In–Depth Analysis of Deer Management in Nova Scotia: A Critique of Current Policy and Suggestions for Future Management Approaches

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Introduction

The white–tailed deer (*Odocoileus virginianus*) constitutes one of the most important ungulate species of North America affecting various aspects of ecosystem dynamics (Russell et al. 2001). Their abundance has seen remarkable growth in recent decades, consistent with an overall increasing trend in ungulate populations worldwide (Stewart and Burrows 1989, Rooney 2001, Takatsuki 2009). Management of deer herds has therefore become an important conservation objective to prevent ecosystem degradation and to control adverse effects on human activity (Fuller and Gill 2001, Cote´ et al. 2004, Scheffer et al. 2001). However, in Eastern Canada, which lies to the northeastern extent of the white–tailed deer natural habitat, their abundance densities have substantially declined after exceeding their natural carrying capacity in mid–1980's (McCullough 1979, Patton 1991, Patterson et al. 2002, Crimmins et al. 2012).

Deer population growth in Nova Scotia is limited by several factors such as habitat quality, reproductive rates, road kill mortality and winter severity. Habitat availability also plays an important role in regulating population size as food competition becomes significant with increasing density. However, in addition to natural mortality, hunting is the most important limiting factor as indicated by several studies (Nelson and Mech 1986, Fuller 1990, Dusek et al. 1992, Van Deelen et al. 1997). Deer harvesting serves as a key management tool to control herd size and quality. This is achieved by increasing the number of antlerless permits when densities are high, thereby serving as a density regulation tool. Thus, effective management of the herd requires precise estimation of abundance which in turn depends on the sophistication of field methods and survey sampling techniques.

The focal areas of interest in this research include a review of existing deer related data collection methods, a synthesis of existing data sources to produce more reliable abundance trends and to build a statistical model to predict future population densities under varying harvesting pressure levels. Especially, given the amount of resources currently invested in conducting yearly Pellet Group Inventory (PGI) surveys, this project attempts to assess adequacy of line transect surveys in producing abundance estimates of the current and future deer densities.

2 Goals and Objectives

The main objectives of the project are as follows.

(i) Review white–tailed deer population assessment approaches in eastern North America, with a comparative assessment of techniques including population indices, population surveys and population models currently in use;
(ii) Critique current NS DNR deer management policy and suggest improvements;
(iii) Evaluate current NS DNR deer data collection and identify information gaps;
(iv) Assess the usefulness of PGIs for determining deer density and population estimates;
(v) Investigate the potential and application of population indices and population surveys; and
(vi) Develop and apply population dynamics models to predict future deer abundance under various harvesting regimes to suggest optimal harvesting policy.

The rest of this report provides a snapshot of the current progress on these objectives and outlines future direction of the project research. Mathematical and technical details of the relevant abundance estimation methods will be provided in the final project report.

Population Reconstruction Techniques

The fundamental building block of population reconstruction methods is a birth cohort, defined as a group of animals that share the same year/time of birth. Thus, a population consists of a specific number of cohorts, evolving over time through fluctuations in cohort mortality and fecundity (Hayne 1984). Hunting is often the major source of mortality in populations undergoing sustained harvest (Roseberry and Woolf, 1991), and therefore, plays a significant role in cohort composition in terms of age structure and sex ratio. This higher rate of hunting mortality as compared to natural mortality, coupled with the availability of harvest count data, allows application of population reconstruction methods to estimate recruitment, harvest mortality and minimum population size (Roseberry and Woolf 1991).

The basic input in most population reconstruction methods is age-at-harvest data comprising number of animals hunted by various age classes. Thus, age-at-harvest data collected over consecutive years provide a history of cohorts' harvest. Accurate determination of age classes is a crucial assumption inherent to all reconstruction methods. Virtual population analysis (VPA) and cohort analysis are the simplest reconstruction techniques originally developed in fisheries (Fry 1949, Pop 1972). The VPA approach is capable of producing estimates of individual cohort sizes and minimum population size. Downing (1980) was the first to develop a VPA based method for estimating terrestrial wildlife abundance. Dawning method produces estimates of age-specific harvest rates, fawn/doe and adult sex ratios, in addition to estimating minimum population size. Table 1 provides a list of various population reconstruction methods, summarizing respective assumptions, data input requirements, population quantities to be estimated and a criticism of their predictive ability.

A recent survey conducted by Tilton (2005) shows that population reconstruction is by far the most commonly used approach to estimate white-tailed deer abundance in North America. The main reason for its preference by wildlife biologists is that age-at-harvest data are readily available from harvest reports. Furthermore, collecting these data is much more cost-effective as compared to other methods such as aerial surveys and mark-recapture studies (Sutherland 2006). However, these methods have been shown to be highly sensitive to departures from key underlying assumptions. For instance, while analyzing the performance of the SAK method (Table 1), Skalski et al. (2002) conclude that the method has low precision when at least one of the input parameters (see Data Requirements in Table 1) is poorly estimated. Reliable application of this approach needs auxiliary sources of data such as an independent radiotelemetry study (Skalsi et al. 2002). In a similar recent study, Davis et al. (2007) discover that the Downing method performs poorly if age determination is biased and/or harvest mortality is not stable over time. At best, population reconstruction methods provide an index of overall abundance rather than an estimate of the absolute abundance (Roseberry and Woolf 1991). A population index provides useful information about long term population change only if it is proportional to the true underlying abundance. Construction of such indices is cost-effective for large scale trend monitoring in harvested deer populations; however low economic cost comes with a corresponding reduction in statistical accuracy and precision.

Alternative methods to estimate population size in game populations also exist that do not necessarily require age-at-harvest data as described in Table 1. These include Pennsylvania method (Lang and Wood 1976), harvest-sex-ratio (Hayne and Gwynn 1977), change-in-ratio (Conner 1986), index-removal (Petrides 1949, Eberhardt 1986) and catch-effort with removal (DeLury 1947, Bishir and Lancia 1996) methods, among others. A detailed review of these methods is provided by Roseberry and Woolf (1991), Tilton (2005) and Jeppesen (2009). These method are more or less similar to population reconstruction techniques in the sense that they provide population indices and are sensitive to departure from underlying assumptions (Boitani et al. 1995, Chen et al. 1998). Boitani et al. (1995) suggest applying various methods to the same harvest data to establish conclusions on the combined analysis for long term herd management. Pursuing this idea, Chen et al. (1998) employed maximum likelihood estimation approach to jointly apply change-in-ratio, index removal and catch-effort methods to construct indices that are more reliable as compared to individual methods.

Statistical Population Reconstruction (SPR) with Auxiliary Information – Recently, there has been a push to improve upon the precision and accuracy of the traditional methods of population reconstruction. It is now well established that reliable estimation of harvest rates, survival, recruitment and abundance is impossible from age-at-harvest data alone (Gove et al. 2002, Clawson et al. 2013). However, these population quantities can be jointly and accurately estimated if age-at-harvest data are augmented with auxiliary information such as independent estimates of annual abundance and annual harvest mortality (Clawson et al. 2013). Such auxiliary information can be collected, for instance, through mark-recapture or radiotelemetry studies. For example, Fieberg et al. (2010) used radiotelemetry data along with indices of hunter-effort and food availability as auxiliary data to reconstruct Minnesota black bear (*Ursus americanus*) population. More recