment to determine appropriate annual antlerless harvest levels. Ideally, monitoring would occur prior to antlerless harvest or account for doe harvest to avoid inflated F:D ratios due to large doe removal.

Buck Harvest Strategies

A variety of harvest criteria and intensities are used in buck management. These include both open-entry (i.e., any hunter can purchase a buck hunting license annually) and limited-entry (i.e., buck permits are available only to a limited number of applicants) systems. Even with limited-entry systems, harvest intensities can range from high buck harvest (total annual mortality rates >70%) to extremely limited (total annual mortality rates <30%). Harvest may also be limited in either system by other selective harvest criteria, such as a minimum or maximum number of antler points.

Very limited-entry buck management (i.e., mature-buck management).— These strategies often severely limit the number of hunters to keep buck harvest mortality rates very low (usually well under 0.50 and frequently <0.30) to produce high B:D ratios and an older age structure among bucks.

- Requires periodic monitoring of buck age structure or B:D ratios to assess success in meeting management objectives. In some cases it may be sufficient to simply monitor success through hunter satisfaction surveys. Socio-political interest may create a need for more intensive monitoring, such as annual assessments.

Limited-entry buck management.— These strategies limit hunter opportunity to reduce buck harvest and annual buck harvest mortality rates (usually to <0.50) and consequently increase B:D ratios and buck age structure. In rare cases, a few agencies have employed antler-point restrictions such as 3- or 4-point minimum strategies to increase escapement of younger bucks in limited-entry hunts (almost exclusively under socio-political influence).

- Requires periodic or annual monitoring of buck age structure or B:D ratios to assess success in meeting management objectives. In some cases it may be sufficient to simply monitor success through hunter satisfaction surveys. Socio-political interest may create a need for more intensive monitoring.
- Under minimum point regulations, periodic monitoring of buck survival rates may be necessary to identify or quantify rates of unlawful harvest (hunters mistakenly or intentionally kill sub-legal bucks that are not retrieved or accounted for in harvest estimates).

Open-entry buck harvest.— Open-entry includes strategies designed to maximize hunter opportunity by allowing all licensed hunters to hunt bucks. These strategies maximize buck harvest and consequently result in lower B:D ratios and a younger buck age structure than most limited-entry systems. Minimum antler-point restrictions are occasionally employed to reduce vulnerability of younger bucks and thus increase post-hunt B:D ratios. However, most increases in escapement of young bucks are usually attributable to voluntary non-participation by hunters, and focused effort on older bucks usually results in a younger or truncated age structure.

- Requires annual monitoring of B:D ratios and periodic monitoring of buck age structure to ensure objectives are met.
- Under minimum point regulations, periodic monitoring of buck survival rates may be necessary to identify or quantify rates of unlawful harvest.

Open-entry spike or 2-point maximum, limited-entry adult buck harvest criteria.— This strategy combines elements of mature-buck management and open-entry buck hunting to maintain high levels of recreation (through open-entry hunts for 1- or ≤2-point bucks) with restricted harvest of adult bucks to allow some escapement into older age classes. Because this strategy is critically dependent upon recruitment of yearling bucks to maintain yearling harvest and allow some escapement into older, lightly harvested, age classes, monitoring of population productivity and buck age structure is needed to determine whether recruitment and escapement of yearling bucks is sufficient to support the limited-entry adult buck harvest.

- Requires annual monitoring of buck age structure and B:D ratios.
- Requires annual monitoring of productivity or recruitment ratios.

Table 1. Recommended population parameters to monitor and frequency of monitoring needed relative to increasing harvest rates for most populations of mule deer. Very small populations of uncertain viability require more frequent and intensive monitoring than levels shown.

Population parameter	→ Increasing harvest rates →			
Harvest	A	A	A	A
Population trend	P	B	A	A
Sex and age composition	P	B	A	A
Population abundance		P	P	A[1]
Fawn survival	If concerns[2]	If concerns	If concerns	If concerns
Adult female survival	If concerns	If concerns	If concerns	If concerns
Examples				
Doe harvest	None	Light	Moderate	Heavy
Buck harvest	Very limited	Limited	Open entry	Open entry 2-pt + very limited adult

A = monitor annually; B = monitor every 2-3 yr; P = monitor at least once every 5 yr; If concerns = investigate if monitoring data suggest concerns over population health (e.g., trends indicate declining population, very low productivity or recruitment, etc.).

[1] If low density population; otherwise B.

[2] If population trend, abundance, or productivity rates show declining trends, agencies may choose to intensively investigate production and survival of juveniles, or adult survival. Most frequently, most annual variation in changes in abundance is driven by high annual variability in production and survival of juveniles (Gaillard et al. 2000), so this demographic should be evaluated first.

Monitoring intensity may vary from levels displayed in Table 1 based on monitoring approach. For example, agencies relying heavily on population modeling, rather than trend or abundance estimates, may need more information on fawn and doe survival rates to populate models. In some cases, managers may desire consecutive annual abundance estimates in order to estimate population rates of change.

PARAMETER ESTIMATION TECHNIQUES

Harvest

Estimating harvest and hunter success rates are major parts of managing mule deer populations. This information is needed to address biological and social aspects of mule deer management. Mule deer populations are difficult to estimate and mathematical models used by managers depend on accurate harvest mortality estimates (as well as other demographic data) to predict population numbers. Hunter success has social and biological importance and is an important factor in setting season structure and hunting opportunity. Many harvest survey methods are similar and only vary in how questions and replies are delivered; thus, many of these methods share limitations and biases. Minimally, hunters are asked to provide data about effort expended (hunter days); where they hunted (e.g., game management unit); and if successful, sex and antler size of harvested deer, harvest date and location, and weapon used.

For sample-based techniques, sample size requirements should be identified before surveys begin so adequate accuracy and precision are obtained. Mandatory harvest reporting, although appealing at first glance, likely never accounts for all harvest or harvest effort. Therefore, additional effort and cost is needed to estimate parameters for non-respondents. Some level of bias is common to all harvest estimation techniques and deer managers need to identify acceptable levels for their program. Carpenter (2000) presented a thorough review and summary of big game harvest surveys.

Web-based surveys.— Web-based surveys are becoming more popular with increased use of personal computers. The proportion of hunters using the Internet increased from 20% in 2001 to 34% in 2002 (Miller 2003). Use of Internet resources by hunters is likely much higher today.

Most agencies now have an online application process that can capture applicants' e-mail addresses. These addresses become a potential e-mail survey list. Utah recently conducted a mule deer hunter opinion survey to help in drafting a statewide mule deer management plan. In this example, e-mails were sent to a randomly selected subsample of all hunters who provided an e-mail address when applying for a permit. The e-mail asked hunters to log on to a web site and complete a survey. Response rate was moderate; only 47% of hunters contacted returned a usable survey after an initial invitation and 2 follow-up e-mails (A. Aoude, Utah Division of Wildlife Resources, unpublished data).

Many agencies have implemented, or are considering, mandatory harvest reporting and web-based surveys are the most cost-effective way to accomplish this for a large population of hunters. There has been little research published on the use of the Internet for conducting harvest surveys, but web-based surveys likely have the combined limitations of mail and phone survey methods. Shih and Fan (2008) found mail surveys usually generate greater response rates than web-based surveys. Kaplowitz et al. (2004) reported comparable response rates for mail and web-based surveys when advance notification preceded surveys, but they noted a significant difference in respondent age by survey type (mail solicited greater returns from older respondents). Given the current older age distribution of hunters, survey designers should be cognizant of this potential bias.

Advantages

- Reduced cost is the greatest advantage of web-based surveys, especially when conducted by agency staff (as opposed to outside contractors).
- E-mails are relatively inexpensive to send, regardless of sample size, and the primary cost is initial programming time (Lukacs 2007).
- Electronically collected information has less potential for transcription error.
- Web-based surveys provide surveyors more control through the use of text validation and logic rules, thus reducing occurrence of incomplete or incorrect answers.

Disadvantages

- Not all hunters have Internet access or use e-mail.
- Surveys may need to be designed for slow transmission speed (because users may access the Internet via a 56K modem) or small e-mail size limits. Therefore, large pictures or maps cannot be included. However, links to web sites that contain additional information can be provided in e-mails.
- E-mail addresses can change frequently.
- Return rates may be variable.

Assumptions

- The main assumption is those hunters who supply e-mail addresses or those who have Internet access are representative of the population of hunters.

Techniques

This survey method is more similar to mail surveys in its biases for response and non-response (see below).

Telephone surveys.— Telephone surveys are currently used by some agencies in the West to estimate harvest of big game species. Response and non-response bias seem to be reduced using this method (Steinert et al. 1994, Unsworth et al. 2002). Sampling designs similar to those used for mail surveys can be used. Random sampling or a complete census can be used depending on size of the hunter pool and return rate.

Advantages

- Allows you to continue calling randomly selected individuals until a predetermined number of samples is reached.
- Allows use of more complex questionnaires (Aney 1974).

Disadvantages

- Costs and non-contact rates for this method can be high (Aney 1974).
- Many people now have caller identification and may disregard calls from unknown sources. This development in technology will likely increase time and costs needed to obtain sufficient sample sizes.
- Caller identification may also exacerbate non-response bias.

Assumptions

- The main assumption is the sample truly reflects the entire population. This assumption is met if a random or systematic sampling scheme is used and if corrected for associated biases.

Techniques

Telephone surveys have been used as an effective way to almost eliminate non-response bias, because ability of the surveyor to contact a hunter was typically unrelated to the way that hunter would answer survey questions. However, this may no longer be the case with increased use of caller identification. Successful hunters may choose to take the call if they recognize caller identification information, whereas unsuccessful hunters may not (Lukacs 2007). Steinert et al. (1994) reported minimal response bias from a telephone survey (compared to previous check station results).

Sample size determination should be based on desired precision for specific groups of hunters (e.g., weapon type) or geographic areas (e.g., management unit). Protocols for operators should be identified in advance and applied rigorously (e.g., number of call backs, completion of all questions, level of data validation, whether surrogates can provide answers for targeted hunters, etc.).

Mail surveys.— Mail surveys have been used by many states and provinces to estimate harvest of big game species. This method can be effective when limitations are considered and correction factors are developed to deal with common sources of bias. There are 2 main sampling schemes when using this method: random sampling and a complete census. Random sampling is the most cost-effective method and can be used when the hunter pool is large and return rates are high. If return rates are low, you may need to conduct follow-up mailings or increase sample size to obtain a statistically valid sample to estimate harvest. However, simply increasing sample size will not solve problems associated with non-response bias. A complete census may be necessary for hunts that are limited to a few hunters or when sample size needed for adequate accuracy is a very large proportion of the entire population.

Advantages

- Likely to reach a large proportion of hunters (regardless of age, economic status, etc.).

Disadvantages

- More costly and labor intensive than Internet-based surveys.
- Potential for bias may be greater than with telephone surveys.
- Data entry from returned surveys can be time consuming and a source of error.
- Questionnaires need to be relatively short and simple.
- Some returned surveys are unusable because they are illegible, incomplete, or contain incorrect information.
- May require multiple contact letters to achieve adequate sample size, which may lengthen the time needed to generate estimates.

Assumptions

- The primary assumption is the sample truly reflects the entire population. This assumption is met if a random or systematic sampling scheme is used and if corrections for associated biases are applied.

Techniques

There are several potential sources of bias associated with mail surveys. Some sources are only applicable when multiple deer can be taken during the season (uncommon for mule deer). These include prestige bias (hunters claim a higher season bag), Type I-memory bias (memory failure causes hunters to overstate their bag by rounding up), and Type II-memory bias (hunters recall small numbers better than large numbers and tend to understate harvest due to large bag limits over a long season) (Geis and Taber 1963).

The 2 primary sources of bias that apply to big game are non-response and response bias (MacDonald and Dillman 1968). Non-response bias is a result of differences in hunting activity or success between respondents and non-respondents. You can correct for non-response bias by telephone sampling a sub-group of non-respondents to determine whether their responses differ significantly from those who responded by mail. If responses are significantly different, data gathered will help you create a correction factor to apply to the mail survey. Non-response bias generally declines with increasing return rates, but minimum response rates needed to avoid bias have not been established. Non-response bias in mail surveys can vary from minor (Atwood 1956, Smith 1959, Taylor et al. 2000) to substantial (Barker 1991). Thus non-response bias should be examined at least periodically.

Response bias is a result of respondents incorrectly reporting their hunting activity. Often the largest response biases come from prestige bias. The most common prestige bias is hunters reporting they have killed a deer when in reality they did not. MacDonald and Dillman (1968) found hunters overstated buck harvest by 6.0% and doe harvest by 11.1%. Other potential examples of prestige bias could include reports of greater body or antler size or points, or claiming harvest of a buck rather than a doe (primarily under either-sex bag limits). Correcting for prestige bias is difficult. One method to estimate and correct for this bias is to send surveys to hunters who were checked at check stations or other mandatory harvest check-ins, and compare survey data with known harvest or hunting activity (MacDonald and Dillman 1968, Steinert et al 1994). More recently, some western managers have identified intentional underreporting by buck mule deer hunters as a bias (M. Cox, NDOW, personal communication), presumably in response to limited eligibility for permits under limited-entry and preferential draw (point) systems.

Telephone and web-based reporting.— Telephone and web-based reports are currently used by some agencies to estimate harvest of big game species as part of either voluntary or mandatory systems. User-selected web or telephone reporting or questionnaires are likely to result in substantive non-response biases which cannot be assumed to equate to biases from mail or telephone surveys. Thus, to obtain statistically valid estimates, user-selected electronic reporting will regularly require follow-up surveys to estimate non-response bias. The apparent reduced financial costs of user-selected reporting should not be the sole determining factor in their use (Duda and Nobile 2010, Gigliotti 2011). Response rates, even when accompanied by incentives (rewards or penalties), are typically moderate and tend to deteriorate over time.

Advantages

- Provide real-time information during ongoing hunting seasons (more quickly than post-season surveys).
- Data can be used to validate other harvest estimation techniques or biases.
- Reduced costs because hunters do the reporting.
- Occurrence of incomplete or incorrect answers can be reduced through survey design (via text validation, logic rules, drop-down lists).

Disadvantages

- Harvest data will very likely be biased (even if reporting is mandatory, some hunters will not respond).
- Non-response bias surveys are usually required.
- Hunters must have access to either a telephone or the Internet.

Assumptions

- Self-reported harvest and hunting activity are representative of respective populations.
- Information provided by hunters is accurate.

Techniques

Hunters are provided with a telephone number or Internet address to report harvest information and hunting effort. Reporting can be either mandatory or voluntary. Telephone operators can be live or automated with differing costs associated with each. Upon completion of a valid report, hunters are typically provided a confirmation number to maintain proof of compliance (for law enforcement, meat processors, taxidermists, license agents, etc.).

Check stations.— Western states and provinces have historically used deer check stations more than they currently do; however, check stations can still provide valuable data about deer populations. Check stations are either required by law or voluntary. Value of harvest data collected at check stations largely depends on intensity of sampling. Even under mandatory check-in, harvest data will likely be biased because some hunters fail to comply. However, such data are often used to provide initial estimates of hunter success and harvest trend from year to year.

Advantages

- Provide real-time information during ongoing hunting seasons (more quickly than post-season surveys).
- Data can be used to validate other harvest estimation techniques or biases (e.g., by comparing known check station data from specific hunters to data collected later from the same hunters with a remote harvest survey).
- Allow for collection of biological measurements and samples (see Body Condition section), including sampling for diseases and parasites.

- Provide opportunities for hunters to interact with biologists, alleviate concerns, and dispel rumors.
- Provide opportunities to explain and promote programs or provide educational materials.
- Can serve as social gathering points for hunters.

Disadvantages
- Even when mandatory, harvest data will very likely be biased.
- Usually labor intensive and expensive.
- May expose staff to potentially dangerous situations.
- May require coordination with or permits from transportation agencies.
- May require specific signage or lighting.
- Mandatory check stations may not be lawful in some jurisdictions.

Assumptions
- Hunters and deer sampled at check stations are representative of the populations.

Techniques
States and provinces vary widely in their use of check stations to estimate harvest trends and evaluate hunting seasons. Nebraska requires all hunters to present harvested deer at a check station. Data collected from this effort allow managers to determine harvest trends for all deer management units. Arizona, Alberta, and California use check stations to obtain harvest information for much smaller areas, such as military bases, wildlife management areas, and wildlife refuges. Harvest data obtained through check stations can include species, sex, age, antler characteristics, success by permit or license type, hunter effort, location of kill, date of kill, and hunter demographics. Most western states and provinces do not use check stations for harvest analysis or population trend information because sampling is nonrandom and subject to potentially large, unknown biases. If unbiased check station estimates of harvest are desired, fishery-access-point survey methods can improve estimates (Unsworth et al. 2002).

Check stations can be operated by trained biologists or trained lay persons depending on data quality needs. If it is necessary to set up check stations at private business locations, operators are typically paid for their cooperation. This payment is usually negotiated prior to the season. Hunters should be provided information about locations of check stations with their licenses or with appropriate signage at local sites of voluntary check stations.

Trends in Population and Demographics

Population trend is the directional movement in relative abundance or other key parameters through time (sensu Skalski et al. 2005). Trend indices are measures that are presumed to correlate with population abundance (or other parameters); thus, trend indices may indicate whether a population has increased, declined, or remained stable over time, if certain assumptions are met. Trend indices are also sometimes used to infer magnitude of annual changes, and, if collected over multiple years, trend indices can also be analyzed to provide a quantitative estimate of magnitude of population change by linear or nonlinear modeling. Trend indices can be either direct (involve direct counts of deer) or indirect (involve counts of indirect evidence of deer presence, such as scat or tracks).

Despite widespread use of trend indices in wildlife management, there is much uncertainty regarding usefulness of these indices (Anderson 2001, Williams et al. 2001, Lancia et al. 2005), including debate as to whether they should be used at all (Anderson 2001, Williams et al. 2001). Also, statistical power of trend indices to detect an actual change in population abundance is often very low. Consequently, changes in population size often have to be quite large (e.g., halving or doubling of the population) to be detected by trend indices. Similarly, statistical theory underlying trend indices has received very little study (Skalski et al. 2005). Despite these questions, trend indices are frequently used, primarily because of cost-efficient application over large geographic areas and challenges involved in developing valid estimates of abundance.

Trend indices are most frequently used to index changes in population abundance, although they may also be used to index trends in age structure, adult sex ratios, or productivity or recruitment ratios. Whereas a great variety of trend indices exist (see below), the underlying assumption of all is there exists a homogenous (across time, habitats, etc.) and proportional relationship between a change in the trend index and a change in abundance or other population parameter. Thus, before using any trend index managers need to consider 3 key questions:

1. Does a change in abundance result in a change in the index?

2. What is the relationship between deer abundance and the index? Frequently, the relationship is assumed to be linear, but often is not.

3. Are the data for the index collected consistently over time and is the sampling representative of the population? Both of these must be true for a trend index to have any real relationship to abundance.

The primary problem with most trend indices is the relationship between the index and abundance has not been determined. Despite this, trend indices are often treated as if they accurately and precisely reflect population abundance even though such a relationship has not been demonstrated. Because of this uncertainty, trend indices are most correctly applied only to determine a relative (as opposed to absolute) change in abundance. A second important problem among trend indices is difficulty in meeting assumptions. Failure to meet explicit assumptions or apply methods to account for unmet assumptions may result in failure of an index to adequately reflect change in populations.

For most trend indices, the relationship between index and deer abundance is not only unknown, but also likely not consistent. Rather, it varies over time and among areas due to changes in environmental factors (season, habitat, weather, deer behavior, etc.), human influences (hunter behavior, differing observers, etc.), and sampling protocols (sampling effort, plots vs. belt transects, etc.). A variety of techniques are used to deal with this variation, which cause violation of the assumption of a homogenous and proportional relationship between abundance and the index. First, sampling strategies are frequently systematic or stratified random as opposed to purely random. These former sampling strategies attempt to account for vegetation type or other environmental attributes varying among survey areas or times. By blocking surveys according to these differences, the overall index should better represent the entire population.

Systematic or stratified random surveys are also often easier to implement than completely randomized designs, especially when surveys are associated with roads or trails which are not randomly located across the landscape. A potential negative effect of systematic sampling is you may not capture all of the environmental variation across the landscape due to your sampling not being random. However, this problem can be overcome by ensuring stratification (blocking) includes all relevant variables in the stratification (e.g., all habitats likely to be used by mule deer). A second way to deal with environmental variables that may affect the relationship between abundance and index includes standardization of survey methodology, which is most often used to account for weather and observer effects. Third, important environmental factors can be included and accounted for in models to relate abundance to the index under “constant” conditions.

Many trend indices (such as pellet-group counts, harvest-per-unit-effort, track surveys,) have been extrapolated to provide estimates of population abundance, creating considerable overlap between trend indices and abundance estimators. Methods most commonly used as abundance estimators require additional assumptions for extrapolation from index to abundance that is beyond this discussion of trend indices and will be covered in the Abundance and Density section.

Minimum aerial counts and classification.— A minimum count represents the absolute minimum number of deer known to be present in a given area (while recognizing an unknown proportion of the population was not seen or counted). Counts and classifications are frequently accomplished through helicopter or fixed-wing surveys; however, several other techniques (e.g., ground counts, spotlight counts, etc.) can also yield minimum counts (see next section). Counts are often standardized to effort, such as numbers seen per hour of flight time or miles of survey route.

Advantages

- Sample sizes obtained from aircraft, and thus minimum estimates, are usually much greater than from ground-based methods.
- Helicopter counts presumably provide more accurate counts and sex and age classification than do ground-based counts because of independence of roads, ability to observe deer in inaccessible areas, longer observation times, closer proximity to deer, and ability to herd deer to provide optimal viewing opportunities (however, observing undisturbed deer from the ground with enhanced optics also allows accurate classification). This may not be true if substantial vegetation cover significantly obscures deer or allows only “fleeting” glimpses of deer.
- A segment of the public strongly favors census and minimum counts over sample-based population estimation. Sample-based estimates are frequently called into question and dismissed by the public if they do not mirror perceptions.
- Provides an absolute minimum population estimate which is understood and accepted by the public (sampling techniques, statistical inference, and probability are poorly understood by many constituents).

Note: the last 2 bullets represent challenges to agencies in educating constituents about the value of sampled-based methods.

Disadvantages

- There are very few cases where mule deer census is possible. Radiomarking studies have shown even very intensive efforts covering 100% of an area fail to account for all individuals due to concealment or observer factors (Bartmann et al. 1986).
- Costs are high compared to most other indices.
- Cost for a census would be prohibitive except for small, mostly confined areas.
- Although presumed to be more accurate than ground-based methods, validation is lacking, particularly for fixed-wing aircraft.
- Significantly more hazardous for biologists than ground-based methods.
- Minimum counts are frequently smaller than annual harvests, causing the public to question survey data and permit allocations.
- Motion sickness or marginally skilled pilots can result in poor viewing opportunities and highly biased data (e.g., large proportions of groups flee to cover before classification).
- Relationship to true population size often unknown or uncertain.

Assumptions

- Census – all members of the population in a given area are detected and accurately counted.
- Minimum count – members of the population counted in a given area are representative of the actual population.
- If minimum counts collected across time, a consistent proportion of the population is counted.
- If population components are separated, sex and age classes are correctly identified.
- Detectability is similar across sex and age classes, or counts are conducted during biological periods where free intermixing occurs between target sex and age classes (Samuel et al. 1987, Bender 2006).

Techniques

Both population censuses and minimum counts are usually conducted from either helicopter or fixed-wing aircraft, with flight protocols (such as airspeed, altitude above ground level, and spacing of transect lines) and observer behavior (including number of observers, direction of observation, and width of transect lines observed) held constant among surveys. Because population census is seldom feasible for free-ranging deer, remote sensing techniques are being evaluated to increase efficiency and improve detection rates (Lancia et al. 2005). Experimental techniques that have been tried include use of aerial photographs to obtain counts of concentrated individuals or thermal imaging. Forward looking infrared (FLIR) sensing has been used for a variety of ungulates with limited success outside of smaller or enclosed areas (Dunn et al. 2002, Drake et al. 2005). Additionally, remotely operated vehicles (ROVs) are being explored as a means to decrease risks to biologists (K. Williams, U.S. Geological Survey, personal communication). However, remote methods seem to have limited applicability, particularly with respect to classification.

Minimum aerial counts are the most commonly used trend index for mule deer. Minimum counts are frequently converted to estimates of population abundance in 1 of 3 ways:

1. Correcting counts for different likelihoods of observing deer based on habitats.
2. Altering size of sampling units based on habitat (Bartmann et al. 1986, Freddy et al. 2004).
3. Assuming all deer along the aerial transect were seen and estimating the width of the transect using distance sampling methods to correct for varying detection probabilities based on habitat, transect width, or other variables.

(See Abundance and Density section for methods used for distance sampling and sightability models). Uncorrected aerial surveys flown with consistent flight protocols to ensure consistent and near total coverage of sampled areas are converted to deer observed/unit area or deer observed/hour to obtain a population index. Aerial counts for population trend, as contrasted with counts used solely for sex and age composition, usually have much more specific survey protocols, similar to those required for abundance estimators such as sightability models. Despite this, as with sightability models and similar methods, estimates will always be negatively biased because topography and other visual barriers will prevent complete observation of survey units.

Spotlight surveys and ground counts.— Spotlight surveys and ground counts are similar, with spotlight surveys representing a special case of ground surveys. Spotlight surveys are conducted at night when deer may be less reluctant to use open habitats or areas adjacent to roads (Harwell et al. 1979, Uno et al. 2006). Both spotlight surveys and ground counts are used to collect minimum count and herd composition data. Typically, routes are standardized, replicated, and usually conducted from motor vehicles (especially for spotlight surveys); ground counts may be conducted on foot or from horseback as well. Surveys can be based on continuous observation along a route or restricted to observation points. Distance sampling methods, including stratification by habitats, are occasionally used to extrapolate minimum counts to abundance estimates.

Advantages

- Easy to conduct, inexpensive compared to aerial surveys, and can cover large geographic areas.
- Produce F:D ratios similar to those from aerial surveys (Bender et al. 2003).

Disadvantages

- Roads do not occur randomly across the landscape and their location likely biases proximity of deer (e.g., may be along a riparian area).
- Buck age structure and sex ratio data likely biased because of poorer sighting conditions and behavior of bucks as compared to helicopter surveys.
- Detection probabilities vary with habitat conditions, weather, observers, disturbance, etc.
- Amount of traffic along trails or roads can affect proximity of deer.
- Sample sizes usually low compared to aerial surveys.

- Low light capability of optics influences results.
- May generate disturbance to adjacent human residents and frequent reports of illegal hunting.

Assumptions

- Sample is representative of the population.
- Index reflects changes in population size rather than changes in deer distribution or detectability.
- Roadsides or trailsides representative of area in general or non-changing over time, or surveys stratified by habitat.
- Deer are equally observable every time the survey is conducted (e.g., vegetation screening between seasons or years is not variable).
- Methods consistent among years and groups counted without error.
- Sex and age classes correctly identified and have similar detectability.
- Observers are equally skilled.
- Extrapolation to population size or density requires further assumptions outlined under distance sampling and sightability models in the Abundance and Density section.

Techniques

Methods used include horseback counts, hiking counts, and counts from motorized vehicles. Ground counts can involve riding, driving, or hiking along a route or between observation points. Surveyors move along a standard route, traveling from one location to another that provides a good vantage point for searching for deer. If using specific observation points, after spending a specified amount of time at an observation point, the observer moves farther along the survey route until the next observation point is reached. Survey data can be interpreted as minimum numbers counted, numbers observed/mile, or used as inputs into distance sampling models to estimate abundance.

Spotlight surveys are usually conducted in habitats that are representative of the unit or area being surveyed. They are conducted shortly after dark, when deer are active and may be less reluctant to use areas close to roads. A driver navigates a vehicle along a permanently established route, while an observer (or 2) shines a spotlight along the side of the route and records all deer seen and classifies deer by sex and age class. Typically, number of deer seen/mile of route serves as an index to deer abundance and sex and age composition provides trend information on population demographics. Data are occasionally used as inputs in distance sampling models. However, managers should recognize deer distribution is likely not independent of roads and a rigorous sampling approach is necessary.

For both ground and spotlight surveys, routes are usually repeated several times each year to account for variability in survey conditions and reduce the chance of an unusually high or low count being used to index population trend. Occasionally, the highest total among replicated surveys is used to index the population as it reflects the minimum number of individuals known to be present.

Harvest per unit effort (HPUE).— Harvest per unit effort scales total harvest by some estimate of hunter effort, most commonly number of hunters or number of hunter-days (i.e., the total number of days hunters actually spent hunting). As the estimate of effort becomes more refined (hunter-days instead of hunters), the trend estimate is considered more sensitive to changes in abundance.

Advantages
- Relatively easy and inexpensive to collect effort data through harvest surveys.
- Presumably more accurate than harvest uncorrected for effort.
- Strong empirical background in fisheries management.

Disadvantages
- Subject to response distortion biases present in social surveys.
- Vulnerable to changes in hunter behavior.
- Influenced by changes in deer vulnerability (e.g., weather conditions, road closures, hunter access, antler restrictions, allocation among weapon types, rutting behavior of bucks, etc.).
- High hunter densities may cause interference in harvest rate and bias HPUE estimates.
- Low hunter densities, limited-entry harvest strategies, and mature-buck management strategies can result in significant hunter selectivity and thus decouple any relationship between HPUE and deer density.

Assumptions
- Harvest and effort data are accurate and unbiased.
- Population closed during hunting season except for harvest removals.
- Probability of harvest constant during the season (can be corrected for differential vulnerability among areas).
- Harvest is proportional to population size.
- Effort measure is constant (i.e., hunters equally skilled).

Techniques
Harvest and effort data are most commonly collected from hunter surveys or check stations. The HPUE index, such as 0.05 deer harvested/hunter-day, is often used as a stand-alone trend index to compare changes within a management unit, and is considered to be more reflective of actual changes in population abundance than harvest alone because of the accounting for hunter effort (Roseberry and Woolf 1991). However, HPUE does not account for variation in harvest rates due to effects of weather or other factors that could impact harvest. Hence, running averages across multiple years are often used to reduce effects of annual variation in these factors. Comparisons among management units differing significantly in habitat is a problem, because HPUE reflects both abundance and vulnerability of deer, and vulnerability can change significantly with the amount of security cover. Roseberry and Woolf (1991) found some HPUE models to be very useful for monitoring white-tailed deer (*O. virginianus*) population trends based on harvest data.

Total harvest.— The simplest trend index is an estimate of total harvest. This index assumes encounters between hunters and deer, and thus harvest, increase as deer abundance increases and decline as abundance declines.

Advantages

- Data easily and frequently collected, primarily from surveys of hunter effort and harvest.

Disadvantages

- Annual variation in harvest estimates can be extremely high and thus provides limited inference for population trend.
- Vulnerability to harvest changes with changes in hunter behavior (e.g., regulation changes, equipment changes, etc.).
- Vulnerability to harvest changes with environmental conditions (e.g., weather conditions, changes in access, habitat changes, etc.).
- Harvest rate varies with hunter and deer density.
- Many potential sources of bias (response distortion) in hunter questionnaires, which are frequently not accounted for.
- Often estimated without variance, thus providing no basis for statistical inference.
- Often of poor or unknown accuracy.
- Generally more effective with very intensive buck harvest strategies such as open-entry seasons.

Assumptions

- Harvest data are accurate.
- Harvest is proportional to population size.
- There is no response or non-response bias if collected through hunter questionnaires.
- Harvest rate (proportion of population harvested) is constant among areas or time periods being compared.
- Population is closed during hunting season except for known harvest removals (e.g., no in-season migratory movements).

Techniques

Harvest data are most often collected via hunter surveys or, less commonly, hunter check stations (see Harvest estimation). If season length and other harvest regulations are the same among seasons, then total harvest alone is often used as a trend index within management units. Because of the substantial influence of habitat on deer vulnerability, total harvest should not be used as an index among dissimilar management units. As limitations on harvest increase relative to deer abundance (e.g., reducing hunter numbers through limited entry), value of harvest as an index declines (Fig. 1). Thus, because female harvest is often more limited, harvest indices are generally based on buck harvest. If season lengths vary, harvest may be modified to harvest/day or daily harvest modeled as a function of season length or numbers previously harvested, with the latter used to estimate population abundance (Davis and Winstead 1980, Lancia et al. 2005). Age-at-harvest data are used in many population reconstruction models (Williams et al. 2001, Gove et al. 2002, Skalski et al. 2005).

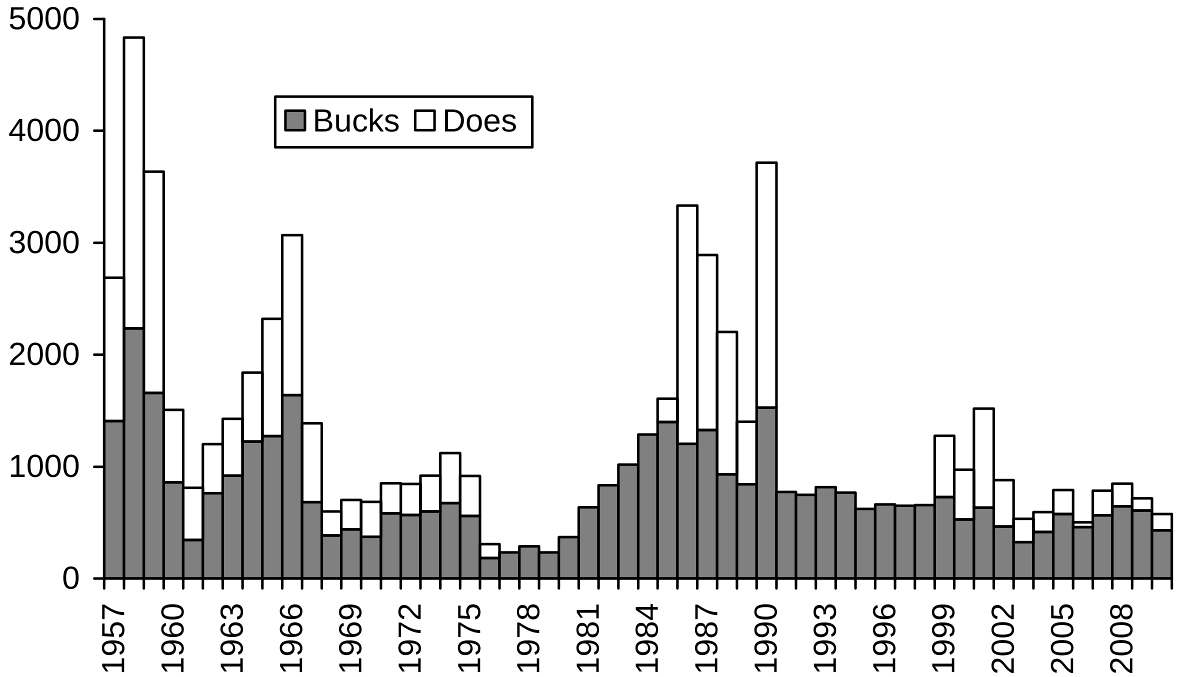

Figure 1. Estimated mule deer harvest, Kaibab Plateau, Arizona, 1957-2010. Limited-entry buck harvest since 1971 and erratic doe harvest severely limit the value of harvest as a population trend index for this area. Figure courtesy of Arizona Game and Fish Department (AGFD).

Track surveys.— Track surveys involve counting numbers of individual tracks or track sets that cross a road or trail, usually with direction of movement limited to 1 way to reduce double counting (McCaffery 1976). Surveys are usually conducted following clearing of roads or trails of old track sets by dragging or following snowfall that covers previous tracks. Data are used most commonly as a relative index or minimum count, but can be used to calculate densities (Overton 1969).

Advantages

- Simple to conduct, relatively inexpensive, and cover a large geographic area.
- May be used for preliminary sampling to implement a more robust method.

Disadvantages

- Limited rigorous validation.
- Difficulty in distinguishing among individuals or species if several ungulate species are present.
- Dependent on activity levels and movement patterns.
- Very dependent upon proper weather or substrate conditions for accurate counts.
- Multiple counts of the same individuals very likely.

- Mild weather conditions that minimize use of winter ranges in some years may result in unreliable data.
- Number of individuals may be indiscernible when deer travel in groups.

Assumptions
- Methods consistent among years and groups counted without error.
- Index reflects changes in population size rather than changes in deer distribution or activity levels.
- Extrapolation to population density requires further assumptions (Overton 1969).

Techniques
Tracks are most commonly counted along dirt or sand roads, which are dragged before counting, or during deer migrations, usually when leaving winter ranges. In the former, roads are dragged to obliterate any tracks that are present; then routes are revisited after some time period (often 1 week, assuming no disturbance to survey substrate, e.g., rain that washes away tracks, etc.) and number of track sets counted. The index is usually presented as number of track sets/mile if collected over the same amount of time annually, but can be converted into density by making several assumptions about deer movement patterns (Overton 1969).

For winter range counts, survey routes are established so they run essentially perpendicular to travel routes between winter and spring ranges. These survey routes are then counted periodically after the start of migration to spring ranges (WGFD 1982). Only deer tracks moving away from winter ranges are counted, with counts run after fresh snowfall or after dragging routes to clear existing tracks. The index in this case is usually presented as the minimum number of individuals counted or number of tracks/mile if routes are run for the same time period each year (usually the entire migration period).

Pellet counts.— Pellet group surveys involve counting the number of fecal pellet groups encountered in plots or belt transects. Mean number of groups can be used as a trend index or is occasionally converted to estimates of population size by integrating defecation rates and number of days indexed (Marques et al. 2001). Pellet group counts for population trend are most frequently conducted on winter ranges. Because habitats are not uniform and pellet group distribution depends on relative habitat use, pellet group transects are most often stratified among vegetation types (Neff 1968, Härkönen and Heikkilä 1999). For greatest accuracy, permanent transects that are cleared of old pellet groups after each survey should be used to eliminate confusion in aging pellet groups.

Advantages
- Easy to conduct, little equipment needed, can cover a large geographic area.
- Have been correlated with other trend indices including aerial counts and hunter observations (Härkönen and Heikkilä 1999).
- Can provide data on relative use of habitats (Leopold et al. 1984).

Disadvantages

- Power to detect trends frequently low, particularly for low density populations.
- Size and shape of plots (e.g., belt transects vs. circular plots) and sampling effort strongly affect results (Härkönen and Heikkilä 1999).
- Bias associated with inclusion or exclusion of groups lying along plot boundaries.
- Difficult to distinguish species in the field if several species of ungulate are present.
- More appropriate for areas of seasonal concentration such as winter ranges.
- Degradation of pellets varies in different environmental conditions and with populations of scavengers such as dung beetles.
- For abundance estimation, there is little validation of most commonly used daily defecation rates which undoubtedly vary with season, diet, etc.
- Labor intensive to conduct over large area.
- Potential for observer bias in aging pellet groups if transects not cleared after each counting.

Assumptions

- Methods consistent among years and groups counted without error.
- Index reflects changes in population size rather than changes in deer distribution, activity levels, or behavior.
- Extrapolation to population abundance requires further assumptions including 1) constant defecation rates, 2) exact knowledge of time of use in days, and 3) population density uniform throughout range.

Techniques

This method involves clearing permanent plots or belt transects of accumulated pellet groups and returning after a specified time period to count the number of new pellet groups. Number of pellet groups/unit area or transect serves as the index to abundance. Pellet group surveys are often used on winter ranges at the end of winter. Pellet group counts are commonly converted to densities by dividing by number of times a deer defecates/day and number of days plots were exposed. For example, if you assume a deer defecates 10 times/day and after 10 days you find 700 pellet groups/acre, it is assumed 7 deer were present (7 deer × 10 days × 10 pellet groups/day/deer) (Neff 1968, Härkönen and Heikkilä 1999). Although used as a trend index or abundance estimator, pellet group counts are usually more valuable in determining relative habitat use patterns (Neff 1968, Leopold et al. 1984, Härkönen and Heikkilä 1999).

Pellet group data are inherently non-normal in distribution, so more complex analysis techniques are useful in teasing out inferences. The negative binomial distribution (Bowden et al. 1969, White and Eberhardt 1980) is particularly useful for examining pellet group data.

Hunter observation surveys.— Hunter observation indices involve having hunters record the number, and occasionally sex and age classes, of deer seen during hunts. Because hunter numbers and effort can be extremely large and are confined to a relatively narrow time frame, numbers of animals seen and herd composition samples collected by hunters can be large and have been correlated with other independent estimates of population size, trend, and composition (Ericsson and Wallin 1999).

Advantages

- Tremendous number of person-days of effort with little cost to agencies.
- Extremely large sample sizes in some cases.
- Have been correlated with other trend indices and with aerial survey data (for other species).
- Provides hunting public with a sense of "ownership" of population data.
- Provides a method requiring little agency time to corroborate other trend indices.

Disadvantages

- Sensitive to response distortion biases of hunters.
- Untrained observers may not count or classify deer accurately
- Independence of observations unknown (but can be accounted for if double counts are assumed when constructing confidence intervals around ratio estimates).
- Detection of target species varies among habitats and thus changes in distribution may be confused with changes in population size unless stratified by habitat.
- Relationships between abundance and observation index vary among areas.
- Precision of estimates low or undefined.

Assumptions

- Numbers of deer observed and recorded without bias.
- Sex and age classification correctly identified and reported.
- Number of hunter-days is consistent or observations are standardized per hunter-day.
- Hunters equally skilled in detecting deer (for abundance trend only).

Techniques

Hunters are provided data forms and asked to record numbers and sex and age classes of deer seen during their hunts and number of days (or similar measure of effort) hunted. Data are usually converted to a standard measure of effort such as deer seen/hunter-day for the trend index (Ericsson and Wallin 1999). Data for deer seen/hunter-day are usually compared within an area between years to estimate annual rate of change in population size. Because ability to detect (observe) deer varies among habitats, this index (as well as all other direct indices) should not be used to compare management units differing in habitats. Although infrequently used for mule deer, estimates of annual population change and calf:cow ratios obtained from this method have been shown to be similar to aerial survey counts for moose (*Alces alces*, Ericsson and Wallin 1999). These data are much less expensive to collect, suggesting this method may provide a useable index for mule deer management with further development of the technique.

Abundance and Density

Estimates of abundance or density (i.e., abundance per unit area) over broad geographical areas are often desired to empirically manage mule deer populations. Because mule deer are widespread and often inconspicuous, total counts have proven to be impractical, even when localized and in fairly open habitats. As a result, statistically-based sampling methods offer the only realistic way to estimate mule deer numbers on the scale of most management units. Cover and terrain often make deer inconspicuous; therefore, methods used to estimate abundance must account for incomplete detectability of deer in the sampling areas. Based on studies with radiomarked deer and counts of known numbers of deer in large enclosures, detectability is often considerably less than 100% even when the census effort is very intensive (McCullough 1979, Bartmann et al. 1986, Beringer et al. 1998). To help address problems related to widespread distribution and incomplete detectability, abundance and density estimates are usually made during winter when mule deer are more concentrated and more visible against snow cover. Estimates of mule deer abundance and density are further complicated because numbers are dynamic and populations are seldom geographically discrete. Deer are born, die, immigrate, emigrate, and frequently move back and forth across management unit or sampling frame boundaries. Methods for estimating abundance and density must take into account whether the population of interest is assumed to be geographically and demographically closed or open during the sampling period.

Population modeling offers an alternative to sample-based population estimation by using demographic parameters such as harvest mortality, sex and age ratios, and survival estimates to predict population numbers. Unfortunately, the public can sometimes be highly skeptical of credible model-based population estimates that do not conform to their perceptions because actual deer are not being counted (Freddy et al. 2004).

Sample-based Methods

Distance sampling.— Distance sampling can be used to estimate number of deer within a fixed distance away from a line or from a point based on distribution of decreasing detection probabilities as distance increases (i.e., deer farther away are harder to see) (Buckland et al. 2001, 2004; Thomas et al. 2010). Distribution of detection probabilities can be estimated based on the assumptions that 1) all deer on the line of travel will be detected or accurately estimated, 2) detection will decrease as distance from the line increases, and 3) deer distribution is independent of sampling design. Population size can be extrapolated from numbers of deer in a sample of line transects or plots that can be stratified by deer density or habitat. Distance sampling for ungulates is usually done along transects from a fixed-wing airplane or helicopter and has been used primarily for species such as pronghorn (*Antilocapra americana*) that occur in relatively flat, open habitats (Johnson et al. 1991, Guenzel 1997, Whittaker et al. 2003, Lukacs 2009). A similar method has been evaluated for mule deer in pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) habitat in a large enclosure with relatively small bias found (White et al. 1989). Use of distance sampling for roadside surveys or spotlight surveys is not recommended because the assumption that deer distribution is independent of transect location is unlikely to be valid when roads are used as transects. Violating the assumption of independent distribution can result in highly biased estimates.

Advantages

- Robust method with relatively few constraining assumptions compared to other methods.

- Provides a probabilistic estimate that accounts for detectability and does not require marked deer if all deer on the line of travel are assumed to be 100% detectable.
- Can be relatively inexpensive if used in fairly open and flat areas where use of fixed-wing aircraft is practical.
- Relatively easy to design and conduct using geographic information system (GIS) software and global positioning system (GPS) units.
- Can be applied to ground mortality transects as well as aerial population surveys.

Disadvantages
- Only realistic in open areas with little terrain relief where deer close to the line of travel are almost 100% detectable. For mule deer, this method would probably be limited to habitats such as upland plains, open agricultural areas, or perhaps some sagebrush (*Artemisia tridentata*)-steppe winter ranges. Even in these habitats, a helicopter would often be required as the sighting platform to achieve acceptable detectability.
- Confidence intervals can be wide (e.g., 95% CI > ±25%) when there is high variability in deer densities between transects within a stratum.
- Dependent on assigning individual deer or clusters of deer to the correct distance interval or accurately determining distance from the line of travel. This can sometimes be problematic, especially with high deer densities.
- Observer fatigue can become an issue during prolonged surveys.
- Can be relatively expensive if a helicopter is used.

Assumptions
- All deer on the line of travel are detected or accurately estimated.
- Distances are accurately measured or deer are recorded in the correct distance band.
- Detection probability decreases as distance from the line of travel increases.
- Deer distribution is not related to transect distribution.
- All deer within a detected group are accurately counted (if group or cluster is the sampling unit). If the individual is the sampling unit, this assumption no longer applies.
- Deer are detected in their original position before any movement related to the survey effort. Deer are not recounted during the survey.

Techniques
Aerial distance sampling for ungulates usually involves
1. Establishing a set of lines of known length across the area of interest that delineate centerlines of a set of fixed-width transects.
2. Flying along each line while maintaining height above ground level (AGL) as constant as possible (with fixed-wing aircraft the flight path may be offset from the line to compensate for the blind spot directly below the aircraft).
3. Accurately assigning individual deer or clusters of deer to fixed-width bands that delineate specific distance intervals away from and perpendicular to the line of travel.

Transects are usually parallel and systematically spaced across the area of interest with a random starting point. Stratification based on deer density or habitat can be used to help reduce variance. As an alternative to 2 and 3 above, actual distances of deer or clusters perpendicular to the line can be determined using a laser range finder and the sighting angle. However, for species such as mule deer that often occur in numerous, small groups, use of distance intervals rather than actual distances is a much more practical method (Guenzel 1997). Fortunately, little bias usually results from assigning deer to distance intervals as opposed to measuring actual distances (Thomas et al. 2010). Distance intervals can be delineated using strut markers (fixed-wing aircraft) or window markers (helicopters) that have been calibrated for a specific AGL (e.g., usually between 75-300 ft [25-100 m] depending on aircraft type, cover, and terrain) to demarcate distance intervals perpendicular to the line of travel using a specific eye position (Guenzel 1997). The AGL can be accurately measured using a digital radar altimeter or a laser rangefinder mounted on the belly of the aircraft. For each observation, AGL should be automatically saved to a computer to allow distance measurements to be corrected, if necessary, for actual AGL. Effective transect width (i.e., truncation limits) and width of distance intervals depend on predicted detectability (i.e., narrower widths are used as detectability decreases). Four or 5 distance intervals are typically used to estimate an adequate detection function.

Program DISTANCE was specifically designed to estimate population size from distance sampling data (Thomas et al. 2010). This software

1. Models detection probabilities as a function of distance from the line of travel when 100% detectability is assumed on the line of travel.
2. Allows covariates (e.g., cluster size, habitat, weather conditions, etc.) to be considered in the distance model.
3. Allows mark-recapture data to be incorporated when detection is <100% on the line of travel.

When detection on the line of travel is not certain, simultaneous double counts using 2 independent observers or a sample of radiomarked deer can be used to correct for incomplete detectability (e.g., Kissling et al. 2006). See mark-resight and mark-recapture for more discussion on simultaneous double counting methods. Cluster size bias can occur using distance sampling because, as distance from the line increases, deer in large groups (i.e., clusters) are more easily detected than individual deer or small clusters. Program DISTANCE can correct for cluster bias using regression methods based on the number of deer counted in each cluster relative to their distance from the line.

Strip-transect sampling.— In areas where cover and terrain make distance sampling infeasible, fixed-width (strip) transect sampling can still be used to obtain a minimum count that can be adjusted using generic or survey-specific detection rates based on detectability of marked deer. Population size can then be extrapolated from the sample of strip transects corrected for detection rates. Helicopter line transects have been evaluated for mule deer and white-tailed deer with satisfactory results (White et al. 1989, Beringer et al. 1998). However, Freddy (1991) compared quadrat sampling to transect sampling for mule deer in sagebrush habitat and reported estimates >200% larger when transects and detection probabilities were used compared to quadrat sampling with a generic sightability correction, leaving doubt as to which method was more biased.

Advantages

- Allows transect sampling to be used in some situations where distance sampling is not feasible because of low detectability or terrain.
- Transect sampling designs are relatively easy to lay out with GIS and are easy to fly with GPS units.
- Provides a probabilistic estimate of the number of detectable deer that can be adjusted using detection probabilities.
- Usually does not require handling and marking of deer.

Disadvantages

- Detection probabilities often must be determined using a sample of radiomarked deer which can substantially add to costs. Depending on diversity of habitats being sampled, different detection probabilities may be required for different strata, transects, and even within individual transects.
- Relatively expensive because an aircraft is required and considerable flying may be needed depending on size of the sampling frame, deer distribution, cover, and desired precision. In areas with substantial cover and terrain, transect widths must be reduced.

Assumptions

- Transect width can accurately be determined and deer can be correctly identified as being in or out of the transect.
- Deer do not move out of a transect before detection and they are not recounted in subsequent transects.
- Detection rate estimates are unbiased and accurately represent actual detection rates. Marked deer have the same probability of being sighted as unmarked deer.

Techniques

Transect counts for mule deer are usually flown using a helicopter. Transect width can be delineated by tape on the windows that has been calibrated for a specific AGL. Unlike distance sampling, there is no need to demarcate distance intervals. Similar to distance sampling, sample transects usually run parallel, are evenly spaced across the area to be surveyed, and have a random starting point. Stratification based on deer density or habitat can be used to help reduce variance. Habitat should be fairly homogenous within each stratum to minimize the number of unique detection probabilities required.

Plot sampling using quadrats.— Quadrat sampling is similar to transect sampling except population size is extrapolated from a sample of randomly selected polygons that are often square and, prior to GPS technology, usually laid out using cadastral coordinates (e.g., section lines). Small (i.e., usually ≤1 mi^2 [2.6 km^2]), intensively surveyed quadrats are used as sampling units in an attempt to improve detectability. Quadrats are usually stratified based on habitat or prior deer density information. Sampling designs can include random, random spatially balanced, and hybrid census and sampling combinations. Quadrat sampling methods for mule deer were described by Kufeld et al. (1980) and Bartmann et al. (1986).

Advantages

- Provides a probabilistic estimate of number of detectable deer.
- Fairly straightforward design that can be laid out with GIS (prior knowledge of deer distribution is very helpful) and flown using GPS.
- Does not require handling and marking of deer.

Disadvantages

- Relatively expensive because a helicopter is usually required and considerable flying may be needed depending on size of the sampling frame, deer distribution, and desired precision.
- Confidence intervals can be wide (e.g., 95% CI > ±25%) irrespective of sample size, especially when deer occur in an unpredictable or clumped distribution.
- Does not include an inherent detectability correction, so actual population size is unknown. Generic sightability factors can be used to adjust the population estimate, but they can be of questionable value because a number of variables can influence sightability (e.g., group size, cover, terrain, snow cover, time of day).
- When deer densities are high, it can be difficult to keep track of deer that have already been counted.
- Deer may move out of a quadrat in response to the aircraft before they are counted.

Assumptions

- Each quadrat within a stratum that may contain deer has a known (often equal) probability of being selected for sampling.
- Deer are detected at a fairly high rate (e.g., >60%), are not double counted, are not erroneously accounted for by being forced into or out of a quadrat, and are accurately identified as being in or out of a quadrat when close to the perimeter.
- Generic sightability factors accurately represent actual detection probabilities.

Techniques

Quadrat methods often use sampling polygons with small areas (0.25-1 mi^2 [0.65-2.6 km^2]) to increase detection rates. Smaller quadrats are used in areas with considerable cover such as pinyon-juniper woodlands, whereas larger quadrats can be used in more open areas such as sagebrush-steppe. Using similar-sized quadrats tends to decrease among-quadrat variation, but is not required. In the past, sampling designs were usually based on cadastral section lines, but GIS and GPS units have greatly increased design flexibility. Use of GPS units has also made quadrat sampling much more practical because quadrats can be accurately flown without landmarks. Stratification can be useful for increasing precision and for optimally allocating sampling effort based on expected deer density. When there is sufficient prior knowledge of deer distribution, stratification can most effectively be achieved on a quadrat by quadrat basis rather than by geographical area.

Quadrat methods for estimating mule deer numbers can require considerable helicopter time (e.g., 20-40 hours is typical for management units in western CO, Kufeld et al. 1980). Extensive amounts of flying can cause observer fatigue and result in prolonged surveys because of weather and conflicting work assignments. Use of multiple helicopters and crews is recommended to finish counts in a timely manner under preferred conditions when snow cover is present. Quadrats should be flown by first following the perimeter to identify deer close to the boundary as being in or out. The interior of the quadrat should then be flown with sufficient intensity to count all detectable deer.

Even though the quadrat method attempts to maximize detectability compared to sampling using transects or larger area units, unknown detectability remains an obvious issue. Survey-specific detection probabilities could be determined by including a sample of radiomarked deer or using sightability covariates (see area sampling using sightability models), but the small size of the quadrats and high cost of the quadrat method make this impractical in many cases. In lieu of specific detection probabilities, generic sightability factors developed using radiocollared deer in similar habitats have been used to adjust quadrat population estimates. In Colorado, a sightability factor of 0.67 is typically used for quadrats in pinyon-juniper winter range and 0.75 is used for sagebrush-steppe (Bartmann et al. 1986; Colorado Division of Wildlife [CDOW], unpublished data). For generic sightability factors to be applicable, quadrats should be flown with as many variables as possible similar to those that occurred when sightability factors were developed (e.g., high percentage of snow cover, same number of observers, quadrats with the same area, etc.). However, even when effort is made to keep survey protocols as consistent as possible, the validity of using generic sightability factors can be questionable because of the number of variables that can affect detectability (e.g., group size, deer activity, time of day, cloud cover, type of helicopter, experience of observers, etc.).

Plot sampling using sightability models.— This method is similar to quadrat sampling except that 1) it includes a model developed using logistic regression methods to account for undetected deer based on a variety of sightability covariates, 2) size of sampling units can be considerably larger than those typically used for quadrat sampling, and 3) sample unit boundaries can be based on terrain features such as drainages instead of cadastral units or GPS coordinates (Ackerman 1988, Samuel et al. 1987, Freddy et al. 2004). A sightability model is developed for a specific survey intensity (i.e., survey time at a given elevation and airspeed per sampling unit area) by relating detectability of radiomarked deer to variables such as habitat, group size, deer activity, screening cover, terrain, snow cover, type of helicopter, and observer experience. Sightability models account for a more comprehensive set of detectability variables than generic sightability factors often used with intense quadrat sampling and allow the contribution that each variable makes to detectability to be evaluated using a stepwise approach. Once the sightability model is developed for a specific survey intensity, covariates supplant the need for determining detection probabilities using radiocollared deer. Even when survey intensity is kept relatively constant, sampling units should be similar in size to help eliminate variables such as increased observer fatigue when larger units are surveyed. Population size can be extrapolated from a set of representative sampling units.

Advantages

- Provides a probabilistic population estimate that includes a sightability correction.
- Once established, sightability covariates are easier and less expensive to measure than detection probabilities.
- Larger sampling units can be flown than with quadrat sampling as long as the sightability model was developed using sampling units similar in size to those being flown and sampling intensity is consistent.
- Larger sampling units are usually less affected by some potential sources of error than small quadrats (e.g., pushing deer out of the sample unit before they are detected, determining whether a deer is in or out of the sample unit, double counting the same deer when densities are high).
- Stratified random sampling of sample units produces precise estimates for lowest costs.

Disadvantages

- High initial costs to develop sightability models. Radiomarked deer must be used to develop different sightability functions for a wide variety of habitats and conditions.
- Relatively high ongoing costs due to extensive helicopter time required to conduct surveys on a management unit basis.
- A sightability model only applies to the specific conditions for which it was developed. Transferability of sightability models to habitats, survey intensities, and conditions different than those used to develop the models is not recommended and could result in highly biased results.
- Variance is likely to increase as detectability decreases.
- Population size can be underestimated if all deer in detected groups are not accurately counted (Cogan and Diefenbach 1998).
- Sampling units based on geographical features such as drainages may not be random, but drawing sampling units under stratified random sampling produces unbiased estimates.

Assumptions

- Probability of detecting deer is >0 and detectability can accurately be predicted using sightability covariates under a variety of circumstances (i.e., model captures all significant variation in sighting probabilities where it will be used).
- Sampling units are representative of the overall sampling frame and those sampling units are analogous to randomly distributed units.
- Deer in detected groups are accurately counted.

Techniques

Unlike quadrat methods that rely on small sampling units to increase sightability, use of sightability covariates allows sampling units to be larger and less intensively flown as long as applicable models have been developed. Sampling units are often defined based on geographical features such as drainages instead of constant-sized quadrats. Similar to quadrat and transect methods, precision of population estimates using sightability models can often be increased by stratifying the sample area by habitat and deer density. Ideally, sampling units should be selected at random or spatially balanced. However, when terrain features such as drainages are to be used as sample units, sample units should be selected to be as representative as possible of each stratum. Population size can be extrapolated from a set of representative sampling units. Sampling units may be stratified according to deer density, thereby reducing variability of a population estimate. All deer in detected groups must be accurately counted to avoid underestimating population size (Cogan and Diefenbach 1998). Sightability survey techniques were described in detail by Unsworth et al. (1994, 1999*a*).

Mark-resight and mark-recapture.— Mark-recapture methods use the ratio of marked (i.e., identifiable) to unmarked deer in population samples to estimate population size (Thompson et al. 1998). The population of interest must be defined in time and space and identified as being geographically and demographically closed or open. Basic mark-recapture models include the Petersen or Lincoln Index (Caughley 1977) for closed populations and the Jolly-Seber Model (Jolly 1965, Seber 1982) for open populations. These basic models have limited practical value because the assumptions required are usually violated when applied to field situations. To address the need for more practical assumptions, a variety of more complex and flexible mark-recapture models have been developed that often require computer-assisted solutions (i.e., no closed form estimator is available). The programs MARK and NOREMARK have been specifically developed for this purpose (White 1996, White and Burnham 1999).

More traditional mark-recapture methods are usually based on sampling without replacement whereby the method of recapture (i.e., being caught in a trap) effectively prevents an individual from being counted more than once per sampling occasion. Although these methods can be very useful for small, inconspicuous, or furtive species, actual recapture is seldom feasible or desirable for more conspicuous large mammals such as deer. As a result, mark-recapture methods that use resighting, with or without replacement, instead of recapture have been developed for more conspicuous species. These mark-resight methods allow relatively non-invasive monitoring instead of actual recapture and subsequent marking of unmarked deer, thereby reducing stress on the deer and costs.

Mark-resight methods have been used to effectively estimate localized mule deer numbers (Bartmann et al. 1987, Wolfe et al. 2004) and newer mark-resight models that incorporate maximum likelihood have improved this method and its potential application to mule deer (McClintock et al. 2009*a*, *b*). Unfortunately, mark-resight methods may not be practical for estimating deer abundance on a large scale (e.g., management unit) because of the cost and time required to mark adequate numbers of deer and conduct resighting surveys. As an alternative, quasi mark-resight approaches have been developed that use mark-resight data to calculate correction factors (i.e., detection probabilities) for incomplete counts (Bartmann et al. 1986, Mackie et al. 1998) or that use simultaneous double-counting to obviate the need for marking deer (Magnusson et al. 1978, Potvin and Breton 2005).

Advantages

- Usually considered one of the most reliable methods for estimating abundance of wildlife populations when sample sizes are adequate and assumptions are not critically violated.
- Unlike most other sampling methods, mark-resight methods explicitly account for detectability (even deer with essentially no detectability).
- Multiple resighting surveys (aerial or ground) can be done over time to increase precision and allow modeling of individual heterogeneity in detection probabilities among individual deer (Bowden et al. 1984, Bowden and Kufeld 1995, McClintock et al. 2009*a*, *b*).
- Provides a probabilistic estimate of population size and, with some more advanced models, allows some demographic parameters to be estimated.
- Can be applied using a wide variety of distinct marks (e.g., tags, collars, radio transmitters, paint, DNA, radioisotopes, physical characteristics, simultaneous duplicate counts) and resight methods (e.g., motion-triggered infrared cameras, hair snags, pit tag scanners, hunter harvest).

Disadvantages

- Can be expensive and labor intensive to achieve an adequate sample of marked deer, ensure marks are available for resighting, and conduct resighting surveys.
- Usually not practical over a large geographical area with a widely distributed species such as mule deer.
- Although the precision of mark-resight estimates is determined by a variety of factors (e.g., number of marks, detection probabilities, number of resight occasions), confidence intervals can be wide (e.g., 95% CI > ±25% for practical applications.
- Dependent on a variety of assumptions (see below), that if violated, can result in spurious results. Methods with less restrictive assumptions may result in reduced precision and accuracy.
- Marked deer may become conditioned to avoid resighting.
- Some quasi mark-resight methods such as simultaneous double-counts can be much less reliable and inherently biased because of individual deer heterogeneity.

Assumptions (Assumptions vary depending on the estimator being used [White 1996]).
Basic assumptions include

- Population in the area of interest is to a large extent geographically and demographically closed unless gain and loss are equal or can be reliably estimated.
- Each deer in the population has an equal probability of being marked and marks are distributed randomly or systematically throughout the population of interest.
- Number of marks available for resighting in the sampling area is known or can be reliably estimated.
- Each deer in the population, marked or unmarked, has an equal probability of being sighted or individual sighting probabilities (i.e., resighting heterogeneity) can be estimated.
- Marks are retained during the resight sampling period.
- Deer are correctly identified as being marked or unmarked when sighted.

Techniques

Most mark-resight population estimates of wild ungulates use radiomarked animals. Radiomarks have the advantages of allowing confirmation of the number of marked deer available for resighting within the area of interest and identification of individual deer. Radiomarks have some disadvantages however (e.g., deer usually need to be captured to attached radios, equipment is expensive, radios can fail). In lieu of radiomarks, a variety of other marks have been used with mixed success for deer including ear tags, neck bands, a variety of temporary marks (e.g., paint balls, Pauley and Crenshaw 2006), and external features such as antler characteristics (Jacobson et al. 1997). Regardless of the marking method, marked deer should not be more or less visible than unmarked deer (e.g., fluorescent orange neck bands could make marked deer stand out more than unmarked deer). Nor should the marking method influence the resighting probability of marked versus unmarked deer (e.g., deer captured and marked using helicopter netgunning may avoid a helicopter more than unmarked deer during resighting surveys). Marks can be generic or individually identifiable. The latter has the advantage of allowing estimation of individual detection probabilities which can greatly improve some models.

Collection of DNA from scat or hair has become an increasingly popular method for identifying individual animals in mark-recapture studies. Use of DNA has the major advantages that deer do not need to be handled for marking, sampling is non-invasive and relatively easy, and the technique can be applied to situations where sighting surveys are not feasible (e.g., densely vegetated habitats or furtive species). Potential downsides include genotyping errors and variable relationships between the DNA source (e.g., fecal pellets) and the deer. Brinkman et al. (2011) used DNA from fecal pellets to estimate free-ranging Sitka black-tailed deer (*O. h. sitkensis*) abundance using the Huggins closed model in Program MARK.

Model choice should be carefully considered before beginning mark-resight surveys because different models are based on different assumptions. Mark-resight models that have been used over the years include the joint hypergeometric estimator (JHE, Bartmann et al. 1987), Bowden's estimator (Bowden 1993, Bowden and Kufeld 1995), and the beta-binomial estimator (McClintock et al. 2006). Bowden's estimator has been one of the most useful mark-resight models for deer and other wild ungulates. Unlike some other models, Bowden's estimator does not assume all deer have the same sighting probability (i.e., allows for resighting heterogeneity), populations can be sampled with or without replacement (i.e., individual deer can be observed only once or multiple times per survey), and all marks do not need to be individually identifiable. More recently, maximum likelihood estimators have been developed with similar practical assumptions. These estimators include 1) the mixed logit-normal model (McClintock et al. 2009*b*) when sampling is done without replacement and the number of marks is known, and 2) the Poisson-log normal model (McClintock et al. 2009*a*) when sampling is done with replacement or the exact number of marks is unknown. These maximum likelihood methods have the major advantage of allowing information-theoretic model selection based on Akaike's Information Criterion (Burnham and Anderson 1998).

Program NOREMARK was specifically developed to calculate population estimates based on resight data when animals are not being recaptured (White 1996). The program includes the JHE (Bartmann et al. 1987), Minta-Mangel (Minta and Mangel 1989), and Bowden's (Bowden 1993, Bowden and Kufeld 1995) estimators. More recently, the mixed logit-normal (McClintock et al. 2009*b*) and the Poisson-log normal (McClintock et al. 2009*a*) mark-resight models have been included in Program MARK along with a variety of other mark-recapture models (White and Burnham 1999, White et al. 2001, White 2008).

A quasi-mark-resight method that can be more effectively applied on a management unit scale, particularly when deer are fairly detectable, is to correct minimum counts for the resight rate of a sample of marked deer (Bartmann et al. 1986, Mackie et al. 1998). This approach does not use the ratio of marked to unmarked deer to estimate population size per se, but rather the ratio of observed marked deer to total marked deer to adjust sample-based estimates for incomplete detectability similar to methods used for correcting transect and sample area counts discussed previously. Mark-resight adjustment factors can be survey-specific (i.e., based on resight of marked deer during the survey) or generic (i.e., based on previous resight probabilities under similar conditions).

Simultaneous double-counting is another quasi form of mark-resight whereby a population estimate is derived based on the ratio of total number of deer counted (marked deer) to number of duplicated sightings (resighted deer) using independent observers (Magnusson et al. 1978, Potvin and Breton 2005). For ungulates, simultaneous double-counting is usually done from a helicopter or fixed-wing aircraft and can be applied to a wide area because it has the obvious advantage of not requiring marked deer. Two observers in the same or different aircraft independently record the location, time, and group characteristics of all deer observed. For population estimation, this method assumes all deer are potentially detectable and observers are independent. Both assumptions are often questionable and there is inherent bias towards underestimating true population size to an unknown extent, which raises substantial concern about the appropriateness of this approach. In cases where sighting probabilities of deer are low (<0.45, Potvin and Breton 2005) or unknown, simultaneous double-counts are more appropriately interpreted as adjusted minimum counts rather than population estimates. To adjust for the inherent bias of the simultaneous double-count method, the method can be used in combination with a known sample of marked deer or sightability covariates to adjust the estimate for sighting probabilities (Lubow and Ransom 2007).

Thermal imaging and aerial photography.— Thermal imaging and aerial photography frequently appeal to the public as ostensibly practical methods to census wild ungulates. Although these methods have some potential for estimating mule deer numbers under the right conditions, they have often failed to show much advantage over standard counting methods because of highly variable detection rates (Haroldson et al. 2003, Potvin and Breton 2005).

Advantages

- Create a visual record that can be reviewed, analyzed, and archived.
- Do not rely on real time observations that could be in error.

Disadvantages

- Potential inability to 1) detect deer under cover, 2) differentiate deer from the background, and 3) differentiate mule deer from other species.
- Highly variable results that can be influenced by a wide variety of factors.
- Require relatively expensive equipment and flight costs, but often result in little or no benefit over standard counting methods.
- Thermal imaging flights must be conducted within a narrow range of environmental conditions.

Assumptions

- A high percentage of deer can be individually detected and accurately differentiated from other species and inanimate objects

Techniques

Thermal imaging typically uses a wide-angle FLIR system mounted on a helicopter or airplane. Random or systematic transects are most commonly flown, but a variety of sampling designs are possible. The system can make a video record of the flight that can be reviewed and analyzed at a later date. Thermal imaging cannot penetrate dense vegetation and differentiating deer from inanimate objects is sensitive to temperature gradients and heat loading. Night flights when deer are more likely to be in the open and heat loading is minimal are seldom practical from a safety standpoint. Surveys using FLIR are usually relegated to a narrow window of time after daybreak. Species identification can be problematic in areas where there are other large species such as livestock, elk, white-tailed deer, pronghorn, and bighorn sheep (*Ovis* spp.). Although FLIR surveys often assume detection probabilities approaching 1, actual detection rates can be highly variable (Haroldson et al. 2003, Potvin and Breton 2005). Therefore, FLIR surveys can have little advantage over visual counts because both methods usually must be corrected for incomplete detectability.

Population estimation using aerial photography involves making a photographic record of the area of interest from an altitude that does not cause disturbance to the deer. Use of aerial photographs has had little utility for deer because they are relatively small and seldom in areas with little or no cover. An attempt to use aerial photographs in Colorado to quantify elk numbers in open areas during winter was unsuccessful because individual elk could not be reliably identified (CDOW, unpublished data).

Population Modeling

Population modeling can be used to provide biologically realistic, mathematical simulations of mule deer populations based on demographic parameters that can be estimated using routinely collected field data. Modeling allows populations to regularly be estimated at a scale that would seldom be feasible with sample-based population methods. There are 2 basic types of population models: cumulative and point-estimate. Cumulative models use a balance sheet approach of adding (recruitment and immigration) and subtracting (mortality and emigration) deer over time from an initial population, whereas point-estimate models predict population size at a single point in time independent of prior history. Cumulative models can be evaluated using objective model selection criteria based on how closely model predictions align with field observations over time and how many parameters are used. Evaluation of point-estimate models is generally more subjective or requires comparison with sample-based estimates.

Cumulative models allow multiple sources of data to be integrated and considered over many successive years. This can result in a much more data-rich estimate of population size than single-point estimates because all relevant sources of data over time are considered. Because initial population size and the numbers of deer to add and subtract annually are seldom known, cumulative models rely on parameters that are more easily estimated to allow population gain and loss to be calculated. These parameters typically include harvest and wounding loss, post-hunt sex and age ratios, natural survival rates, and, in some cases, immigration and emigration rates. In practice, field estimates of some of these parameters are often not available, and even when they are measured, they often contain sampling error as well as process variance (White and Lubow 2002, Lukacs et al. 2009). Therefore, it is usually necessary to roughly estimate or adjust some parameters to better align model outputs with observed values. Most cumulative population models for mule deer are based primarily on alignment of modeled and observed post-hunt B:D ratios (Fig. 2). Cumulative models work the best when 1) the data set extends over several years, 2) field data are unbiased, and 3) adult male harvest rates are fairly high.

All models are dependent on the quantity and quality of data utilized. As the saying goes, "garbage in is garbage out." The public and some wildlife professionals can often be highly skeptical of modeled population estimates for mule deer (Freddy et al. 2004). Although there can be legitimate reasons for this skepticism, it is too often focused on how models work rather than quality of data going into models, with the latter being a crucial component.

In addition to their use for estimating population size, mule deer population models can also be useful for predicting outcomes of different management actions, evaluating density-dependent effects, and understanding effects of stochastic events on mule deer population dynamics.

Optimally Fitted Cumulative (OFC) population models.— These models objectively align predicted and observed parameter estimates using mathematical algorithms that are often based on an ordinary least-squares estimator (which is a maximum likelihood estimator when a normal distribution is assumed, White and Lubow 2002). Alignment is accomplished by allowing some parameters (e.g., survival rates and initial population size) to be adjusted within biologically realistic constraints to minimize relative deviation between fitted and observed values (i.e., squared differences adjusted for precision of field estimates). Multiple OFC models with various assumptions and parameter sets can be objectively evaluated and compared based on fit and parsimony using Akaike's Information Criterion (AIC, Burnham and Anderson 1998, White and Lubow 2002). Recently, Bayesian methods have been developed to provide probabilistic population estimates using OFC modeling (Lukacs et al. 2009, Johnson et al. 2010).

Although OFC models are primarily based on alignment of modeled and observed post-hunt B:D ratios, sample-based population estimates, minimum counts, and trend data can also be simultaneously used for, or considered in, alignment (Fig. 3). Occasional use of sample-based population estimates for alignment help give greater credibility to OFC models and allow population estimates over time to be considered in a more comprehensive context.

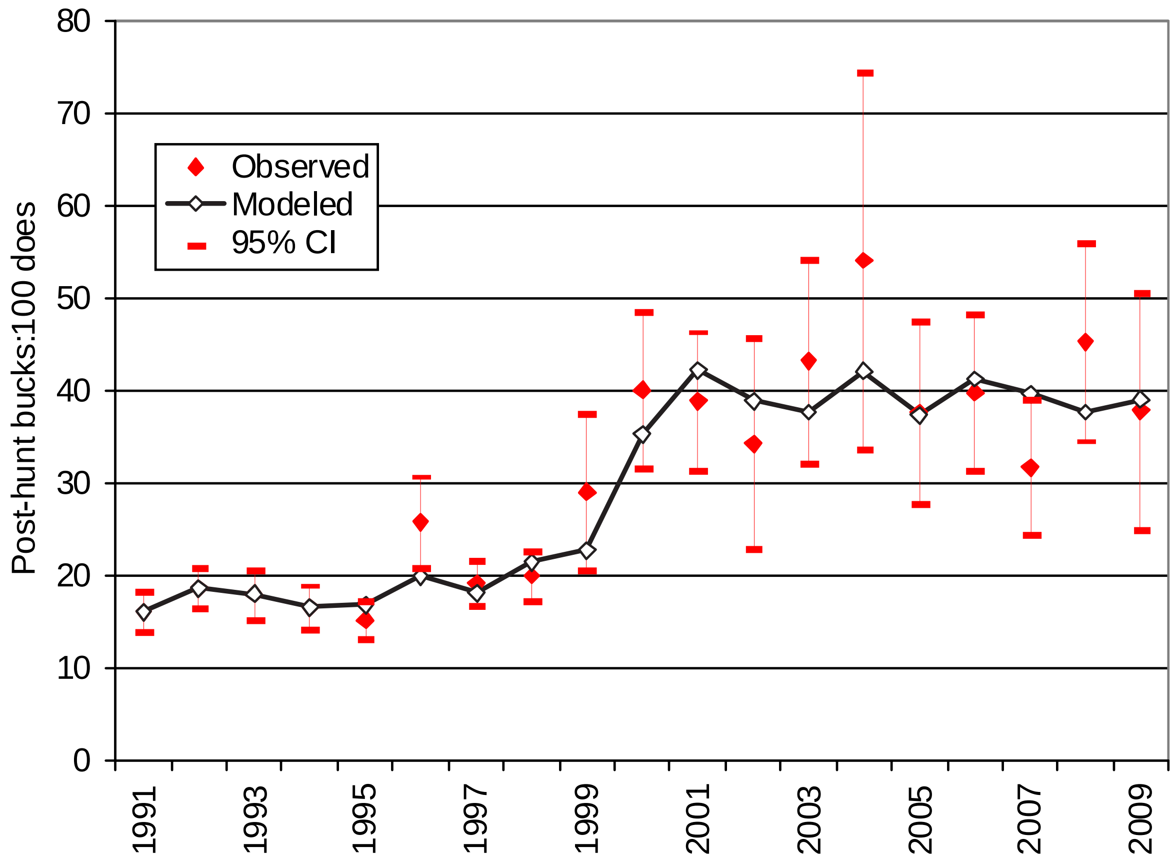

Figure 2. Modeled versus observed (with 95% confidence intervals) post-hunt mule deer B:D ratios using an optimally fitted cumulative population model, DAU D-9, Middle Park, Colorado, 1991-2009. Figure courtesy of CDOW.

At a minimum, OFC models require annual harvest estimates by sex and age (adult or juvenile) and reasonably regular field estimates of post-hunt sex and age ratios. Generic (i.e., determined in representative monitoring areas) or unit-specific field estimates of winter fawn survival rates and annual adult survival rates are also highly recommended (White and Bartmann 1998, Bowden et al. 2000). An example of an optimally fitted, cumulative population model for mule deer was described by White and Lubow (2002).

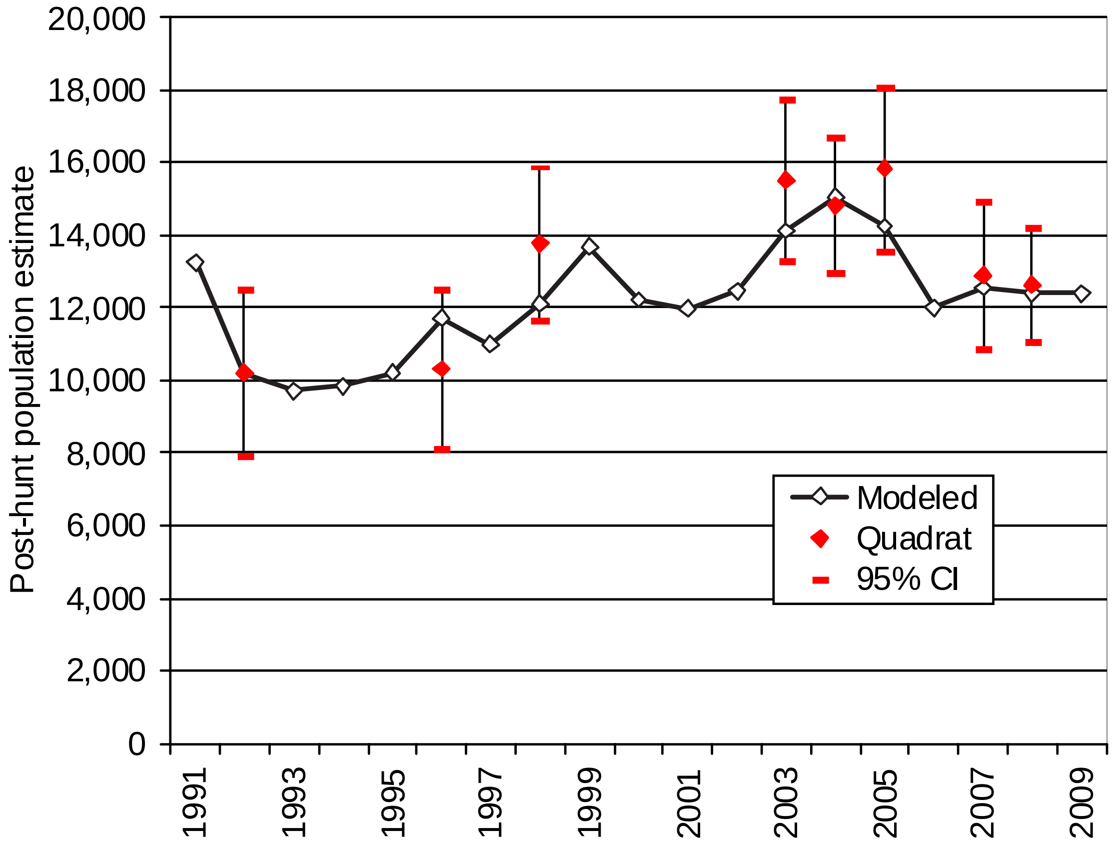

Figure 3. Modeled versus observed mule deer population estimates using an optimally fitted cumulative population model, DAU D-9, Middle Park, Colorado, 1991-2009. Quadrat population estimates were corrected for detectability using a generic sightability factor for sagebrush-steppe winter range. Figure courtesy of CDOW.

Advantages

- Relatively inexpensive compared to sample-based population estimate methods.
- Practical alternative for estimating deer numbers in multiple management units on a regional or statewide basis.
- Highly transparent when spreadsheet-based. All formulas can easily be viewed.
- Can incorporate multiple sources of data over time in a comprehensive context.
- Accounts for precision of field estimates.
- In some cases, Bayesian modeling can be used to obtain probabilistic estimates of population size.
- Not highly dependent on an accurate initial population estimate. Dependence on an initial population estimate decreases as quantity and quality of data in the model increase.
- Very flexible. Additional variables and calculations can easily be added or modified.
- Model solutions are determined using an objective mathematical process rather than by subjective manipulation.

- Allows various model solutions to be evaluated using objective model selection criteria such as AIC.

Disadvantages

- Does not provide a probabilistic estimate of population size unless Bayesian modeling approaches are used (see Techniques below).
- At a minimum, unbiased, relatively accurate harvest estimates and unbiased sex and age ratios are required. Biased data obtained using some common methods (e.g., voluntary hunter harvest reports) would not be appropriate for OFC modeling.
- Credibility of an OFC model is ultimately based on alignment with unbiased, sample-based, population estimates which can make this approach impractical for statewide implementation unless it is assumed that, given adequate, relatively unbiased field data, models can satisfactorily represent population size without corroborating population estimates.
- May lack sufficient data for developing credible models. Data-poor models can have little value except to put harvest estimates into a population context.
- Biologically unrealistic assumptions and constraints can lead to spurious results.
- Users can inadvertently modify formulas in error.

Assumptions

- Parameter estimates are unbiased (or bias can be corrected) and consistently estimated over time (see sections on Harvest, Survival, and Age and Sex Composition for more discussion of potential bias in these parameters).
- To reduce the number of variables, harvest and F:D ratios are usually assumed to be estimated without error. Variance of these estimates can be considered in more complex, data-rich models, however.
- Population being modeled is geographically closed over time or immigration and emigration rates are equal or can be reliably estimated.
- Constraints and constants (e.g., 50:50 fawn sex ratio) are biologically realistic based on available data.

Techniques

Optimally fitted cumulative models can be built and effectively run using spreadsheet software that incorporates an optimization program such as Solver (Frontline Systems, Incline Village, NV, USA). Optimization programs have a target cell, decision variables, and constraints. The optimizer minimizes or maximizes the target cell by iteratively adjusting the decision variables within specified constraints. Optimization of OFC models is accomplished by minimizing a target cell which is the sum of all deviances and penalties in the model. Deviances apply to parameters that are fitted (e.g., B:D ratios) whereas penalties apply to other parameters that might be adjusted (e.g., F:D ratios). Deviances and penalties are calculated relative to the standard error (SE) of each observed value:

$$\text{Deviance or Penalty}_i = [(\text{Observed Value}_i - \text{Modeled Value}_i)/\text{SE of the Observed Value}_i]^2$$

Decision variables in OFC models usually include winter fawn survival rates, annual adult survival rates, and initial population size. While it is also possible to include F:D ratios and harvest estimates as decision variables this can result in excessive complexity and increase the amount of play in the optimal solution. Use of male survival rates as decision variables can be justifiable if there are data indicating differential survival rates between adult males and adult females. However, allowing male survival rates to be adjusted can effectively wash out other variables when aligning sex ratios. Therefore, male survival rates should only be allowed to vary if reliable male survival estimates are available or if they are expressed as a function of adult female survival rates. Performance of OFC models can be improved by removing sampling variation from survival estimates and using process distribution of survival parameters to make more informed adjustments in these decision variables when they have not been measured (Lukacs et al. 2009).

Because population size is treated as a decision variable, OFC models are not highly dependent on entering an accurate estimate of initial population size. However, an optimal solution will be determined much more efficiently if a reasonable initial population estimate is entered. This can be accomplished by determining the relationship between OFC model estimates and buck harvest across management units (data analysis units [DAU] are used for this purpose in Colorado) and years. For example, after all deer hunting became limited in Colorado in 1999, an initial post-hunt population estimate for most DAUs can be approximated by multiplying average buck harvest for the first 3 years of the model by 17.3 (CDOW, unpublished data; Fig. 4). Prior to 1999 when buck licenses were unlimited, an estimate of initial population size can be approximated by multiplying initial buck harvest by 11.4 (CDOW, unpublished data; Fig. 5).

Fit will often improve as additional parameters are added to OFC models or constraints are relaxed. However, the model with the best fit may not provide the best representation of reality. Therefore, evaluation of OFC models should not only take into account goodness of fit between observed and modeled values, but also how many parameters and assumptions are used and biological legitimacy of all parameters, constants, and constraints. Model selection criteria such as AIC can be very helpful for balancing fit and parsimony, but cannot explicitly identify illegitimate constraints or assumptions.

Population reconstruction methods.— Population reconstruction uses cumulative age-specific harvest and mortality data to estimate population structure and size using a bookkeeping approach for all known mortalities by cohort. In their simplest form, population reconstruction models for deer would only have practical application if almost all mortality is assumed to be accounted for using harvest surveys or for small, contained populations where all mortalities can be detected (McCullough 1979). Reconstruction based primarily on harvest data usually underestimates population size and requires mortality recovery rate estimates by cohort to be more realistic (Roseberry and Woolf 1991). More complex reconstruction methods such as the statistical age-at-harvest model incorporate survival rates estimated with radiomarked deer to include non-hunting mortality (Gove et al. 2002).

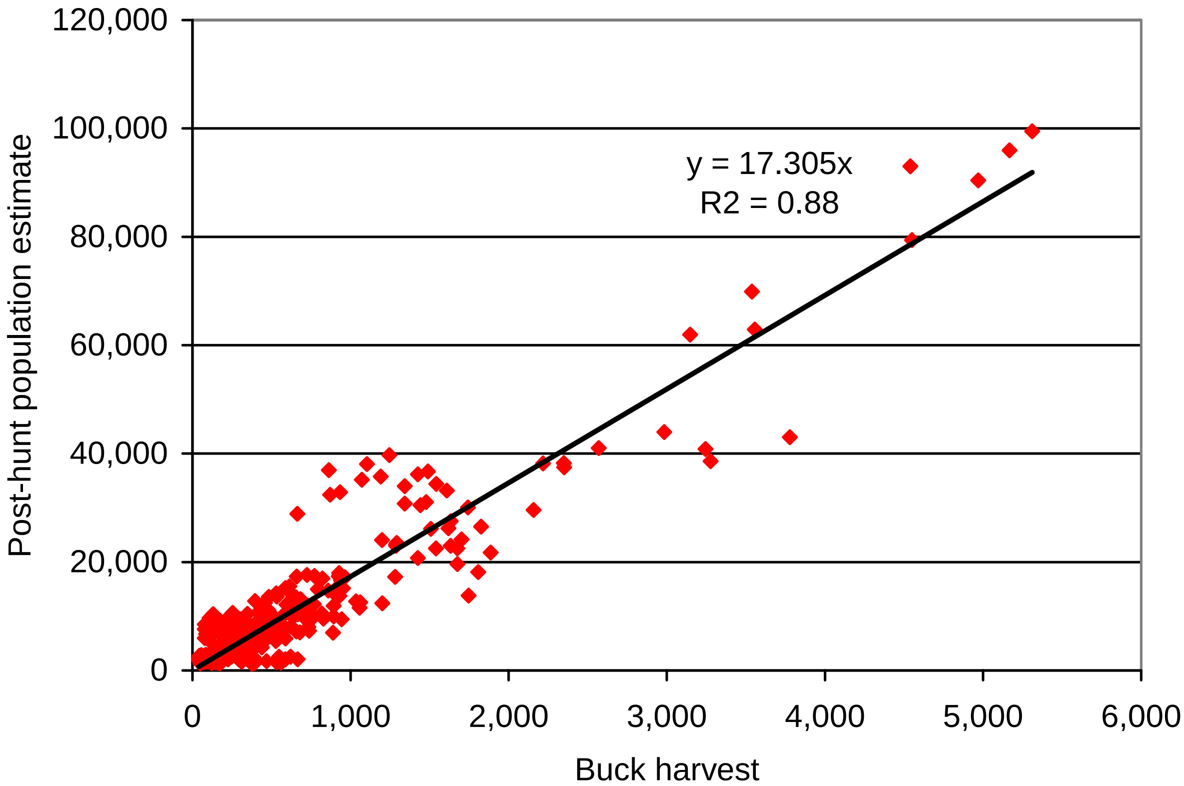

Figure 4. Relationship between buck harvest and modeled post-hunt population estimates for 55 deer DAUs in Colorado using optimally fitted cumulative population models, 1999-2006. All deer licenses in Colorado were limited in 1999 and statewide post-hunt B:D ratios increased from an average of 17:100 prior to limitation to 32:100 after limitation. Figure courtesy of CDOW.

Advantages

- Only requires age-specific harvest or other mortality data.
- Can provide a detailed record of population sex and age structure including age-specific survival rates.

Disadvantages

- Requires age-specific harvest and mortality data which can usually only be reliably obtained by collecting tooth samples from adult deer.
- Population size can only be estimated after all deer alive in that year have died unless assumptions are made to predict future mortality. Such assumptions reduce reliability of population estimates.
- Non-hunting mortality, particularly of fawns, is known to be a major source of mortality in most mule deer populations. Mule deer population reconstruction that does not take into account non-hunting mortality would be of questionable value.

Assumptions

- Usually assumes mortality is primarily due to harvest and the proportion of mortality accounted for is relatively constant over time by cohort.
- Age-specific mortality can accurately be estimated based on harvest surveys and field data. That is, age structure in the harvest is representative of age structure of the population.

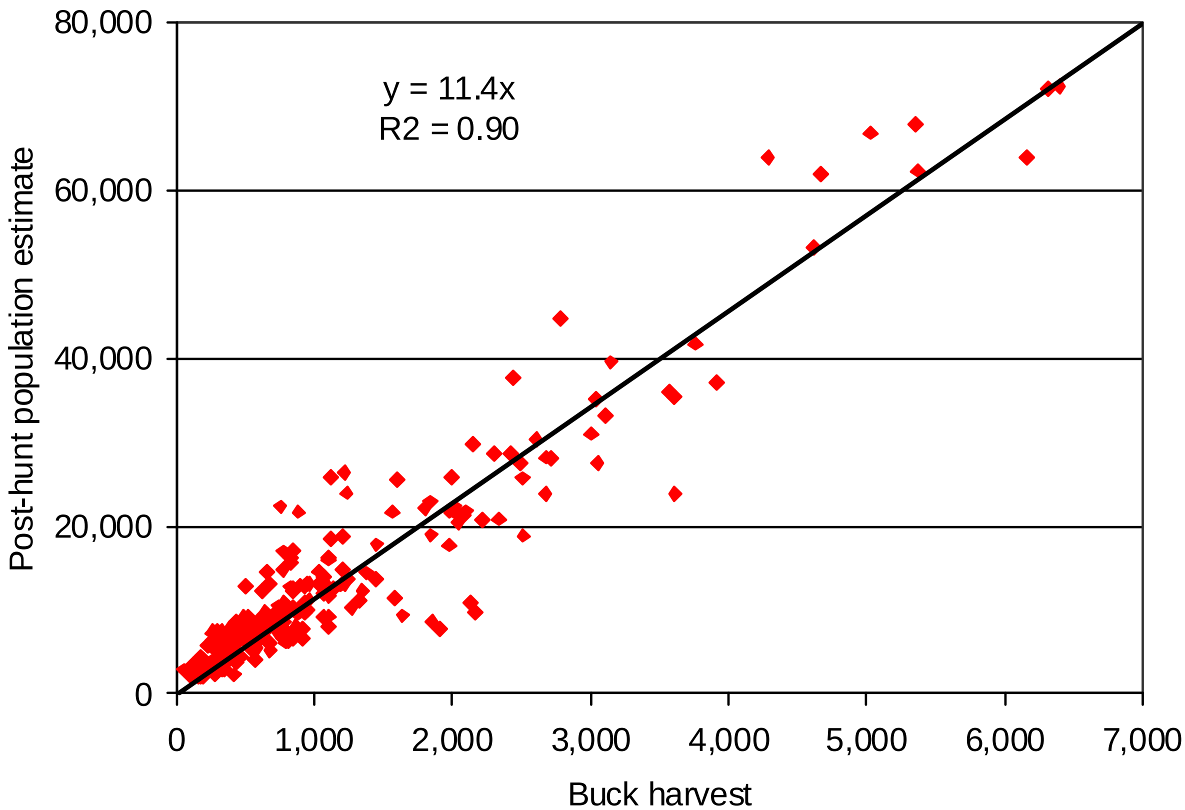

Figure 5. Relationship between buck harvest and modeled post-hunt population estimates for 33 deer DAUs in Colorado with unlimited buck licenses, 1990-1998. Post-hunt B:D ratios averaged approximately 17:100. Figure courtesy of CDOW.

Techniques

Population reconstruction uses year of death and age of known mortalities to populate a post hoc bookkeeping model that follows each cohort over time. Given that mule deer in the wild can potentially live ≥12 years, simple population reconstruction methods usually have limited application for management purposes. Models that predict future mortality to allow more timely reconstruction and include estimated mortality recovery rates introduce additional uncertainty into estimates.

Sex-Age-Kill (SAK) models.— This type of model is used by some states in the Midwest and East to provide a post hoc, pre-season point estimate of white-tailed deer numbers and to project a pre-season population estimate for the following year (Millspaugh et al. 2009). Pre-season population estimates are based on estimating adult male (≥1.5 years) abundance from harvest data and an estimated harvest rate and then estimating total population size based on sex and age ratios.

Advantages

- Uses routinely collected data (harvest by sex and age to calculate pre-hunt sex and age ratios) to estimate density or population size.
- Cost efficient to collect the minimum data typically used.
- Simpler than accounting methods when data are available.

Disadvantages

- Proportion of buck mortality associated with harvest is not empirically estimated. Therefore, adult male harvest rate is modeled based on harvest age structure (units with high hunter pressure and exploitation have lower non-harvest loss) or roughly estimated.
- Fawn:doe ratios are based on opportunistic observations made prior to hunting season. This would seldom be possible with any confidence for many mule deer populations that occupy remote, mountain summer ranges. Pre-hunt F:D ratios for mule deer would be more effectively estimated based on post-hunt aerial classification and adjusted to pre-hunt ratios by accounting for harvest and wounding loss.
- Adult sex ratios are estimated based on proportions of yearling bucks and does in the harvest and the pre-birth sex ratio. For mule deer, adult sex ratios could be more effectively estimated based on post-season aerial classification.
- Model performance can decline as scale is reduced (i.e., statewide vs. management unit basis).
- Sensitive to sudden changes in male harvest rate as may occur with extreme hunting conditions or major changes to hunting rules.
- Model is highly dependent on accurate estimation of the adult male segment.
- Does not usually provide a probabilistic estimate unless all parameter estimates are unbiased and all assumptions are met.
- Not well understood by the public.
- Complicated by antler point restrictions because age structure of harvested bucks is unlikely to represent age structure of bucks in the population.

Assumptions

- Buck harvest is a reliable index of pre-hunt population size and age structure of harvested bucks mirrors buck age structure of the population (i.e., rate of buck harvest is independent of age and size class). This assumption is only likely to be valid when buck licenses are unlimited.
- Population has a stable age structure and is stationary in size for pre- and post-hunt population estimates.
- Model parameter estimates (e.g., F:D ratios, harvest estimates, adult male harvest rates) are unbiased. Generic estimates (e.g., pre-birth sex ratio) are representative.

Techniques

Pre-hunt adult male abundance is estimated by dividing adult male harvest by estimated adult male harvest rate. This rate is calculated as the product of total annual adult male mortality rate and proportion of adult male mortality resulting from harvest. The latter variable is either predicted based on the proportion of 1.5-year-old males in the adult male harvest (a measure of total mortality) or roughly estimated. The assumption of a stable age distribution and stationary size is necessary to calculate total annual adult male mortality rate without bias and to estimate the adult sex ratio. However, a 5-year average of percent yearlings in the buck harvest closely approximates total adult buck mortality under a stable-stationary condition when using uniform hunting rules each year.

Change-in-ratio (CIR) estimators.— This point-estimate method uses changes in sex or age ratios before and after known harvest to estimate population size (Paulik and Robson 1969, Seber 1982). For deer, CIR estimators are usually based on a change in sex ratios after a disproportionately high harvest of bucks compared to does (Conner et al. 1986). Differential harvest between bucks and does is required and the difference should be large enough to result in a substantial change in the sex ratio. In practice, this method is only effective when a large proportion of pre-hunt bucks are harvested.

Advantages

- Relatively inexpensive.
- Uses routinely collected data.

Disadvantages

- Requires unbiased and relatively precise estimates of sex ratios and harvest. Sex ratio variances are often too large to give much confidence in resulting population estimates.
- If harvest does not change the sex ratio relative to the change that can be detected with sex ratio surveys, the estimator fails and does not produce an estimate.

Assumptions

- Harvest and wounding loss by sex are usually assumed to be estimated without error.
- Pre-hunt and post-hunt sex ratios can be estimated with fairly high precision and without bias (i.e., bucks and does are equally detectable during each sex-ratio survey).
- Population is closed between pre-hunt and post-hunt surveys except for known harvest.

Techniques

Change-in-ratio methods rely on unbiased and fairly precise sex-ratio estimates (see Age and Sex Composition). Sex ratios can often be biased because bucks are less likely to be detected than does when male harvest rates are disproportionately high (Roseberry and Woolf 1991). Even if sex ratios are assumed to be unbiased, they often lack enough precision to make CIR population estimates for mule deer very reliable.

POP-II and POP-III models.— POP-II is a commercial, cumulative population modeling program based on the ONEPOP model developed at Colorado State University in the early 1970s (Bartholow 1999). POP-II is similar to OFC models in that it is essentially a bookkeeping program that uses alignment between observed and modeled sex ratios as the basis for adjusting variables in the model. The POP-II model uses parameters generally similar to OFC models and is therefore also highly dependent on unbiased field estimates. However, POP-II is a deterministic model that does not optimally fit observed data, but rather allows the user to manipulate a variety of parameters and assumptions to improve subjective fit. Precision of field estimates is not accounted for in POP-II, nor does the model incorporate sample-based population estimates. Because POP-II is a commercial program, it has much less transparency than a spreadsheet-based model and cannot be customized. POP-III is an extension for POP-II that incorporates stochasticity.

Advantages

- Readily available and turn-key.
- Consistent model framework that cannot be altered by the user.
- Uses an intuitive bookkeeping approach.
- Familiar to biologists in some agencies who have used it for many years.
- Allows “what if” population scenarios and management alternatives to be evaluated.

Disadvantages

- Does not objectively fit observed data using a mathematical algorithm, but rather allows the user to manipulate different aspects of the model to improve fit. Evaluating how the fit of the final model selected compares to a model that is optimally fit is not possible. Model selection can be subjective to conform to expectations.
- Does not provide full transparency to allow the user to understand how parameters are being used and how calculations are being performed.
- Does not have the flexibility of spreadsheet-based models that can be readily customized by the user.
- More dependent on an accurate estimation of initial population size than OFC models. POP-II also requires initial age and sex structure to be entered.
- Does not take into account precision of field estimates.
- Unlike OFC models, outputs cannot be evaluated using model selection criteria such as AIC.
- Requires oldest age class in the field to be specified (older deer are automatically removed). Although contribution of this factor to bias in mule deer models is unknown, specification of the oldest age class has clearly biased some elk models based on longevity of some radiocollared elk.
- Because necessary parameter inputs are rarely empirically measured, incorrect rough estimates can produce large deviations from actual population size.

Assumptions

- Whatever model is selected is representative of the true population.

- Parameter estimates are unbiased (or bias can be corrected) and consistently estimated over time (see sections on Harvest, Survival, and Age and Sex Composition for more discussion of potential bias in these parameters).
- Harvest and F:D ratios are usually assumed to be estimated without error.
- Population being modeled is geographically closed over time, or immigration and emigration rates are equal or can be reliably estimated.
- Constraints and constants (e.g., 50:50 fawn sex ratio) are biologically realistic based on available data.

Techniques
POP-II calculates population size based on a straightforward bookkeeping approach that requires estimates of initial population size and structure and annual estimates of 1) preseason natural mortality, 2) harvest, 3) wounding loss, 4) post-season natural mortality, and 5) birth pulse. Model solutions can be manually manipulated to improve fit between modeled and observed values by changing a number of variables, including natural survival rates, a mortality severity index, harvest effort values, and reproductive rates by group. A correlation coefficient and goodness-of-fit statistic are calculated to help evaluate fit for each simulation. POP-II models are parameter rich and use some data (e.g., age-specific structure, harvest, and reproductive rates) that are rarely estimated in the field for mule deer.

Harvest per unit effort methods (HPUE).— Models employing HPUE are based on an inverse relationship between number of deer harvested or counted for each unit of effort (e.g., per hunter-day, per hour of observation) and population size (Lancia et al. 1996*a*). These models have been used for many years to estimate commercial fish abundance, but have received relatively little use for estimating big game populations. Models incorporating HPUE for estimating white-tailed deer numbers were described by Novak et al. (1991), Roseberry and Woolf (1991), and others.

Advantages
- Relatively inexpensive. When based on harvest per hunter-day or percent success, only hunter survey data are required.

Disadvantages
- Hunter-hours and harvest data are often not available on a daily basis.
- Two or more harvest periods may be required.
- Harvest success must be high enough to cause a significant decline in the population or the slope of HPUE models will not change, and thus not produce an estimate.

Assumptions
- Vulnerability to harvest is constant. Changes in conditions (e.g., weather, snow depth), hunting methods and regulations, and deer behavior during the harvest period are assumed to have little effect on vulnerability or the effect can be reliably estimated.

- Hunters are not highly selective (e.g., hunters do not hold out for larger bucks) and selectivity does not change during the harvest period (e.g., hunters do not become more likely to shoot a small buck or doe later in the season).
- Populations are closed while harvest is occurring.

Techniques

There are several variants of the HPUE method (e.g., 2 harvest periods, Leslie method, direct index, etc.) with different assumptions (Roseberry and Woolf 1991). Relationships between harvest per effort and abundance are determined by regression analysis and are often assumed to be linear. If harvest effort is constant, percent success can substitute for effort in some models. Managers can extrapolate HPUE to estimate population abundance using DeLury non-linear HPUE or similar models (Roseberry and Woolf 1991, Skalski et al. 2005). Currently, HPUE methods have little practical value for estimating mule deer numbers because underlying assumptions are seldom realistic. These methods are more suitable for providing a population index rather than a population estimate and, even then, should be used in conjunction with other methods.

Survival Rates

Finite survival rate is the probability of an organism remaining alive through a specified time period and is usually estimated by the proportion of survivors in a sample. Survival rate estimates, particularly for adult females, are the most sensitive parameters in cumulative mule deer population models (White and Bartmann 1998, Bowden et al. 2000). Although mule deer models are less sensitive to changes in fawn survival, fawn survival rates can also be very influential on model performance because fawn survival can be much more variable (i.e., larger process variance) than adult doe survival (Unsworth et al. 1999*b*, Lukacs et al. 2009).

Survival rates are usually calculated as “natural” survival rates that exclude harvest and, in some cases, wounding loss and illegal kills. Survival rates of adults are usually expressed on an annual basis, whereas, for the purpose of population modeling, fawn survival rates are more practically based on winter survival from the time of post-hunt classification surveys until fawns are recruited as yearlings. Pre-hunt fawn survival is not required for population modeling but can be of interest to better understand population dynamics. Pre-hunt fawn survival is most effectively estimated by locating and radiomarking fawns soon after birth (best accomplished via use of vaginal implant transmitters; Bishop et al. 2007, 2009*b*). Alternatively, but with less accuracy and precision, estimates of pregnancy and fetal rates along with fawn:adult female ratios may be used to estimate pre-hunt fawn survival.

Although annual doe and winter fawn survival rates for mule deer have been commonly monitored, relatively little information is available on natural buck survival rates (Pac and White 2007). This has been because 1) managers often assume doe and buck survival rates are similar (White and Lubow 2002), 2) buck survival is considered to be the least important survival parameter in population models, and 3) placement of radiocollars on adult bucks is problematic because of annual changes in neck circumference. The assumption that doe and buck natural survival rates are similar is probably not valid in many cases and these rates can likely be influenced by buck and doe harvest rates (Mackie et. al 1998; B. Watkins, CDOW, unpublished data). Differential survival can affect model outcomes when B:D ratios are used for alignment.

Most survival rate estimates for mule deer have sampling variation and process variation. Process variation refers to the inherent biological variability (temporal and spatial) in the survival rate across time or space. Survival estimates across multiple years and locations are required to separate process variation from sampling error (White and Bartmann 1998, Bowden et al. 2000, Lukacs et al. 2009). Estimating process variation in mule deer survival rates can improve OFC population model performance, particularly when field data are sparse (Lukacs et al. 2009). Although survival rates can theoretically be estimated based on changes in sex and age ratios, using band recoveries, or using age data to reconstruct populations, by far the most useful method for mule deer is to use samples of radiomarked deer.

Known-fate using radiotelemetry.— With few exceptions, survival rates of wild ungulates are estimated using a sample of radiomarked animals. Using radiotelemetry, survival rates can be efficiently estimated for specific sex and age classes and information can be obtained on cause-specific mortality and spatial distribution. Radiomarks allow the fate (i.e., live, dead, or censored) of marked deer during a specified time period to be known with certainty and allow calculation of survival rates using known-fate models based on simple binomial likelihoods.

Advantages
- Most efficient, direct, and potentially least biased method to determine survival rates.
- Survival probabilities can be continuously estimated over time depending on the frequency of monitoring.
- Allows estimation of survival rates for specific deer groupings (e.g., age class, sex, geographic area, habitat, etc.), potential identification of cause-specific mortality, and estimation of the contribution of specific mortality factors to overall survival.
- Deer with unknown fate can be censored, but still be included in survival rate estimation while they are still known to be alive.

Disadvantages
- Relatively expensive equipment and monitoring costs.
- Infrequent monitoring can be problematic depending on the timeframe of survival estimates.
- Depending on analysis method used, small initial sample sizes can bias survival rates unrealistically low if much mortality occurs early in the survival period.

Assumptions
- Collars are randomly distributed within sex and age classes of interest.
- Date of death can be accurately determined to have occurred within or outside of the period of interest.
- Capture and radiomarking do not affect survival probabilities.

Techniques

Survival studies using radiotelemetry involve
1. Marking a sample of deer with transmitters equipped with mortality sensors.
2. Periodic telemetry monitoring from the ground, from aircraft, or by satellite.
3. Timely field investigation of mortality signals.

4. Estimating date of death when monitoring is infrequent.
5. Censoring deer that cannot be located because of radio failure, shed transmitters, movement out of the study area, or any other reason.

Survival rates can be estimated from known-fate data in a variety of ways. The simplest method is to simply divide the number of deer alive at the end of the period by the number marked. This method has obvious limitations (e.g., censoring is not possible) and is seldom useful. A more common technique is to calculate survival rates using the Kaplan-Meier method (Kaplan and Meier 1958, Pollock et al. 1989). This method

1. Allows staggered entry of fate data (i.e., additional marked deer can be added to the sample at any time during the survival period).
2. Allows available data from censored deer to be considered while their fate is still known.
3. Provides an estimate of precision.

Small initial sample sizes may need to be lumped over time for entry to avoid unrealistically low survival rates when using staggered entry. For example, if only 2 deer are initially radiocollared and 1 dies before other deer are added to the sample, the survival rate using the Kaplan-Meier method will be ≤50% no matter how many additional deer are collared and survive unless appropriate analysis alternatives are used to address this issue.

For more detailed analyses that can take into account specific attributes of known-fates data, program MARK can be used to calculate mule deer survival rates using a variety of models (White and Burnham 1999). A major advantage of MARK is that binomial models based on maximum likelihood estimation can be used to estimate survival, allowing the use of AIC for model selection. Program MARK also includes analysis alternatives for ragged data when deer are not monitored in discrete intervals and exact day of death is unknown.

Adequate sample sizes for survival monitoring depend on rate and timing of mortality and level of precision desired for population modeling. White and Bartmann (1998) recommended samples of at least 40-60 fawns and 20-40 does to achieve reasonable precision in Colorado DAUs. However, replacement or additional doe radiocollars should be deployed each year to help maintain a doe sample that more likely represents age structure of the female population (i.e., younger age cohorts are represented). This approach usually results in a sample of 60-80 does because of relatively high doe survival rates (CDOW, unpublished data).

An attempt should be made to randomly or systematically distribute the radiomarked sample across the area of interest. This can be most effectively accomplished by helicopter net-gunning the deer to be collared. However, to help reduce costs, other less expensive methods (e.g., drop nets, cage traps, chemical immobilization, drive nets) can also be used in combination with net-gunning as long as the sample is spatially well distributed.

For the purpose of population modeling, the beginning of the period for estimating overwinter fawn survival should closely coincide with estimation of F:D ratios. For example, if the survival rate period begins well after age ratio classification, recruitment of fawns to the yearling age class will be overestimated if appreciable mortality occurs during this time interval. To help reduce costs and ensure collars do not become too tight with additional growth, overwinter fawn survival can be estimated using collars designed to drop off in 6-9 months. This can economically be accomplished by cutting collar belting and reattaching the ends using latex surgical tubing that will degrade with ultraviolet light exposure. Another alternative is to use expandable collars, particularly on female fawns, some of which will be recruited into the future adult doe sample.

Band recovery.— Although frequently used for migratory game birds, band recoveries have seldom been used to estimate big game survival rates. White and Bartmann (1983) attempted to use band recoveries to estimate survival of mule deer and concluded the method was generally impractical because of the large sample sizes required and incomplete reporting.

Advantages

- Does not require radiotelemetry equipment and monitoring.

Disadvantages

- Known-fate models do not apply. Survival can be estimated with much higher precision and less bias using radiotelemetry.
- Requires large numbers of deer to be marked which can result in considerable costs.
- Sources of mortality cannot be readily differentiated.
- Requires high band recovery rate to obtain precise estimates.

Assumptions

- Banded and non-banded deer have the same probability of survival.

Techniques

Band recovery methods have been used for many years to estimate survival rates for migratory game birds and fish (Brownie et al. 1985). For mule deer, inexpensive neck bands and ear tags can be used for band recovery studies. However, use of band recovery methods to estimate mule deer survival is seldom justifiable unless large numbers of deer are being marked for other reasons. The only potential advantage of using band recoveries for estimating deer survival is to avoid the expense of radiotelemetry equipment and monitoring. This is seldom justifiable because deer capture costs, rather than telemetry costs, are often the most expensive aspect of survival studies. Program MARK can be used to analyze band recovery data (White et al. 2001).

Change-in-ratio estimators.— This method provides estimates of overwinter fawn and adult survival rates using pre- and post-winter fawn:adult ratios and the estimated age ratio of overwinter mortalities (White et al. 1996). Fawn:adult ratios are used because bucks cannot be readily distinguished from does at a distance in the spring after antlers are shed. The age ratio of overwinter mortalities must be estimated to determine the effect of adult mortality on post-winter fawn:adult ratios. Although theoretically sound, the change-in-ratio method would likely result in very imprecise and likely biased survival estimates for mule deer.

Advantages

- Relatively inexpensive because deer do not need to be captured and marked.

Disadvantages

- Requires accurate and precise estimates of age ratios. Accurate classification of fawns in the spring can be highly prone to error.
- Aerial classification is recommended to achieve a well distributed, representative sample. This adds to the cost and makes accurate age classification more difficult.

Assumptions

- Age-ratio estimates are unbiased or have the same bias in all surveys.
- Deer are not misclassified.
- Fawn mortalities are as likely to be detected as adult mortalities during spring surveys.

Techniques

Pre- and post-winter age ratios can be estimated using ground or aerial surveys. However, aerial surveys are less likely to be biased because bucks are more prone to be segregated from does during post-winter than during pre-winter because of the rut (White et al. 1996). Age ratios of mortalities can be estimated using ground transects in winter range areas.

Population reconstruction methods.— Age-specific annual survival rates can be calculated from reconstructed population data by dividing the number of deer alive in each cohort during year $t+1$ by the number alive in year t. Unlike the use of population reconstruction to estimate population size, survival rate estimates do not require a full accounting of mortalities as long as recovered mortalities are assumed to be representative of total mortalities. This method is equivalent to the cohort life table of the older population dynamics literature. With the possible exception of small, confined populations, population reconstruction methods have little practical value for estimating mule deer survival rates because non-harvest mortality must still be estimated.

Advantages

- Can provide a detailed record of population sex and age structure, including age-specific survival rates.

Disadvantages

- Requires age-specific harvest and mortality data which can usually only be obtained by collecting tooth samples from adult deer.
- Cohort size during years t and $t + 1$ can only be estimated after all deer alive in year $t + 1$ have died unless assumptions are made to predict future mortality or recovered mortalities are assumed to provide an unbiased representation of total

mortalities. This long time lag makes this method of limited value for adaptive management approaches.
- Non-hunting mortality is difficult to estimate unless deer are in a relatively small enclosure or radiotelemetry is used.

Assumptions
- Age-specific mortality in the population can be accurately estimated based on harvest surveys and field data.
- Population age structure is assumed to be stable.

Techniques
Population reconstruction uses year of death and age of known mortalities to populate a post hoc bookkeeping model by cohort. A variety of methods have been developed for estimating survival rates from age structure data including methods for populations with dynamic age structures (Udevitz and Ballachey 1998).

Age and Sex Composition

Age and sex composition data are simply a classification of relative proportions of bucks, does, fawns within a population. Bucks may be further classified into approximate age or antler-point classes (e.g., 1-2 points or yearling, 3 points, ≥4 points). Ratios of B:D and F:D are generally presented in standardized fashion as bucks:100 does:fawns.

Age and sex composition data can be most useful when adjusting limited entry buck permit numbers among annual seasons, although they are also necessary for population model inputs. As the proportion of surveyed bucks changes, permit numbers can be adjusted accordingly (e.g., reduced permits in response to decreased proportion of bucks in a population). Similarly, buck permits may be adjusted in anticipation of expected recruitment (e.g., increased permits in response to increased proportion of fawns in a population). Because population size can change while B:D or F:D ratios remain stable (Caughley 1974), a population estimate or index to population size (e.g., deer/hour of survey) should be considered with this approach.

Generally, surveys should be conducted within areas accessible for harvest. Surveying areas where hunting is precluded may misrepresent availability of bucks for harvest or fawns for recruitment, although at times these areas may serve as a source from which immigration or recruitment occurs. Decisions regarding including these areas within surveyed habitat should be considered deliberately prior to initiating surveys.

Agencies generally establish a range of acceptable B:D and F:D ratios beyond which managers recommend increases or decreases in permits. These data may be used to determine which type of season may be held (limited entry or open entry, short season or long season) based on similar acceptable ranges. Antlerless harvest may be more difficult to manage with these types of data, except in specific situations (e.g., when F:D ratios drop below a specific threshold, the habitat may be overstocked and reductions in antlerless deer may be recommended to reduce the overall population although weather conditions undoubtedly play an overriding role in many situations).

Composition data are most useful when combined with additional data on population estimates or indices. Without companion data on population trends, age and sex composition data may be misinterpreted because populations can increase or decrease without any associated change in ratios (Caughley 1974). If collected shortly before and shortly after a buck-only harvest, the change in ratio can be used to infer population size (however, this approach is expensive and rarely used for management-level monitoring).

Timing of surveys used to collect age and sex composition can affect the sample. Bucks are generally associated with does and more visible during the breeding period, probably allowing more reliable estimation of actual B:D ratios. Surveys outside of the breeding period generally result in lower B:D ratios. Even during the breeding period, B:D ratios are more variable than F:D ratios (McCullough 1992, Carpenter et al. 2003). Observers should recognize that although antler morphometry is correlated with buck age (Anderson and Medin 1969), differentiating yearlings from adults in the field based on antler characteristics is subjective and, in some cases, unreliable (D. Lutz, WY Game and Fish Department [WGFD], unpublished data). Fawn:doe ratios differ substantially by time of year because fawn survival differs substantially from adult survival. Detectability of various age and sex classes differs by time of year as well. To be useful for comparative purposes, these surveys must be conducted at the same time each year. The later in the winter that surveys are conducted, the greater the difficulty in differentiating among fawns, does, and yearling bucks that have shed antlers. Further, a substantial doe harvest can cause apparent changes in these ratios because both B:D and F:D ratios depend on the denominator of does.

<u>Bias in sex and age ratio estimates</u>

Observer bias in ratio estimation can result from an observer's inability to correctly classify by sex or age, or tendency to select for 1 population segment over another. A common classification error is to incorrectly distinguish between juveniles and yearlings (Downing et al. 1977). This bias can potentially increase or decrease age ratios, but probably most often results in lower F:D ratios. This source of bias can be minimized by using only trained personnel to conduct classifications. Classification by less experienced personnel (those being trained) should be verified by experienced observers. Accuracy of classification and efficiency during aerial surveys are improved by using experienced pilots who know what characteristics the biologist must observe to classify deer. Some aerial observers are finding that viewing animals with image-stabilized binoculars enhances their ability to classify sex and age (however, incidence of motion sickness may increase). Ideally, observers from different areas and jurisdictions should go through periodic training or conduct classifications with experienced observers to improve consistency. When possible, observers should use a consensus approach for classification of deer groups when initial individual classifications differ or simply to ensure a greater level of consistency among and within observers. Although somewhat challenging to obtain from aircraft, photographic documentation of groups may provide an opportunity to verify classifications following the survey.

Another classification error is classifying males with small or shed antlers as adult females (Downing et al. 1977). In some areas, observers may misclassify yearling bucks that have shed antlers as juveniles. Antler loss in mule deer begins in December and continues through April and is typically earlier in northern latitudes than in more southerly locales (Heffelfinger 2006). However, antler loss varies locally and biologists should identify onset of antler loss in their specific area. The later in winter classification surveys are conducted, the more biased (i.e., lower than actual) B:D ratios will become. Deer classification in late January will likely have some inherent bias in northern states and provinces due to shed antlers, whereas in more southerly habitats this may not occur until late February. This source of bias can be reduced by restricting deer classification to periods prior to antler drop and by training observers to look closely for small-antlered males. Again, photographs of observed herds can allow closer scrutiny following the survey. Bias resulting from an observer's tendency to select 1 population segment over another usually relates to preferentially classifying mature males over females, juveniles, and small males. This source of bias can be reduced by classifying large groups of deer in a systematic manner (e.g., from left to right, from back to front, within a specific field of view, etc.) rather than preferentially classifying obvious large males first.

Sampling bias results from not taking a representative sample of a population. This bias can result from surveying only part of a population area, concentrating only on 1 habitat, only surveying specific locations where deer are known to occur, classifying too few deer, or classifying only part of some groups (if subgroup composition is nonrandom). Sampling bias is likely to be more of an issue with sex ratios than age ratios, but both can be affected. Sampling bias can be reduced by using random sampling designs or by making an attempt to broadly survey across a population area, including all habitats where deer could occur. Because nonrandom subgroup composition is common (e.g., bucks tend to lead or follow, fawns tend to clump together), only entire groups should be classified. Appropriate sample sizes should be specified before surveys begin (based on previous or expected variation and desired precision). Identifying a target sample size can also reduce costs in a random sampling framework if surveys are terminated upon acquiring the needed sample, and a spatially balanced sample has been obtained.

Detection bias arises from differential detectability of different population segments (e.g., 1 population segment is more or less detectable than another). This is primarily an issue with adult males because they often form bachelor groups and occupy different habitats than other segments (particularly outside of breeding season). These small groups often have much lower detectability than larger groups of females, juveniles, and young males. Detection bias for deer can be reduced by flying during the peak of breeding season when bucks and does are more likely to be together. However, conducting surveys during the rut can be disruptive and unpopular with the public if concurrent with big game hunting seasons. Further, sampling during mule deer breeding season should still encompass the full range of habitats available to deer (i.e., avoid sampling bias). Considerable post-rut segregation may occur depending on snow depth and winter concentrations.

Redundancy bias occurs when the same deer are unknowingly classified more than once. This bias is more prevalent when large numbers of deer occupy dense vegetation or large groups mix and shift during classification. Redundancy bias can be considered a form of sampling with replacement and addressed with appropriate statistical methods.

Aerial observations.— Aerial observations are conducted to reduce biases typically associated with ground surveys. Aerial surveys provide observers the ability to traverse large tracts of broken terrain using a random or systematic sampling design which is impossible to deploy from the ground, where vehicles and foot surveys are limited by accessibility. Aerial surveys also provide a platform from which observers effectively can look through even relatively dense vegetation because of the improved vantage point (Fig. 6). Because most wildlife will flee from low-level flights, increased detection rates are also possible due to movement of deer.

Figure 6. Helicopters can provide useful platforms for classifying sex and age of mule deer. Photo by T. Keegan, Idaho Department of Fish and Game (IDFG).

Advantages

- Aerial surveys allow use of robust sampling designs, such as systematic or random grids.
- Allow for an improved observer platform that provides improved visibility through vegetation from above.
- Wildlife often move in response to low-level aircraft, which can increase their detectability.
- Helicopters can hover or maintain wildlife within view to improve classification time and position for observers.

- Because aircraft can cover relatively large areas in relatively short periods of time, sample sizes can be large.

Disadvantages

- The primary challenge associated with aerial surveys is increased cost. Helicopters are generally the preferred aircraft for most surveys, but are the most expensive on an hourly basis. Fixed-wing aircraft are less expensive, but not appropriate for areas with rugged terrain and more dense habitats.
- Low-level aerial survey is probably the most dangerous work-related activity for wildlife biologists (Sasse 2003), even though safety is a constant focus of survey pilots.
- Aerial surveys generate bias associated with misclassification because deer are typically moving when classified. Bucks with small antlers or spikes may be misclassified as does, yearling bucks with shed antlers and yearling does may be misclassified as fawns, and older fawns may be misclassified as adult does. This misclassification influences estimates of both sex and age ratios.
- Mountainous terrain requires modification to sampling grids. Helicopters are not able to follow a straight grid line and remain at a constant elevation above ground level in rugged terrain. Fixed-wing aircraft must be relegated to flat terrain with relatively open vegetation.
- Motion sickness can limit observer ability, and survey flights should end immediately if an observer develops motion sickness.

Assumptions

- The primary assumption of aerial survey techniques is the sample is representative of population of interest.
- Aerial surveys not corrected for differential visibility bias assume all age and sex classes are equally observable, which is generally untrue, so such surveys should not be conducted.

Techniques

Classification of sex is typically based on presence or absence of antlers. Observers must see the forehead of each deer to eliminate the possibility that small spike antlers are present. Large ears of mule deer can obscure relatively large spikes if viewed only from the side. If the forehead is not visible, that animal should be noted as "unclassified." Further, depending on area and timing, observers should be aware that some bucks may have shed antlers. Pedicles are typically not obvious, but may be visible under close scrutiny. Other features such as a larger, stockier body; dorsal bridge or curve of the rostrum; and greater contrast between a dark forehead and lighter muzzle provide further evidence that one is observing a buck that has already shed antlers.

Identification of fawns should be based on several characteristics. The following scenario is based on a helicopter survey in which the aircraft approaches from the rear of moving deer and flies by on a parallel path, but many of the characteristics can also be observed during ground observations. The first characteristic to observe is the shape of the rump, which appears more rounded in fawns than adults. The overall appearance of a fawn's hair is often described as “fuzzy,” which likely contributes to the more round and stocky appearance. Fawns may also display a “dorsal stripe,” a darker looking strip of hair along the back (Fig. 7). However, lack of a dorsal stripe does not conclusively identify an adult. As the helicopter moves alongside, observers should note a deer’s gait; fawns tend to have a more erratic or “choppy” gait than adults and often appear to move in a confused or panicked manner in contrast to the deliberate movements of adults. Also note the ratio of neck length and girth to head length. Length of a fawn’s neck will appear similar to head length, making the neck appear relatively thick, whereas an adult doe’s neck appears longer than the head and relatively thin. Lastly, length of the rostrum relative to the head is the primary characteristic used for separating fawns from adults. A fawn’s rostrum appears short and stout compared to that of an adult doe (Schroeder and Robb 2005, Fig. 8), giving a fawn’s head a more-triangular shape when viewed from the side (Fig. 7). Note that relative body size can be a misleading characteristic and should not be used alone to differentiate age. For example, a large buck fawn may appear larger than a small yearling doe.

By following the above approach, observers should be able to develop a relatively strong preliminary conclusion about classification of each animal and derive final confirmation from viewing the rostrum. If the rostrum does not confirm initial classification, the helicopter should be turned back so biologists can further observe individuals and obtain definitive classification of all deer in the group.

Typically, observers should count total deer in a group from some distance away; before deer begin moving or when moving slowly. The helicopter can then move closer so observers can conduct actual classification in which only fawns and bucks are counted. Afterward, fawns and bucks are simply subtracted from the total number to obtain the number of does.

Figure 7. The rounded rump, dark dorsal stripe, stout neck, and "fuzzy" appearance help identify the fawn (right). Photo by T. Keegan, IDFG.

Survey design should take into account desired outcomes in terms of adequate sample size, expected precision, and deer distribution. Sample size requirements can be calculated based on expected or previous variance. Alternatively, assuming adequate geographic coverage, graphic representation of cumulative age or sex ratios can be examined to identify approximate numbers of groups beyond which ratios tend to stabilize (Ockenfels 1983, Fig. 7). Typically some form of stratified random sampling that takes into account differential distribution of bucks and does is needed to adequately estimate sex ratios. Although ad hoc surveys can often yield large sample sizes, they should be avoided because of unknown biases, particularly in sex ratios. Surveys require an aircraft that provides adequate visibility for observers, is capable of following a predetermined survey route, and can safely operate in the terrain and conditions in the an aircraft that provides adequate visibility for observers, is capable of following a predetermined survey route, and can safely operate in the terrain and conditions in the survey area. Pilots for deer surveys should have experience with the specific survey methods, herding deer, and flying in the type of terrain being surveyed. Some agencies have initiated protocols for observer experience and training to enhance consistency among observers. For example, primary observers for IDFG undergo annual training, must have 100 hours experience conducting similar surveys, and must have spent 30 hours on similar surveys during each of the most recent 3 years.

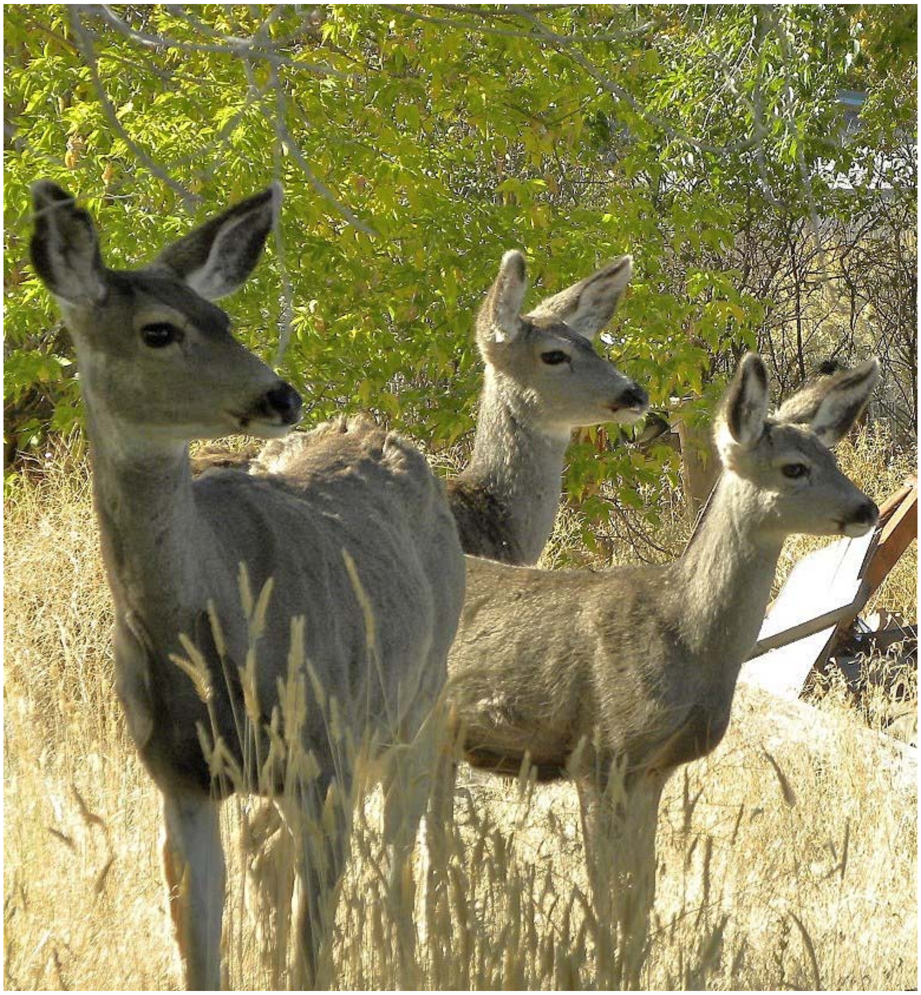

Figure 8. Relative rostrum length ranges from shortest in fawns (right) to longest in adults (left). The middle doe displays the intermediate length rostrum of a yearling. Photo by T. Keegan, IDFG.

Limited use of technologically advanced detections systems, such as FLIR scanners, has been attempted (e.g., Naugle et al. 1996). However, these techniques greatly increase costs of conducting surveys and have generally been inadequate for sex and age classification (Wakeling et al. 1999).

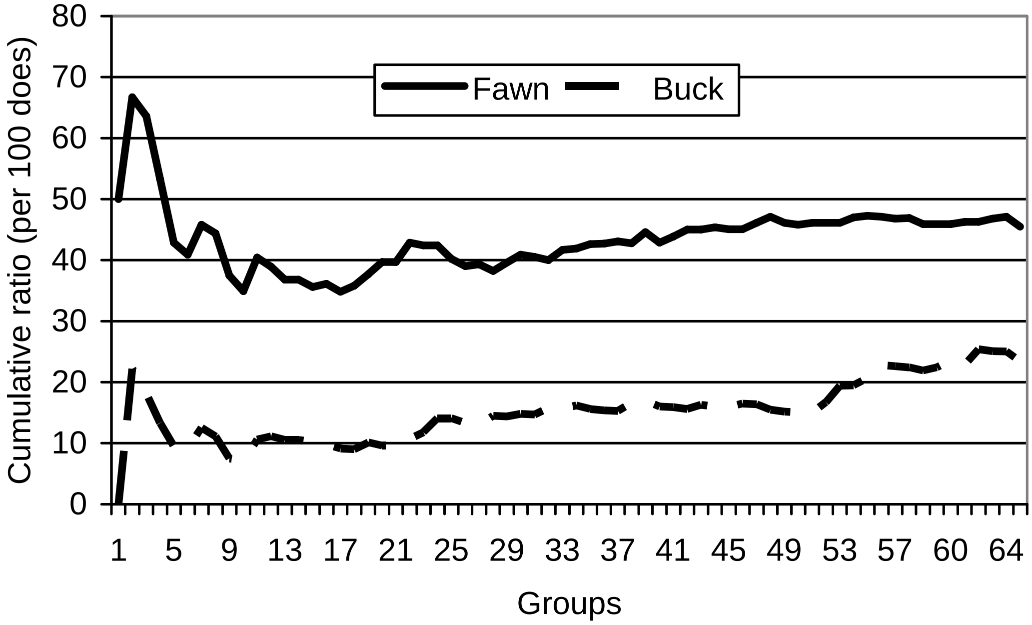

Figure 9. Cumulative sex and age ratios obtained in a stratified random sample within a large mule deer population management unit in east-central Idaho, Dec 2009. Stabilization of cumulative F:D ratio occurred at approximately 45-50 groups, whereas B:D ratios did not stabilize. This survey was designed to obtain only accurate F:D ratios; a different stratification and likely additional groups would be needed to accurately estimate B:D ratios. Using this approach to estimate sample size requires adequate geographic coverage of the population area. Data courtesy of IDFG.

Ground observations.— Ground observations may be obtained from a variety of platforms, including on foot or from livestock or motor vehicles; and may consist of continuous observation routes or fixed-point observation surveys. These types of surveys require relatively little financial resources when compared with aerial surveys. Ground observations generally are less likely to result in disturbance typical of low-level aircraft, and wildlife generally remain visible for greater periods of time than with aircraft, although substantial disturbance is possible during ground surveys as well. Observing undisturbed deer may enhance an observer's ability to correctly classify individuals when using optics such as binoculars or spotting scopes. However, obtaining adequate sample sizes can be difficult. Ground observations are influenced by the same annual breeding cycle observation biases for bucks as are aerial surveys.

Advantages

- Ground observations are less expensive to obtain and usually pose much less risk to observers than aerial surveys.
- Observers viewing undisturbed wildlife are likely to have more time to use optics and may be able to more accurately classify deer they observe (compared to aerial platforms).
- Observers can record additional information about deer habitat condition (e.g., condition of browse, intensity of grazing, availability of water, etc.) while conducting ground surveys.

Disadvantages

- Ground observations are limited by terrain and accessibility. Vehicles cannot access many portions of occupied deer range, especially during breeding season when buck classification may be best accomplished.
- Livestock or foot surveys are limited by speed and area that may be covered. Many areas may be too inaccessible for foot surveys, and access may be limited for even all-terrain vehicles.
- Detectability of deer and ability to count and classify individuals may be limited in areas with dense vegetation or under some weather conditions.
- Observer biases may differ for some portions of age and sex classes.
- Difficulties associated with speed, access, and visibility reduce the ability to obtain adequate sample sizes, which can lead to estimates with large confidence intervals.
- Conducting surveys from roads and trails introduces bias because these features are not randomly distributed across the landscape.
- Most ground-based surveys have been criticized in the literature because of biases that are impossible to detect, correct, or overcome. Nevertheless, many agencies continue to use ground surveys because of the low cost of these data.
- Despite lower overall cost compared to aerial surveys, actual cost per deer observed may be greater for ground surveys than aerial surveys (A. Fuller, AGFD, unpublished data).

Assumptions

- The primary assumption of ground survey techniques is the sample is representative of population of interest.
- Ground surveys assume all age and sex classes are equally observable.

Techniques

Classification techniques for sex and age are generally the same as those described above under aerial observations. However, ground observers may have difficulty observing all the characteristics for classifying fawns. Ground surveys may be employed from virtually any means of traversing habitat so long as it is done consistently among years. Periodic stops in which optics are used to systematically scan visible terrain are generally employed. Undisturbed observations are desired because this provides the greatest potential for accurate classification. Ground surveys should be implemented using a random sampling scheme to reduce biases.

Age determination from teeth.— Determining ages of a large sample of individuals provides information on age structure of a population and helps direct appropriate management actions. Age structure of a deer population tells us much about effects of harvest strategies (e.g., Wakeling 2010). Only rarely do biologists have the opportunity to observe teeth in living deer; inferences from deer teeth are primarily limited to teeth collected from harvested deer via hunter check stations and field checks, or via an alternate tooth collection system.

Deer teeth can provide estimates of age in 2 ways. First, changes in tooth eruption, replacement, and wear of the lower jaw are well-correlated with the age of the deer, particularly through 2.5

years. Second, deer also acquire annual rings in the cementum (cementum annuli) of their teeth (Larson and Tabor 1980). Counting cementum annuli provides accurate age estimates for deer of all ages, but tooth eruption and wear (field aging) for deer is generally only accurate for deer <3.5 years of age (Dimmick and Pelton 1994). However, field aging techniques can be used to assign older deer into age classes (e.g., 3.5-5.5, ≥6.5).

Advantages

- Tooth eruption and wear patterns may be observed and readily compared with published guides (e.g., Larson and Taber 1980).
- Tooth extraction is simple and relatively inexpensive to analyze in a laboratory, although care must be used during extraction (Dimmick and Pelton 1994).
- Relatively large numbers of samples may be compiled during routine hunter checks.

Disadvantages

- Sufficient sample sizes to determine age structure can be derived economically only from harvested deer at check stations or by asking successful hunters to mail or turn in incisors (or other samples) for subsequent analysis.
- Tooth eruption and wear patterns may be used to develop age structure information from live deer, but this requires capture and handling of many deer in a population, which substantially increases cost.
- Tooth eruption and wear patterns can be subjective to some degree, and wear patterns differ depending on primary forage consumed. Regional differences in wear are common.
- Cementum annuli analysis and reporting often requires 3-5 months.
- Extracting teeth from live deer is often not practical or desirable.

Assumptions

- The sample is representative of the population or segment of interest. When sampling from harvested deer, care must be used when extrapolating to the entire population because of bias in hunter selection and differential vulnerability by age to harvest.
- Observers correctly assign classifications of age when assessing tooth eruption and wear.
- Observers correctly remove the proper incisor (I_1), or correctly identify and label alternate teeth.
- Laboratory personnel correctly enumerate cementum annuli.

Techniques

Knowledge of the arrangement and numbering of teeth is essential to evaluate age. Deer have 3 pairs of lower incisors (I_1, I_2, I_3) which are pressed against a hard upper palate (there are no upper incisors). The lower canines (C_1) are incisor-like (incisiform). Upper canines are absent except in rare cases. The lower jaw has 3 premolars (P_2, P_3, P_4) and 3 molars (M_1, M_2, M_3) on each side. There is no P_1. Fawns are born with all lower incisiform teeth (I_1, I_2, I_3, C_1), all 3 premolars (P_2, P_3, P_4), and 1 molar (M_1) on each side. All incisiform teeth and premolars are replaced with adult teeth before the age of 2 years, but molars are permanent (never replaced). This pattern of tooth replacement allows for very accurate aging through the 2.5 year-old age class. After all adult teeth erupt, tooth wear can be examined to estimate age. Inexperienced observers should be trained by experienced observers to learn key attributes on which to focus.

Techniques for determining age from tooth eruption and wear or from cementum annuli are described within most wildlife textbooks (e.g., Larson and Taber 1980, Dimmick and Pelton 1994). When applying tooth eruption and wear in field situations, age is typically recorded in classes (e.g., yearling, 2.5, 3.5-5.5, ≥6.5) because assessing wear is subjective and overlap among age classes in common. Because most deer observed in the field or at check stations display rigor mortis, a simple jaw spreader made from 0.5-in (1.25 cm) rebar or similar material (Fig. 8) can be used to pry the mouth open, which facilitates examination of teeth. Simply insert the flat end between the jaws in front of the premolars and rotate the tool to spread the jaws. Cutting through cheeks (with approval of the hunter) also enhances ability to evaluate tooth eruption and wear. If cheeks can not be cut, a flashlight or other bright light source may be needed to adequately observe molars.

Figure 10. This simple jaw spreader allows biologists to quickly and easily pry open a deer's mouth to examine tooth eruption and wear. The smaller end (approx. 2.75 x 5.5 in [7 x 14 cm]) is used for deer and the larger end (approx. 3.5 x 7 in [9 x 18 cm]) for elk. Overall length is approximately 20 in (51 cm). Photo by T. Keegan, IDFG.

Cementum annuli can provide accurate age estimates, and the preferred tooth for age estimation is I_1 because it is the first incisor replaced with a permanent tooth. This method requires the root tip be intact, so personnel must be careful to not break teeth during extraction. A tooth can be removed by cutting through the gum tissue alongside the tooth and gently pulling and twisting with pliers. Teeth are typically placed in a small paper envelope to allow drying. The tooth is then submitted to a laboratory where technicians cut a cross section of the tooth, stain it, and determine the number of cementum annuli by examining the stained section microscopically.

Mathematical models.— The utility of mathematical models is primarily in evaluation of possible and probable outcomes that may result from proposed management actions. Evaluation of model performance can be achieved through comparison of predicted values to empirically derived data (e.g., population size, harvest, age and sex ratios). Mathematical models include change-in-ratio estimators, published population models, agency-developed models, and population reconstruction models. Although models are routinely criticized for inaccuracies in predictions or being overly complex, mathematical foundations for most models are relatively simple. The challenge lies in obtaining accurate and realistic inputs for these models. Because most estimates of age and sex classifications may be biased and imprecise, the best models incorporate a component of variability. However, other necessary inputs include estimates of survival for specific age and sex classes in the population, and these estimates are generally even less well quantified than age and sex classification data.

Advantages

- Mathematical models are inexpensive to use (although precise and accurate data are often expensive to obtain), as many require few human resources once model runs have been initiated.
- Models allow managers to consider multiple management scenarios and use reasonable rationale to predict effects of management actions.
- The greatest benefit in comparing models with survey data is in developing an understanding of factors most likely to contribute to observed differences.

Disadvantages

- Mathematical models are limited by accuracy and precision of data input into the model. With a perfect knowledge of natality, cause-specific mortality, emigration, and immigration, and effects of weather and habitat changes on these factors, modeling deer populations would be straightforward and more useful.
- Because of the imprecision of mathematical modeling, most models require constant comparison and recalibration with empirical field data.
- Some models, like the change-in-ratio estimator, require ≥2 surveys within a relatively short time frame.
- All models yield predictions for next year based on assumptions that are difficult to quantify.
- When discrepancies between observed and modeled age and sex ratios occur, biologists routinely disagree about which values are less accurate: the empirical input data or the empirical comparative data.

Assumptions

- Input data needed to drive a model (e.g., initial population size, age and sex composition, birth rate, survival rates, and immigration and emigration rates) are accurate and, often, precise.
- When comparing predictions from models to observed data, those observed data are also accurate.

Techniques
The techniques, and assumptions, associated with each model differ somewhat. However, in practice periodic comparisons with empirical data are needed to gauge performance and test inferences derived from models.

Body Condition

Body condition is the term used to describe the physical parameters of a mule deer as it relates to age, skeletal growth, antler growth, mass, and muscle and fat levels. Indices or measurements of those parameters, in carefully designed monitoring programs or research projects, can provide a better understanding how harvest, nutrition, weather, and habitat influence mule deer populations (Harder and Kirkpatrick 1994). Typically, measures of body condition parameters are used as surrogate measures of nutritional quality of mule deer habitat.

Researchers have investigated a variety of measurements and indices of fat deposition and body condition to identify effective predictors of overall deer and habitat condition. Techniques have run the gamut from simple, minimally invasive methods (e.g., Riney 1955) that usually produce relatively low or untested correlations with body condition to intensive techniques requiring specialized equipment (e.g., ultrasonography) that provide strong predictive capability.

There are 2 main categories of body condition measures: measures of body fat (such as body condition score, rump fat depth, and kidney fat), and morphometric measures such as skeletal size (e.g., hind-foot length), chest girth, and body mass. Some techniques can only be applied to dead deer (carcass scores, kidney fat, marrow fat), whereas others can be applied to living or freshly dead deer (skeletal measures, body mass, body condition scores, ultrasonography; see Riney, 1955, Kistner et al. 1980, Wallmo and Regelin 1981, Austin 1984, Stephenson et al. 2002, Cook et al. 2005). When using any condition index, the relationship of a measurement or index to body condition should be well validated. In particular, care should be taken to recognize limitations or sensitivity of different indices, as some are only valid within specific ranges of body condition due to their curvilinear relationships with condition (such that small differences in a measurement can produce large differences in estimated body condition). Further, some body condition measurements are not easily measured in the field, and personnel must be trained (sometimes extensively) to take these measures consistently (Cook et al. 2007).

When choosing indices or parameters to measure, it is important to recognize some measures have been validated against whole body composition in the laboratory. In particular, predicting body fat allows comparisons across studies that use different techniques (e.g., data from a kidney fat index obtained via hunter collections with data from ultrasound from live deer). Estimation of body fat also allows users to make predictions about health and productivity of deer based on published values (e.g., probability of breeding) that would otherwise be less objective if simply using index values (R. Cook, National Council for Air and Stream Improvement [NCASI], personal communication).

Seasonal variation in nutritional quality (and quantity) of forage plants and foraging efficiency of ungulates is evident in the annual cycle of fat deposition and catabolism (Kistner et al. 1980, Wallmo and Regelin 1981, Austin 1984). The role of fats in life histories of mammals was reviewed by Young (1976). As deer gain condition, fat deposition occurs first in the marrow;

then the viscera, including kidneys, heart, and omentum; and finally in subcutaneous depots (Cederlund et al. 1989). Deposited fat is utilized in the reverse sequence (Harris 1945). In general, fat deposition typically peaks in early fall for buck mule deer and early winter for does (Anderson et al. 1972), but consideration should be given to variation in fat deposition cycles throughout mule deer range. For example, mule deer in the Rocky Mountains should be in prime or close to prime condition during the fall hunting seasons, whereas mule deer in the Southwest Desert ecoregion may be coming out of the dry summer and into a period of nutritional abundance. Therefore, standard or consistent timing of data collection for some measures of body condition is necessary for valid comparisons through time.

Body condition scores.— Body condition score (BCS) methods were initially developed to evaluate live domestic animals and later adapted to wild mammals. A BCS involves evaluating fat and muscle amounts through palpation at different places on the body and assigning condition scores (Gerhart et al. 1996, Cook 2000). Proper use of these techniques requires various amounts of training; but if carefully applied, this approach can yield consistent and predictable results.

Advantages

- Method is representative of whole body fat measures, particularly when combined with other measures (e.g., fat depth, see below).
- Non-invasive and usable on live deer.
- Requires little time.
- Validated models exist.

Disadvantages

- Requires training (sometimes extensive) for consistent application.
- Potential for measurement bias.
- Not all methods are widely documented in the literature.

Assumptions

- No measurement error.
- Age of deer is known or estimated accurately.

Techniques

Unfortunately, specific scoring criteria for the most recent versions of the BCS technique for mule deer (e.g., Cook et al. 2007) have not been made widely available (because of the authors' contention that the procedure cannot be used without training; R. Cook, NCASI, personal communication). To date, most biologists using the BCS technique developed by Cook et al. (2007) have obtained direct or indirect training from those authors.

Gerhart et al. (1996), from which succeeding techniques were modified, developed a body condition scoring system for caribou (*Rangifer tarandus*). The procedure developed by Gerhart et al. (1996) evaluated fat and muscle on a scale of 1 (emaciated) to 5 (obese) at 3 points: withers (shoulders), ribs, and rump-hips. However, this technique has not been validated for other species.

Ultrasound.— Ultrasonography is one of the most reliable methods for determining body composition in live deer prior to depletion of subcutaneous fat reserves (Cook et al. 2007, 2010). This method allows direct measurement of fat and muscle thickness at specific locations that can be used to predict percent body fat and gross energy (Cook et al. 2007, 2010; Bishop et al. 2009*a*). Subcutaneous rump fat thickness (MAXFAT, determined by ultrasonography, Stephenson et al. 1998) can be mathematically combined with BCS to produce an index referred to as LIVINDEX (Cook et al. 2001). Cook et al. (2007, 2010) found a combination of rump condition score and fat depth was superior to BCS or MAXFAT taken individually and provided high correlations with total body fat over the entire range of body condition.

Advantages
- Objective measurements that are highly correlated with fat and gross energy composition determined by whole body analysis (when body fat is >6%).
- Relationships between measurements and body condition are nearly linear.
- Non-invasive and usable in live deer.

Disadvantages
- Equipment is expensive.
- Training is required. Inexperience can result in measurements being taken in incorrect locations, measurement errors, or measuring incorrect tissue layer.
- Deer must be captured and handled.
- May be difficult to use under some field conditions.
- At body fat levels <6%, rump fat is no longer present, so ultrasonography alone will not detect differences in condition.

Assumptions
- Ultrasound measurements are made at the correct location, on the correct tissue layer, and without measurement error.

Techniques
Ultrasound measurement techniques have been described by Cook et al. (2007). Measurements usually include longissimus dorsi muscle (loin) thickness (as a possible threshold index for extreme protein catabolism) and subcutaneous rump fat thickness. When ingesta-free body fat is <6%, ultrasonography must be replaced with BCS or other methods to accurately predict body composition.

Kistner index.— This index (Kistner et al. 1980) has proven quite useful for estimating body condition and displayed relatively strong correlation with total body fat when slight modifications to the original scoring system were made (Cook et al. 2007). The technique is only applicable to dead deer and requires several internal organs to complete the assessment. The Kistner scoring system evaluates fat deposition at 6 sites (heart, pericardium, kidney, omentum, rump, and brisket) and body musculature. Scores can range from 0 to 95 (or 100 as modified by Cook et al. 2007). However, subsets of the full Kistner score provide predictions nearly as robust as using the entire score (Cook et al. 2007).

Advantages

- High correlation with total body fat (r^2 = 0.92 when modified by Cook et al. 2007).
- Relatively easy to assign scores with moderate training and appears repeatable across observers.
- Requires no specific tools or equipment.

Disadvantages

- Body muscle and fat assessments are somewhat subjective.
- Requires internal organs typically removed by hunters (generally not available at check stations).
- Relationship is somewhat curvilinear at very high condition levels.

Assumptions

- Body muscle mass and fat deposition are accurate indicators of body condition.

Techniques

The Kistner index is a summation of body musculature assessment and body fat assessment scores. Body musculature (as modified by Cook et al. 2007) is rated as either 0 (bony), 5 (moderate musculature), or 10 (full musculature). Each of the fat depot sites is scored from 0 to 15 in increments of 5 (0 = none, 5 = slight amounts, 10 = moderate amounts, 15 = heavy amounts) in the original score and in increments of 1 as modified by Cook et al. (2007). To be scored as heavy amounts (score = 15), subcutaneous rump and brisket fat should be ≥0.75 in (2 cm) thick (Kistner et al. 1980). Subset scores (e.g., pericardium plus kidneys scores) can provide robust predictive measures of body fat if the entire deer is not available for assessment (Cook et al. 2007).

Femur marrow fat.— Marrow fat (in particular from the femur) has been studied and used as an index to body condition in cervids for many years (Cheatum 1949, Neiland 1970, Verme and Holland 1973, Torbit et al. 1988). Methods developed to assess femur marrow fat from dead deer range from cursory field methods based on color and texture to more quantitative methods utilizing wet and dry mass differences as a measure of fat content. Because marrow fat is the first to be deposited and the last to be mobilized (Cheatum 1949), this technique does have limitations and should be combined with some other measure of body condition to assess deer carcasses above 6% body fat. Cook et al. (2007) mathematically combined femur marrow fat and a kidney fat index (total fat mass) to create a separate index referred to as CONINDEX (Connolly 1981), which provided a robust predictor of mule deer body fat (r^2 = 0.92). Perhaps the greatest value of femur marrow fat alone as a condition index is to determine whether certain thresholds of body fat depletion have been reached (i.e., whether fat reserves are depleted to the point where marrow fat is being mobilized and whether marrow fat is mostly gone indicating most mobilizable fat reserves have been used).

Advantages

- Specimen collection is often relatively easy.
- Visual inspection can be done in the field without laboratory work.
- Laboratory processing techniques are fairly simple.
- Reliable indicator of malnourishment (when marrow fat is being mobilized).

- When combined with a kidney fat index, can provide a useful predictor of body fat over a larger range of body condition than when either is used alone.

Disadvantages

- Relationship to body fat is curvilinear and provides no predictive value when body fat levels are >6% (very narrow range of usefulness).
- Relatively low predictive value for body fat (r^2 = 0.79, Cook et al. 2007).
- Visual inspection techniques are typically not sufficiently robust for quantitative use.
- Can be difficult to collect on frozen carcass.

Assumptions

- Any depletion in marrow fat (<85%) indicates body fat is <6%.

Techniques

Remove the femur from the deer; if possible, estimate age of the deer. The bone can then be sampled or frozen for later examination. If the femur will be stored in a freezer for a long period, whole bones should be sealed in an air-tight bag to prevent desiccation. To assess marrow fat, break or saw the femur so as to remove a section of marrow. Examine marrow for color and texture as described by Cheatum (1949). Color and texture ranges from almost white and firm (prior to mobilization) to a red, jelly-like stage (poor condition). Texture and firmness, determined by feel, often provide more accurate determination than color in field examinations. The same sample can be used in the drying technique described by Neiland (1970) or chemical extraction methods described by Verme and Holland (1973). A common use of femur marrow fat examination is as an aid in assessing contribution of malnutrition in studies of cause-specific mortality.

Kidney fat indices (KFI).— A variety of measurements of fat deposition around kidneys have been developed as indices to body condition (see Riney 1955, Anderson et al. 1972, Cook et al. 2007). Different KFIs vary primarily with respect to what portion of the perirenal fat is measured (e.g., trimmed or whole fat mass) or whether a ratio is used that includes mass of the kidney (i.e., instead of using the fat mass as a stand-alone index). These indices provide moderately accurate estimates of total body fat in mule deer (Torbit et al. 1988; r^2 = 0.81-0.87, Cook et al. 2007). Cook et al. (2005) indicated KFI was a moderately useful technique, but had a limited range of usefulness, at least in elk. However, when combined with femur marrow fat into a CONINDEX (see femur marrow fat above), the value of KFIs can be improved.

Advantages

- Measurements can be collected in the field with simple equipment.
- Moderate correlation with body condition.

Disadvantages

- Curvilinear relationship to total body fat limits the range over which KFIs are considered sensitive to changes in body condition.
- Small measurement errors could have large effects on body fat estimation.
- Some KFI scores are subjective and may be influenced by observer effects.

- Accuracy and consistency of sample collection can be poor because identifying fat associated with kidneys is subjective.

Assumptions
- Measurement errors are very small and unbiased.
- Scores are consistent within and among observers.
- Age of deer is known or estimated accurately.

Techniques
Wide variation in kidney mass and KFIs have been noted by some investigators, so KFI should be determined consistently (use right, left, or an average of both; not a mixture). Techniques were described by Anderson et al. (1972) and Cook et al. (2007). Basically, kidneys and associated fat are removed from a carcass and weighed (to the nearest 0.1 g). For developing the KFI, perirenal fat can either be trimmed as per Riney (1955) or kept intact as per Anderson et al. (1972). To avoid issues with seasonal fluctuations in organ mass, mass of the fat alone can also serve as an index to condition. No matter which variation is used, log-transformed indices tend to provide greater correlation with total body fat (Torbit et al. 1988; Cook et al. 2001, 2007).

Wyoming index.— This index provides a quick and easy technique to use in the field or at a check station that requires only the typical field-dressed carcass. In deer, subcutaneous body fat is deposited along the spine starting on the rump, then over the kidneys, and finally over the shoulders. Thus, a deer in excellent condition will have fat along the entire length of the spine. A deer in fair or poor condition will only have fat over the rump. This technique is an assessment of body condition that incorporates the index of muscle condition developed by Kistner et al. (1980) and an index of subcutaneous body fat deposition along the spine (Lanka and Emmerich 1996, Lutz et al. 1997).

Advantages
- Can be used on harvested deer.
- No internal organs needed.
- Easily applied in the field and at check stations with only the carcass.

Disadvantages
- Body muscle assessment is subjective.
- Inexperienced observers can mistake connective tissue for fat.
- Even with modifications, only moderately correlated with total body fat in mule deer due to the categorical nature of this index ($r^2 = 0.75$, Cook et al. 2007).
- Relationship to total body fat is highly curvilinear when deer are at higher levels of body condition (limited range of use).

Assumptions
- Body muscle mass and fat deposition are accurate indicators of body condition.

Techniques
The Wyoming index is a summation of body musculature assessment score and body fat assessment score. Scores range from 0 (poor) to 20 (excellent) in increments of 5. Rump fat on deer in excellent condition (body fat score = 15) should be ≥0.75 in (2 cm) thick (Kistner et al. 1980). Because of the limited range of use and moderate correlative value, use of the Wyoming index should be limited to broad scale evaluations (e.g., herd unit).

Body Musculature (Maximum score = 5) – Ocular assessment of muscle mass of the deer. If body is bony, score = 0; body musculature is full, score = 5.

Body Fat (Maximum score = 15) – This parameter is obtained by making incisions in the deer's hide to assess whether or not fat is present at 3 locations over the spine: 1) just above the base of the tail, 2) above the kidneys, and 3) above the front shoulders (Fig. 9). If

No visible fat at point 1, score = 0;
If fat visible at point 1, score = 5;
If fat visible at point 2, score = 10;
If fat visible at point 3, score = 15.

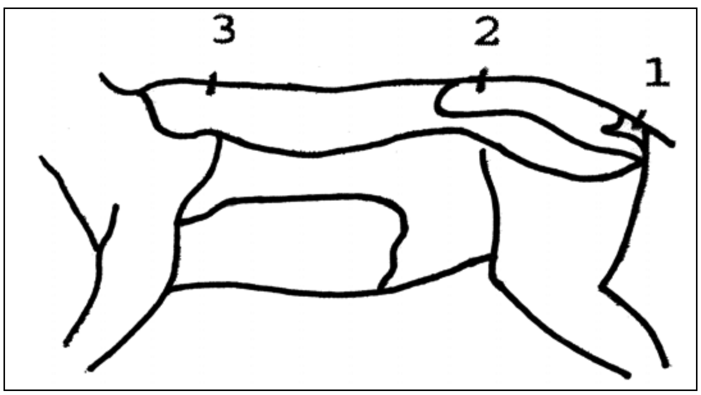

Figure 11. Body fat scoring incision locations and representative fat deposition. Figure courtesy of WGFD.

Xiphoid fat.— Xiphoid fat depth can be used as an index to overall body fat, and therefore body condition (Austin 1984). Body fat in northern mule deer is at a maximum in late fall and reflects the annual nutrition cycle (Wallmo and Regelin 1981). Thus, body fat can be inferred as a measure of summer habitat quality (Kistner et al. 1980). Xiphoid fat is deposited subcutaneously and thus is deposited last and used first (Harris 1945). Austin (1984) found xiphoid fat was most sensitive in yearling bucks, with fat deposition varying more in older deer.

Advantages
- Can be gathered at check stations or during field contacts.
- Minimally invasive to a carcass.
- Detects gross differences in condition.

Disadvantages

- Has not been validated against whole body fat.
- Does not reflect fine scale changes in overall body condition well.
- Usefulness generally limited to yearling bucks.
- Need ≥100 samples for useful comparisons.
- Measurement bias can be a problem.
- Can only be measured on dead deer.
- Fat depth may be obscured or altered by hunters during field dressing.
- Some hunters do not want their deer cut across the xiphoid process.

Assumptions

- Measurement is accurate and consistent.
- Fat deposition on the xiphoid is representative of the rest of the deer.

Techniques

Begin by making a 2-in (5-cm) incision through the hide to the base of the sternum and through the xiphoid process. Use a clear plastic rule to measure depth of fat between the skin and the process perpendicular to the sternum at several points along the first 0.75-1.25 in (2-3 cm) of sternum without deforming the layers. There is a thin layer of muscle <1 mm thick that lies beneath the fat layer; use that layer as a boundary for the measurement. Measure to the nearest millimeter and calculate a mean of multiple measurements. Occasionally there are multiple layers of fat, in which case, only the top layer should be measured (Austin 1984). Xiphoid fat depth is generally considered to have limited usefulness because of difficulty in obtaining accurate measurements and lack of sensitivity.

Metabolic indicators.— A variety of blood, urine, and fecal compounds have been investigated as potential indicators of nutritional status and body condition in deer (e.g., Saltz and White 1991*a*, *b*; Saltz et al. 1992; Saltz et al. 1995). Of all these compounds, serum thyroid hormone concentrations appear to have the most potential for evaluating the metabolic status of mule deer if used under the right conditions (Bishop et al. 2009*a*). Although serum thyroid hormone concentrations can be used to predict percent body fat, their greatest potential value is for evaluating relative condition of deer populations over time and by area. Mule deer does that received supplemental feed during winter in Colorado could be readily differentiated from does that did not based on their serum thyroid hormone concentrations (Bishop et al. 2009*a*).

Advantages

- Relatively easy and inexpensive to obtain if deer are being captured for other reasons, such as radiomarking.
- Applicable to live deer with minimal handling.

Disadvantages

- Deer must be captured to obtain blood samples.
- Thyroid hormones are only useful indicators when deer are in a catabolic state during late winter (limited range of usefulness).

- Samples must be taken during the same time of year and from the same sex and age classes to be comparable.
- Metabolic indicators are rate variables as opposed to state variables and can be highly influenced or confounded by nutritional status (diet), season, and sex and age of a deer.

Assumptions

- Serum thyroid hormone concentrations are related to long-term metabolic status rather than circannual patterns and short-term fluctuations or nutritional status (diet).

Techniques

The optimal time to take blood samples for thyroid hormone analysis is in late February and early March when deer are catabolizing their body reserves. Thyroid hormones can have little relationship to body condition when deer are in an anabolic state (i.e., during fat accretion) and can vary seasonally. Does are recommended for sampling over fawns and bucks because they will likely show a greater range of body condition and thyroid hormone concentrations in late winter. Bishop et al. (2009*a*) found total thyroxine (T4) and free T4 had higher correlations with body fat than total triidothyronine (T3) and free T3 in mule deer does, whereas Watkins et al. (1991) found T3 to be the best indicator in white-tailed deer fawns.

Skeletal size.— Skeletal size measures can be used as an index to growth, and thus nutrition, of deer when they were fawns. Skeletal measures have long been used as an index to age, growth rates, and body condition as a function of growth (Verme and Ozoga 1980). Common skeletal measures include total length, chest girth, femur length, hind-foot length, and metatarsal length. Hind-foot or metatarsal length measurements have been found to represent age and overall growth of mule deer fawns (e.g., Robinette et al. 1973) and can be more accurately measured than total length. Chest girth can be confounded by subcutaneous body fat, particularly in adults, and thus should be used in conjunction with other measures. Combinations of hind-foot length, chest girth, and body mass were used to assess winter fawn size and condition (M. Hurley, IDFG, unpublished data)

Advantages

- Skeletal measures are easy to obtain on live-captured or harvested deer.
- Measurement error for most variables is a minor issue with minimal training (however, chest-girth measurements may be prone to inconsistency).
- Skeletal growth can index nutritional quality of habitat during the period when most growth occurred (e.g., fawn measurements in early winter reflect summer nutrition; M. Hurley, IDFG, unpublished data).

Disadvantages

- Measurement errors can bias data, especially for longer measurements when a tape must be repositioned to complete the measurement.
- Requires large sample size and multiple years of data in order to make inferences about annual differences in body condition.

- Limited value unless used in conjunction with mass measurements for analysis.

Assumptions
- Systematic relationship between body condition and skeletal measurements.
- Ages and lactation status are estimated accurately.
- No measurement errors.

Techniques
Skeletal measurements should be made with a soft measuring tape (e.g., cloth, fiberglass) that will conform to body contours (when applicable) and not stretch or shrink under field conditions.

Total length – Measure is taken from the end of the nose to the tip of the tail by contouring along the spine.

Chest girth – Measured around the chest immediately behind the front shoulder and perpendicular to the spine. The tape end is then pulled firmly alongside the tape and length is measured on the exhale (Fig. 10). When measuring chest girth, tape tautness should remain as consistent as possible across deer and measurers in an effort to minimize measuring error.

Figure 12. Measuring chest girth of a mule deer fawn. Photo by T. Keegan, IDFG.

Hind-foot length – Measured from the tip of the calcaneus to the tip of the hoof along the lateral side (Fig. 11).

Figure 13. Measuring hind foot length of a mule deer fawn. Photo by C. Austin, IDFG.

Metatarsal length – Best measured with a large caliper starting at the tip of the calcaneus forward to end of the metatarsal with the hoof bent at 90 degrees to the metatarsal bone.

Body mass.— Body mass is a function of the combined mass of musculature, skeleton, viscera (with contents), and body fat of a deer. Monitoring differences and changes in mass can be a useful tool for examining body condition. For a small ungulate like mule deer, body mass is a relatively simple measure to obtain. Mass can be measured in terms of total body (alive or dead) or eviscerated carcass. Gerhart et al. (1996) used mass in combination with a body condition score to obtain a body reserve index for caribou. However, Cook et al. (2007) found mass did not improve predictive value of condition scores for mule deer.

Advantages

- Relatively easy to obtain.
- Small measurement error.
- Can be measured on live deer.
- May have potential for combination with other body condition measures to create condition indices.

Disadvantages

- Body mass is only moderately correlated with body composition in mule deer (Cook et al. 2007, Bishop et al. 2009*a*) and what mass alone indicates may be ambiguous.
- Ingesta mass and products of conception can greatly influence live body mass.
- Measures of eviscerated carcasses can be biased depending on which organs and other tissues are removed from the carcass.
- Differences in individual scales can bias data.
- Deer must be physically handled.

Assumptions

- All scales are calibrated the same.
- All measurements are accurate.
- Organs and tissue removed from eviscerated carcasses are the same.

Techniques

Body mass measure is taken by weighing the deer with a scale. Scales can vary from spring scales (most commonly used) to strain gauges (mechanical and electric). To obtain accurate measurements, the range of scales must completely overlap the range of expected deer body masses, while maximizing sensitivity of the measure. For example, if weighing deer neonates where maximum expected mass will be 15 lb (7 kg), biologists should use a 20-30-lb (9-14-kg) scale with ≤0.1-lb (0.5-kg) graduations, rather than a 300-lb (136-kg) scale with 5-lb (2-kg) graduations.

To obtain masses on un-sedated mule deer, they must be adequately restrained to reduce excessive movement. One of the easiest restraint methods is wrapping a nylon hobble around the 4 legs. Most wildlife veterinarians recommend weighing hobbled deer in a sternally recumbent position in a cloth or nylon bag. Maintaining sternal recumbency during the procedure helps prevent aspiration of rumen contents and gut torsion. For weighing neonates or young fawns, a small cloth or nylon bag that will securely hold the deer works well. Another acceptable method is to suspend the deer below a scale on a cradle or stretcher. Tare weights of restraining materials should be taken into account. When possible, someone other than those lifting the scale and deer should read the scale to ensure accuracy of measurements.

To provide useful information, mass measurements must be collected and reported by sex and age class. Mass of fawns and yearlings should be most reflective of recent environmental variation and thus more important in identifying relationships among habitat and weather conditions.

Antler size.— Antler size is directly related to 3 factors: age, nutrition, and genetics. Males on a higher nutritional plane are more likely to approach their maximum genetic potential for antler growth. Antler growth has been linked to nutrition in captive white-tailed (French et al. 1955) and mule deer (Robinette et al. 1973). Anderson (1981), using data from Snyder (1959), identified significant differences in yearling buck antler beam diameter between years of substantially different rainfall and attributed increases to increased nutrition. Similarly, several authors noted declines in proportions of spike-antlered yearling bucks under improved habitat conditions (Swank 1958, Snyder 1959, Wallmo 1960). Conversely, Anderson and Medin (1969) found antler growth did not change with changes in forage quality and availability during years of extreme difference in moisture in Colorado, but suggested antler growth was an accurate predictor of age for mule deer <40 months of age.

Although attempts have been made to use antler growth as an index to condition by age class throughout mule deer range, antler growth appears to be a poor or inconsistent predictor of body condition in free-ranging mule deer. Use of antler growth measures as an index to mule deer body condition may be limited because of the large degree of variation in antler growth across regions, probably in relation to differences in climate, habitat, and soil mineral content. Further, antler growth may only correspond to nutrition during a portion of the year. Antler measurements are typically collected from harvested deer.

Advantages

- Data can be easily gathered at check stations or in the field.

Disadvantages

- Only applies to males.
- To date, little, if any, quantitative relationship to forage quantity and quality (nutrition) has been documented for mule deer.
- Potential for measurement errors if data collectors are not properly trained.
- Reflective of only nutritional conditions before and during antler growth period and may not reflect current body condition.
- Age, genetics, and regional differences in nutrition exert a substantial and highly variable influence on antler growth.

Assumptions

- Ages accurately estimated.
- Antler development of local deer is similar and something less than the maximum genetic potential.
- Antler growth changes with buck age.

Techniques

Several different measures have been taken by researchers, including a main beam length, basal circumference, inside spread, number of points, and symmetry (Lindsdale and Tomich 1953, Anderson and Medin 1969, Robinette et al. 1973). Other researchers have measured antler volume using water displacement, antler mass, and combinations of tine length and diameter measurements (e.g., scoring systems developed for record keeping) to measure antler growth. As with body mass, data should be reported by age class, with yearling antler growth having the most potential to reflect nutritional conditions during the previous spring and summer. At this time, we recommend against use of antler size as a measure of body condition.

DATA STORAGE AND RETRIEVAL

Much has been written about study design, data collection, statistical analysis methods, and computer programs for population analyses (e.g., Bookhout 1994, Anderson 2001, Braun 2005, this handbook). But the wildlife literature is surprisingly deficient in describing methods for effectively storing and managing wildlife data. Organized and cost-effective data management, coupled with appropriate retrieval systems, is critical for efficiently synthesizing information and answering questions about mule deer populations.

Most mule deer managers are accustomed to storing and analyzing data they collected at a local level. However, demands and expectations for data typically exceed local needs. To be useful for jurisdiction-wide or regional management of mule deer, data must be shared and analyzed at those scales. Technical aspects of data management at such large scales, such as design of relational databases, may exceed the expertise of many mule deer managers and fall under the purview of information technology specialists or biometricians. But managers and biologists need to understand requirements and processes for correct data collection and storage as well as those for retrieving, analyzing, and reporting data.

There exist a number of common challenges in using and storing data. In this section, we address how to store your data in the most effective and efficient ways, now and in the future. Given the tremendous rate of change in computer technology, tools available in the future may be very different than what we have today, but we must ensure our data (past and present) are stored so their value is maintained in perpetuity.

Standardization

Carpenter (1998) identified the lack of standardized inventory methodologies and data management among agencies as an obstacle to understanding deer population status and management. He and others (e.g., White and Bartmann 1998, Bowden et al. 2000, Carpenter et al. 2003) recommended types of data that should be collected to monitor mule deer populations. Similarly, Ballard et al. (2002) were unable to conduct a synthetic analysis of deer radiotelemetry data from several western states because original data were often unavailable or irretrievable; they made a compelling case for integrating such data into centralized archives.

Mason et al. (2006) made a case for standardizing ungulate surveys and data management in the West and articulated a need for more research and monitoring at regional scales. Among their recommendations were:

- Review existing agency monitoring and management strategies to increase consistency and data sharing.
- Explore inconsistencies that impede greater interagency cooperation.
- Develop practical methods for statistically reliable deer and elk population monitoring and guidelines for data collection, storage, and sharing.
- Have each agency's results stored in a searchable relational database.
- Develop a regional archive of scientifically defensible data.

- Use interagency data to study trends and causes of population changes at landscape scales.
- Improve research and monitoring at regional scales.

Mason et al. (2006) concluded combining data among agencies will leverage increasingly scarce resources and lead to more efficient management and cost-effectiveness for each agency. They also suggested development of a regional data archive would strengthen credibility of agencies, broaden public support of harvest regulations, and reduce potential for legal problems caused by differences among agency management regimes. Rupp et al. (2000) suggested future challenges to population survey results would likely be based on statistical arguments about deficiencies in deer data. Consistent, long-term data are very valuable for adaptive management of wildlife species (e.g., Lancia et al. 1996*b*, Enck et al. 2006).

To aid in meeting recommendations of Mason et al. (2006), we suggest the following goals for any mule deer inventory or research project:

1) Collect high quality data (important and measured without error).
2) Ensure data are correctly and accurately entered into an electronic format.
3) Store data appropriately so information can be easily accessed when needed.
4) Store data securely to ensure integrity.
5) Provide access to data for everyone who needs or wants it (now and into the future).
6) Ensure data are easily comparable across subareas within your jurisdiction and across time, as well as among states and provinces.

Data Collection (Goal 1)
Previous chapters focused on appropriate data collection methods for mule deer. However, there are some basic aspects of data collection that can enhance data storage and retrieval. Raw data should be collected and stored at the lowest level possible, along with summarized or interpreted results (Huettmann 2005). Raw data can always be recombined or summarized, but the reverse is not possible. Maintaining raw data allows application of new or improved correction factors, statistical procedures, data groupings, or other analyses.

Widespread availability of GPS-enabled systems has been a boon to mule deer monitoring, allowing managers to record spatial locations with relatively high accuracy. However, inconsistent or erroneous use of geodetic datums and coordinate systems can reduce accuracy of such data (O'Neil et al. 2005). Ideally, all staff within an agency should use a single standard. At the very least, geodetic datum must be recorded and included with all records. Although conversion among datums is not difficult, for compatibility with current GIS, recommended datums are North American Datum of 1983 (NAD 83) or World Geodetic System of 1984 (WGS 84) (FGDC 1998, O'Neil et al. 2005). For ease in data entry and usage, latitude and longitude coordinates should be recorded as decimal degrees.

Data Entry (Goal 2)
Data must be accurately entered into a database or spreadsheet and double-checked for accuracy. Entry should be governed by data validation rules to help prevent erroneous, invalid, or duplicate data from being entered and uploaded. Data entry should be kept as simple, efficient, intuitive,

and well-defined as possible. Most database programs allow constraints on data being entered to prevent out-of-range values, incorrectly formatted entries, or missing data. Spreadsheet entry provides an option for uploading large data sets as long as validation occurs during entry and upload.

Data Storage (Goal 3)
Most wildlife agencies have trained professional database managers (e.g., information technology specialists) who manage large databases of financial transactions such as license sales and budgets, and other specialists who develop web sites and user applications. But it is field staff who collect data describing deer populations, and this is typically where problems arise in data management.

The following scenarios characterize effective data management systems in keeping with recommendations of Mason et al. (2006):

- All similar data are combined into 1 large database (e.g., relational, hierarchical), covering all years and areas of the state or province.
- All data of a given type are in a single format.
- The database contains metadata which describe source, contents, and limitations of the data.
- The database is stored at a central location on a common network drive.
- All agency staff are networked together and use the same software (and same version) so they can all access central network drives.
- The network is protected by a firewall, virus scanners, and other security features.
- Network databases are backed up automatically (daily, weekly, monthly) and updated to account for new versions of software and hardware.
- Important datasets are password-protected and read-only, so only authorized users can make changes or view sensitive data.

Data Security (Goal 4)
Data security falls into 2 broad categories: maintenance of correct biological data and protection of personal information. Data maintenance begins with field data collection. Whether data are recorded on paper or electronically, care must be taken to protect the media until data can be replicated and transferred to permanent storage. Any number of mishaps can cause loss of data (e.g., theft, physical damage, or loss of equipment or storage media; accidental or malicious computer problems; large-scale disasters), so data must be replicated and stored in several locations to ensure integrity. In concert with an appropriate storage system, data security can be enhanced at various levels through read-only access protection, password protection, firewalls, and protective programs (e.g., against viruses, malware, spyware). Any changes to a database should be recorded as part of the metadata (see below).

Although security of biological data is integral to mule deer management, security of personal information has more far-reaching legal and social ramifications due to potential for identity theft and other fraudulent uses. Most agencies have developed policies and procedures for protection of personal information, but some information may still be widely available to agency personnel (e.g., lists of license holders with personal information, harvest reports). Personal information, particularly Social Security or driver's license numbers, should not be transferred from agency databases to portable computers or storage media or unsecure computers. If such transfer is required, data should be password protected and encrypted.

Data Accessibility (Goal 5)
Data (raw and summary) should be made easily accessible so it can be provided to other users in your own agency, agency managers, other agencies, and stakeholder groups (Huettman 2005). Although wide access to data may be a cause for concern (e.g., misinterpretation, misuse, pre-publication release), data collected by government employees are essentially public property and thus available to anyone through various public records laws. In the case of sensitive or draft data, access can be controlled through a variety of security measures.

Access to data may take several forms: collaboration and analyses among agency staff; information needs of policy makers (directors, commissioners, legislators); requests from stakeholders; and legal requirements (reports to funding agencies, legal challenges). Thus, requests for information can range from simple to extremely complex. Regardless of complexity, the process of providing answers is facilitated through use of queries and well-organized databases.

An important aspect of data management, access, and queries is database structure. Data must be structured so as to allow efficient queries. Required products might include a sub-set of data records, summary table, graphic representation, statistical analysis, or GIS map. Producing these items usually requires exporting data into a statistical or graphics software package. Therefore, data should be structured to enhance extraction and be flexible in a number of different formats. Relational or hierarchical database structures offer several advantages in accessing, managing, and summarizing data. In some cases, connections can be designed to directly access a database and transfer specific data on demand. Professional credibility is enhanced by having and providing high quality data in an appropriate format with advanced analyses when requested.

For some assessments, different types of data from several sources must be compiled. For example, harvest, GIS, and license data are usually kept in separate databases from inventory data, but might be used together to assess harvest success by management unit. Similarly, multiple data sets might be needed for population modeling. Ability to integrate multiple datasets for applications should be considered when designing a database system. Most database programs allow data from many sources to be easily connected.

Positive attributes of data accessibility include

- Accessible via commonly available software (others could find and access data in your absence).
- Easy to understand (e.g., simple formats and clearly labeled variables).
- Metadata available to describe the database.
- Easy to summarize (e.g., within and across years, geographic areas).
- Easy to analyze (using queries, statistical packages, etc.).
- Ability to generate automatic analyses and summaries for users (including those who collected and entered the data).

- Data tables can be exported directly into other programs (statistical packages, graphics software).
- Data can be linked to or easily uploaded to an agency website.
- Data can be linked to other applications (e.g., on-line hunter assistance programs).
- System is adaptable to take advantage of new technologies.

An important feature of centralized databases with well-designed access is cost savings. Cost of data storage is now so low that there is very little expense involved in storing and backing-up the largest data files (possibly excluding high-resolution photographs and GIS maps). A much greater expense would likely arise from inefficiently finding, managing, and comparing many separate smaller data files on different computers. Further, a single database approach is more efficient with regard to back-up procedures and software updates and conversions.

Data Comparability (Goal 6)
The most important requirement for ensuring data are comparable is standardization. Each user should record data in the same format, across years and management units, and have them stored in the same location. Ideally, raw data collected in one jurisdiction would be similar to data collected in nearby jurisdictions. Object-oriented data storage models (e.g., eXtensible Markup Language [XML]) provide a flexible structure to store and transport data in different formats and across different systems and may facilitate information exchange among agencies via the Internet. This approach allows comparison and collaboration among jurisdictions, resulting in more rigorous scientific results, more appropriate policy decisions, and hopefully, the ability to withstand social and legal challenges. Numerous benefits derive from being able to compare data collected by different methods in the same or similar locations (e.g., Unsworth et al. 1999*b*, Freddy et al. 2004). Vast amounts of data have been collected across the range of mule deer, and we would all benefit from regional or range-wide analyses of this information (e.g., Ballard et al. 2002).

Most large organizations are moving toward standardized and centralized data management. There are many advantages:

- Data are much more secure. Likelihood of data loss due to accidental erasure, computer breakdown, corrupted data files, stolen hardware, retirement or death of an employee, power surges, natural disasters, etc. is significantly reduced. Files can be password protected or placed behind firewalls.
- Datasets are all-inclusive through time and space, facilitating summary and analysis at multiple scales.
- Data can be backed up more efficiently.
- Data can be jointly viewed by many different users, in different locations, at the same time.
- Software upgrades, and corrections and improvements to data can be done once and provided to everyone (e.g., revision of DAU groupings).
- Purchasing power of entire government agencies allows use of similar computers and software packages which enhances computer maintenance and reduces training needs.
- Consistent data formats and management can be applied to multiple species.

However, no system is without some negative aspects. Potential disadvantages for centralized data management include

- Some agency staff may resist due to perceived loss of control over data, concerns about ability to access data, or unfamiliarity with software.
- Conversion may require strong leadership to convince everyone involved to use standard formats and central storage. Clear agency policies on data management are essential.
- May require a dedicated database manager and additional specialists to manage data and run complicated queries.
- May require multiple back-up methods (e.g., tape, server, CD-R) and locations (on-site and off-site).
- The need for automated queries or programming usually requires additional staff time.
- Networks can occasionally suffer from technical problems (low speed, service disruptions), particularly for remote users.

Computer Technology

There have been incredible changes in computer technology since approximately 1986, when many biologists began using personal computers. White and Clark (1994) described in detail software and hardware available at the time and noted "computer use had exploded" in the previous 20 years. They went on to state computer use was the fastest developing part of the wildlife profession and predicted huge changes in the future. Some 15 years later, some of the technology they described is now obsolete.

And yet, many problems identified by White and Clark (1994) are still with us: entering, storing, and documenting data for effective use; backing up data to prevent loss; obtaining appropriate, affordable software; and staying current with computer technologies. Perhaps surprisingly, there is little mention of these topics in the most recent wildlife techniques manual (Braun 2005).

Keeping up with technology is just as large a problem for us now. For example, by the time this document was published, there was a new version of the software used to produce it. In the near future, computers, servers, networks, and storage devices may barely resemble current technology.

Older media (e.g., floppy disks, diskettes, tape drives, and now CD-Rs), once standard technology, are rapidly becoming outdated and data backed up on those media may already be difficult to retrieve. Stability of various digital storage media are not well understood, but failures of CD-Rs within 5 years have been noted and stability varies among different types and manufacturers (Slattery et al. 2004, Bradley 2006). Further, CD-Rs may become obsolete as technology advances (Bradley 2006). In contrast, portable hard drives and flash drives can inexpensively store enormous amounts of data (e.g., 1 terabyte = 1 million megabytes or approximately 1 million 3.5-in diskettes). Regardless of the storage media, managers must develop specific plans for updating storage as technology advances.

Software

Making recommendations about specific software is difficult and such recommendations can quickly become obsolete. The computer industry is very competitive and there are numerous similar products available to serve a specific purpose, often at a range of prices. In many cases, agency staff have computers and software purchased as a package through government purchasing (lowest bid), and therefore not under direct control of individual staff. Therefore, for simplicity, we will speak generically of several kinds of software.

Microsoft (Redmond, WA) products (e.g., Excel, Access, SQL Server) are the most widely purchased programs running on personal computers. However, there are other similar products available, with different features or prices, including open source counterparts available through the Internet at no cost. Users should look for products that allow for simple exchange of data among various software programs.

A variety of statistical packages are available, both as stand-alone commercial software (e.g., SAS [SAS Institute, Cary, NC], SPSS [Chicago, IL], Statgraphics [Statpoint Technologies, Warrenton, VA], Systat [Systat Software, Richmond, CA]), or freely downloadable programs (e.g., R-Project, www.r-project.org/). R is a free software language and environment for statistical computing and graphics that provides a wide variety of statistical (e.g., linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering) and graphical techniques.

Either spreadsheet or database software can be used for managing and analyzing a dataset (entering data; combining, comparing, and manipulating these data; joining with other data sets; and backing them up). Which is more appropriate depends on size of the dataset and types of manipulations to be applied. If you can store and analyze all of your data on 1 worksheet of a spreadsheet, then a spreadsheet may be a practical alternative to a database program, although spreadsheets have limitations. Conversely, a database program is the best way to store and manage large amounts of complicated data, particularly when data must be combined from multiple sources or files to conduct analyses.

Spreadsheets (for use as a database)

Advantages

- Relatively simple to learn and use.
- Best for small datasets (e.g., <1,000 records).
- User can easily conduct complicated arithmetic (including population modeling) and moderately advanced statistical procedures.
- Producing charts and graphs is convenient.
- Easy to print simple reports and lists of records.
- More efficient for a one-time analysis.
- Easy data duplication.
- Many diverse plug-ins available.

Disadvantages

- Unable to check data validity during entry.
- Creating subsets of data can be challenging.
- Difficult to join or compare 2 lists.
- Data records (cells) are not linked and can be scrambled by improper sorting.

- Difficult to conduct complicated queries or analyze across multiple groups.
- Known to produce mathematical errors under some circumstances, particularly when there are missing data values (Powell et al. 2008). Difficult to check math for large spreadsheet calculations.
- Difficult to print records in complex formats (e.g., reports).
- Lack database security features.
- Limited capacity.
- Only available to 1 user at a time, which can lead to creation of multiple versions.

Relational databases

Advantages

- Capable of efficiently storing and manipulating large, complicated databases (thousands to millions of records).
- User can create data input forms with constraints on data input, which reduces invalid entries (e.g., prevent missing values, ensure correct format, specify bounds, limit entries to drop-down lists).
- Allows user to develop and save powerful queries (e.g., sort and group records, select subsets of records, join several subsets of records to create a new table for analysis, conduct arithmetic and simple statistical procedures).
- Flexibility in specifying export content and format; allows use in many other programs.
- Data records are unique entities that cannot be scrambled by sorting procedures.
- Ability to develop automated queries for common data analysis questions.
- Allows for online analytical processing to conduct real-time, easily customized, or complex queries.
- Allows for advanced security.
- Can be accessed by multiple users at the same time.

Disadvantages

- More difficult to learn and use.
- May need a technical specialist for more complicated queries or specialized uses.
- Limited graphics capabilities, so user must export data to other software packages to create charts and graphs.
- Limited capability for statistical analysis, so user must export data to other software packages.

Data Continuity and Metadata

Guaranteeing availability and maintenance of datasets through time is a critical aspect of mule deer management. As databases grow through time, so does reliability of estimates derived from the data and ability to conduct more complicated analyses. Many attempts to retrieve and analyze important, expensive information have failed because data have been lost or stored in unusable or obsolete formats (e.g., Ballard et al. 2002). Provisions for data continuity and compatibility should be a foremost goal in the design of data management systems. Although determining likely future data formats is challenging, these actions will enhance future compatibility and continuity:

- Upgrade files and data to newer data storage media as they become available (but maintain older versions as well).
- Update software (e.g., database, spreadsheet) to newer versions as they become available.
- Store data media in ≥2 safe places (e.g., network server, office, home).
- Name files clearly with appropriate dates so someone else can find them.
- Provide metadata to describe files, their sources, and their purposes.

What do you wish you knew about data collected by your predecessors 30 years ago? What will your successors want to know about data you collected, 30 years from now? A large proportion of wildlife managers are nearing retirement age (McMullin 2004) which may result in a significant loss of institutional knowledge. In the context of database management, this knowledge is equivalent to metadata.

Metadata are information which describe and document data in a dataset. A data file is simply a set of numbers or words unless there is documentation to identify what values mean and how they can be used. O'Neil et al. (2005) noted the importance of metadata to document contents of a dataset, as well as how data were created, how to use data efficiently and effectively, and how to prevent loss of critical information, especially when staff move to other positions or retire. Inclusion of metadata is particularly important if data are made available to other people (within or outside your agency).

Over time, methodologies and personnel involved in mule deer monitoring will gradually change. Tracking those changes can preserve the value of data, either by maintaining consistent protocols or documenting transitions. Correct use of metadata can prevent problems such as loss of information with staff changes, data redundancy (multiple similar versions, sometimes conflicting), misapplication of data, and improper decisions based upon poorly documented data. As with all data, metadata need to be stored securely in a central location, in one format, following standard protocols (e.g., Kimball 1998), and backed up.

Metadata documentation is required of any spatial datasets created with federal funding (Huettman 2005, O'Neil et al. 2005). The Federal Geographic Data Committee (FGDC) provides detailed standards for spatial data sets and justification for their use (www.fgdc.gov/metadata). These standards should be applied to all mule deer datasets.

Typical metadata include

- Why data were collected and how they should be used.
- Who collected the data.
- What is included in the dataset.
- Definitions of variables and data fields, including units of measure.
- Clear definitions of any codes, labels, or specific terms (e.g., 1=male, 2=female).
- Methods used to collect data: where, when, and how collected (e.g., aircraft type).
- Conditions under which data were collected (e.g., weather).
- For spatial data: geodetic datum, coordinate system, and format (e.g., NAD 83, latitude-longitude, decimal degrees).
- When data entry occurred.

- How any secondary calculations were made.
- Known biases or other issues inherent in the data.
- Where data are stored (including back-up) and how they can be accessed.
- What software and statistics were used to create the database and analyze data.
- Who has permission to use, edit, and distribute data to others.
- Location of any summaries, reports, or publications.
- For data acquired elsewhere, a description of its origin and how it was obtained.

Images

Photographs, slides, and digital images represent unique and valuable data that cannot be stored in the same ways as typical data. Although many of the same principles of storage and accessibility apply, images must be cataloged to allow efficient retrieval and use. A first step is developing a system for naming files of digital photographs, including important identifying information (metadata) such as photographer's name, date, location, subject, and direction or aspect of view. Physical photographs and slides should be scanned to produce digital images and stored in a central repository, as well as saving physical originals.

Commercially available software is available for managing images. Images can be stored within databases, but usually require additional software or computer programming to allow for uploading files. Additionally, images stored in databases may be difficult to view or be viewable in limited software packages. A preferable alternative to storing images in databases may be to store images in a central filing system, then add locations of files to the database.

SUMMARY

The importance of designing monitoring efforts in the framework of statistically sound sampling cannot be over-emphasized. Many monitoring efforts fall short because they lack this critical component. Sampling designs allow the investigator to determine precision (reliability or repeatability) of resulting estimates. Measures of precision are necessary to determine the probability that implemented management approaches will achieve desired outcomes. The importance of statistically sound sampling must be recognized from the beginning of any monitoring effort, not at the end, by seeking advice of a statistician early in the design phase.

We present and discuss a wide variety of monitoring techniques organized by monitoring topic. Numerous population indices are discussed, with special attention given to weaknesses of correlating indices to actual changes in population abundance. Discussions of individual techniques are accompanied by descriptions of principal advantages and disadvantages of each. In addition, critical assumptions about techniques are presented, with pertinent literature sources provided for further investigation. Our intent is that readers of this document will find it essential to become informed on mule deer monitoring techniques.

Management Objectives

Before any monitoring data are collected, it is important to clearly state and understand your mule deer management objectives. Which type of data and technique are needed to meet objectives of the management effort? Management objectives are a combination of biological and social needs and are arrived at after considerable discussion and debate.

Some management objectives are easier to achieve than others and may require considerably less intensive monitoring than more complex objectives. You must understand what your management system is designed to do and critically evaluate what information is needed to reach those objectives. The section on recommended monitoring standards is designed to help the reader better understand what type of data and what intensity of measurement will be needed given a variety of typical mule deer harvest systems. As population management moves closer to maximized harvest objectives, monitoring intensity should increase to ensure harvest levels are appropriate. Developing a monitoring approach to provide data to ascertain if and when you have reached stated objectives is highly critical to efficient and successful management. A table is presented that identifies potential population parameters and the frequency at which measures should be made as management intensity increases. This analysis and synopsis is a very useful tool and deserves careful review and understanding. The first 2 sections in this handbook address these important topics and are a “must read” before moving on to selection of specific techniques.

Parameter Estimation Techniques

As would be expected, the meat of the document resides in the section on parameter estimation techniques. The reader is provided with a thorough discussion of a wide variety of mule deer monitoring techniques to estimate harvest, population trend, abundance and density, survival, age and sex composition, and body condition. A brief description of the purpose and use of each technique is presented. References to key literature sources for each technique are also provided. Following the introductory material, bulleted lists of advantages and disadvantages, including critical assumptions that must be made with each technique, are presented. To the uninitiated, this array of techniques may at first seem overwhelming. However, having these concise and succinct descriptions available in 1 document is an advantage and serves a need that has existed for some time.

This document is titled "Methods for Monitoring Mule Deer Populations." The reader will be exposed to a variety of methods presented to inform and assist in selection of the most appropriate approach for a given monitoring objective. Considering the wide variability in terrain, vegetative cover, and weather conditions across the range of mule deer, recommending any one approach is difficult and perhaps presumptive. However, the methodologies that have proven to be most reliable and dependable are recommended.

No single method can be expected to perform in superior fashion for every situation. Unfortunately, the adage "you get what you pay for" is pertinent to choosing monitoring approaches, and often methods that require the largest investments, either in human or fiscal resources, provide the most "bang for the buck." A key challenge in choosing a monitoring technique is to first decide the level of precision or accuracy required to answer the questions you are asking. That decision will then provide the basis for determining the most appropriate technique and level of investment required. However, users have demonstrated certain methods, if applied appropriately, will produce robust data. To aid the investigator in making these choices we have selected the methodology that we judge to be the most reliable and preferred approach for each basic parameter estimation process.

Harvest

Delays in obtaining harvest data prior to making future harvest decisions have haunted mule deer managers for decades. Mail or telephone surveys have been the gold standard for many years, but changing computer technologies are rapidly altering the landscape for estimating mule deer harvests. Development and access to the Internet opens doors to surveying hunters more easily and quickly. Concomitantly, improved software packages enhance the ability of a manager to analyze harvest data without having to handle the data. Recently, wildlife agencies have incorporated web-based surveys with telephone surveys (Lukacs 2007). Results of these efforts are promising, and with continued development this approach will likely be the preferred technique of the future. However, these probability-based surveys should not be confused with user-selected web or telephone reporting or questionnaires which are likely to result in substantive non-response biases.

Trends in Population and Demographics

Historically, one of the most common measures for assessing mule deer populations and demographics was some index of population trend. The underlying assumption of a trend index is that there exists a homogenous (across time, habitats, etc.) and proportional relationship between a change in the trend index and a change in abundance or other population parameter. The primary problem with trend indices is the relationship between an index and the population parameter in question has not been determined and is most likely not consistent.

Consequently, recommending any single trend index is difficult. We thoroughly describe advantages, disadvantages, and assumptions for a wide variety of indices that have been used. If a trend index is to be used, it will only be valid if employed with a sound sampling framework and when assumptions are met or addressed statistically. Historically, indices such as pellet group counts, minimum aerial counts, and harvest per unit effort, when applied appropriately, have provided useful information. Minimum aerial counts and classifications are the most commonly used indices. If an index is chosen as a method to monitor population trajectory or performance, it is imperative that the user investigate and determine the relationship between the index and the population parameter in question.

Abundance and Density – Sample-based Methods

One of the most desired measures of any wildlife population is an estimate of abundance. In all likelihood, more fiscal resources are allocated to estimating abundance than any other parameter. Estimates of abundance over broad geographical areas are often desired to manage mule deer populations. Given that obtaining total census counts of mule deer is impractical, development of statistically-based sampling systems becomes necessary.

There are a plethora of methods that have been employed, and most are based on the likelihood that deer can be observed from an aerial-based platform. The fact that detectability of mule deer is typically <100% has been widely demonstrated. Further, detection rates vary across habitats and result in underestimates of total deer present and the need to calculate some measure to account for this bias. The most common approach to estimate these biases includes variations and combinations of mark-resight, distance sampling, and sightability models. We present a thorough discussion of the advantages, disadvantages, and assumptions of each approach and it appears use of detection rates is appropriate.

The variability in detecting mule deer over widely differing habitats makes it necessary to develop correction factors by determining detectability of deer related to variables such as group size, overstory cover, terrain, snow cover, type of aircraft, observer experience, and survey intensity. Correction factors may be developed through a variety of techniques, although using radiomarked deer is the most common approach. Once an investigator develops a sightability model for a specific situation based on relevant covariates, future surveys can be conducted without the need for radiocollared deer. This approach, when applied under a sample-based system, seems to be the most robust and should be the template for obtaining mule deer abundance estimates.

Population Modeling

Various models have been used for years to provide mathematical simulations of mule deer populations. All models are dependent on the quantity and quality of data utilized. Earlier population models essentially allowed the user to manipulate a variety of parameters and assumptions to improve "fit" between observed and modeled data. These models were not very transparent and a major disadvantage was that users frequently did not understand or appreciate how data were being manipulated.

Optimally Fitted Cumulative models align predicted and observed parameter estimates using an objective mathematical algorithm based on an ordinary least-squares estimator. These models can be objectively evaluated and compared based on fit and thrift and appear to have several advantages over previous models. Advent of these models and associated software programs have greatly improved population modeling and brought greater credibility to this approach. We do not recommended use of population modeling alone as a method to make management decisions about mule deer populations, but OFC models can be valuable tools to better understand and evaluate population measures.

Survival Rates

Survival rates of adult females and fawns are the most important parameters influencing mule deer populations and very useful data for population models (Lukacs et al. 2009). A variety of approaches have been used to estimate survival rates, but use of radiotelemetry is the most efficient and direct method. A disadvantage is the relatively expensive equipment and monitoring costs. Software to analyze survival data has greatly increased utility of such data. Considering the costs of this approach, we recommend a subset of management areas be chosen to serve as "representative" of other areas, thereby avoiding the need to sample all populations of concern. The utility and robustness of data obtained from radiotelemetry renders it the method of choice when the observer is measuring survival.

Age and Sex Composition

Knowledge about the age and sex composition of a mule deer population is an important consideration in mule deer management. Various approaches have been utilized to determine these parameters. Bias in data obtained is a significant concern and can come from several causes such as observer error, or inadequate or improperly designed samples. Having well-trained, experienced observers who are able to accurately identify age and sex categories is highly important to obtaining valid data. The most common and recommended approach is to obtain composition data via observers in aircraft, preferably helicopters. Under some circumstances, observers might be more accurate if classifying deer during ground observations. However, the ability to sample larger and more inaccessible areas and obtain more observations from the air makes aerial measurements most efficient. Detection biases by age or sex class are major problems and must be accounted for. Generally, improved sampling designs that cover all habitat aspects are recommended.

Body Condition

Growing concerns and interest in the condition of mule deer habitats have spawned efforts to improve measures of mule deer body condition. There are 2 main types of body condition measures: morphometric measures such as skeletal size and body mass, and measures of body fat. Some measures are suited only to dead deer whereas others can be applied to living or dead deer. Once again, measures of body condition are indices and concerns about reliability of an index discussed earlier also apply here. Many of the body condition measures are somewhat subjective and rely upon observer training and consistency to be meaningful. Others, such as ultrasonography, produce more objective and repeatable measures of body composition. Few methods are robust across the entire range of mule deer body condition, so combinations of measures are often necessary and improve reliability of estimates. Combinations of more direct measures of body fat, supplemented by morphometric measures, seem to be the most promising approaches. As always, sound sampling approaches must be implemented.

Data Storage and Retrieval
Any monitoring effort is only as good as the data obtained. Considerable effort and care must go into planning how data will be recorded, transcribed, analyzed, stored, reported, and updated as media technology changes. Any break in this chain of events risks the loss of very expensive and perhaps irreplaceable information. Efforts directed at improving the data gathering process at the beginning of the monitoring effort will return great dividends once field work is done.

Stages of data handling are presented to help break the process into important components. To maximize benefits, data must be standardized and consistent in format, widely available to other users, secure, and safely backed up at multiple sites. Efficiencies of today's hardware and software allow data to be statistically analyzed and immediately reported. The ability to immediately construct summary tables and graphics must be maximized. How to organize and store data so these important steps can be realized is covered in considerable detail in the section on data storage and retrieval.

This handbook is designed to provide all mule deer investigators with useful reference information. The intent is to foster more informed and potentially consistent approaches to mule deer monitoring among investigators across the range of mule deer and lead to enhanced data sharing within and among states and provinces.

Finally, an important, but often overlooked, factor is the level of training of observers and, in the case of aerial monitoring, pilots. Data obtained using an appropriate technique, which has been implemented correctly, but collected by inexperienced or inadequately trained practitioners may suffer in quality. Time spent ensuring observers are familiar with the entire monitoring experience before actual data collection begins will pay great dividends.

As professionals, we owe the magnificent mule deer and the many publics who enjoy them our very best efforts in our monitoring work. The decisions we make can only be as good as the information we collect. This document should be a valuable link in this important process.

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APPENDIX A

OBJECTIVES AND PRACTICES APPLIED TO MULE DEER MANAGEMENT IN 18 WESTERN STATES AND PROVINCES

The following tables are based on survey responses from 18 of 23 wildlife agencies that are members of the Western Association of Fish and Wildlife Agencies and manage mule deer.

Table 1. Objectives applied to mule deer management in 18 western states and provinces.

Management objective	Jurisdiction	Percent
Population trend	AK, AZ, ID, KS, MT, NE, NV, ND, SD, SK, TX, YK	67
Population abundance	AB, AZ, CO, ID, MT, ND, OR, SD, SK, TX, UT, WY	67
Pre-season B:D ratio	ND, SD, SK, TX	22
Post-season B:D ratio	AB, AZ, CO, ID, MT, NE, NV, OR, TX, UT, WY	61
Buck age structure	AZ, KS, MT, NE, NV, SD, TX	39
Antler composition of harvested bucks	AZ, ID, MT, NV, OR, TX	33
Fawn:doe ratio	AZ, MT, NV, SK, TX	28
Hunter days	AK, AB, AZ, ID, KS, NV, ND, SD, YK	50
Habitat considerations	AK, AB, AZ, CO, ID, KS, MT, NV, SD, TX, UT, WY	67
Min. or max. buck harvest	AK, MT, NE	17
Min. or max. doe harvest	NE	6
Conflict management	AB, CO, ID, KS, MT, NE, ND, SD, SK, TX, UT, WY	67

Table 2. Harvest frameworks for any-weapon mule deer seasons in 18 western states and provinces. Does not include archery, muzzleloader, and special situations.

Harvest framework	Jurisdiction	Percent
Limited entry buck	AB, AZ, CO, ID, MT, NE, NV, NM, ND, OR, SD, UT, WY, YK	78
Limited entry either sex	CO, KS, NE, NV, OR, SD, SK, WY	44
Limited entry doe	AB, AZ, CO, ID, KS, MT, NE, NV, ND, OR, SD, SK, UT, WY	78
Unlimited buck	AK, ID, MT, NM, OR, TX, WY	41
Unlimited either sex	AK, ID, MT, SK, TX, WY	33
Unlimited doe	SK,WY	11

Table 3. Methods used to estimate mule deer harvest in 18 western states and provinces.

Management objective	Jurisdiction	Percent
Mail		
Random survey	AK, AZ, KS, ND, SD, SK, TX, WY	44
Complete survey	AZ, ID, NV, YK	22
Telephone		
Random survey	AB, CO, ID, MT, OR, TX, UT	39
Complete survey	AZ, NM, OR	17
Web-based		
Random survey	CO, KS, OR, WY	22
Complete survey	ID, NV, NM, OR, UT	28
Check station	AZ, MT, NE, ND, TX, UT, WY, YK	44

Table 4. Methods used to estimate mule deer population trend in 18 western states and provinces[a].

Method[a]	Jurisdiction	Percent
Helicopter		
Double count	AZ	6
Targeted (no detectability correction)	AB, MT, NM	17
Random sample (no detectability correction)	TX	6
Distance sampling	OR	6
Fixed-wing aircraft		
Double count	AZ	6
Targeted (no detectability correction)	MT, ND	11
Ground-based		
Count	AZ, KS, MT, SK	22
Pellet count	AK	6
Modeling		
Change-in-ratio	MT	6
Sex-age-kill	NM	6
POP-II	AZ, OR, WY	17
Agency model	AB, AZ, MT, SD	22
Population reconstruction	AZ, MT, NM	17
Harvest per unit effort	AZ	6
Monitor harvest	AK, AB, AZ, CO, ID, KS, MT, NE, NV, ND, SK, TX, WY	72

[a] The following methods were not used by any jurisdiction: helicopter sightability or mark-resight; fixed-wing sightability, mark-resight, random sample without detectability correction, or distance sampling; ground-based mark-resight or track counts.

Table 5. Methods used to estimate mule deer abundance in 18 western states and provinces[a].

Method[a]	Jurisdiction	Percent
Helicopter		
Sightability	ID, MT, OR, WY	22
Mark-resight	MT	6
Double count	AZ, MT	11
Targeted (no detectability correction)	MT, NM	11
Random sample (no detectability correction)	AB, CO, SK, TX	22
Fixed-wing aircraft		
Sightability	MT	6
Mark-resight	MT	6
Double count	AZ, MT	11
Targeted (no detectability correction)	MT, ND	11
Ground-based count	AZ, KS, MT, OR	22
Modeling		
Change-in-ratio	MT, WY	11
Sex-age-kill	NM	6
POP-II	AZ, NM, OR, UT, WY	28
Agency model	AB, AZ, CO, ID, MT, NV, SD, SK	44
Population reconstruction	AZ, MT, NV, NM	22
Harvest per unit effort	AZ	6

[a] The following methods were not used by any jurisdiction: helicopter or fixed-wing distance sampling; fixed-wing random sample without detectability correction; ground-based mark-resight, pellet counts, or track counts.

Table 6. Methods used to estimate survival of mule deer in 18 western states and provinces[a].

Management objective	Jurisdiction	Percent
Telemetry	AK, AZ, CO, ID, MT, OR, WY	39
Modeling		
Change in ratio	MT, UT, WY	17
POP-II	AZ, OR, UT	17
Agency model	AB, AZ, CO, ID, NV, SD	33
Life table analysis	AZ	6

[a] The following methods were not used by any jurisdiction: sex-age-kill or weather-based models.

Table 7. Methods used to estimate age and sex composition of mule deer populations in 18 western states and provinces[a].

Method[a]	Jurisdiction	Percent
Helicopter		
Sightability	ID	11
Double count	AZ	6
Targeted (no detectability correction)	AZ, CO, MT, NV, NM, WY	33
Random sample (no detectability correction)	AB, AZ, CO, ID, OR, TX	33
Fixed-wing aircraft		
Double count	AZ	6
Targeted (no detectability correction)	AZ, MT, ND	17
Random sample (no detectability correction)	AZ	6
Ground classification	AZ, ID, KS, MT, NE, NV, OR, SK, TX, UT, WY	61
Modeling		
Change-in-ratio	MT	6
POP-II	AZ, OR	11
Agency model	AB, AZ, SD	17
Population reconstruction	AZ, MT	11
Harvest per unit effort	AZ	6

[a] The following methods were not used by any jurisdiction: helicopter mark-resight or distance sampling; fixed-wing sightability, mark-resight, or distance sampling; SAK models.

Table 8. Methods used to estimate body condition of mule deer in 18 western states and provinces[a].

Method	Jurisdiction	Percent
Xiphoid fat	ID, UT	11
Body mass	CO, ID, MT, TX, WY	28
Antler growth	AZ, ID, MT, TX, UT	28
Skeletal growth	ID, MT	11
"Cook" method	ID	6
Femur marrow	WY	6

[a] The following methods were not used by any jurisdiction: kidney-fat index, Kistner score, ultrasound, blood indices, or urine indices.

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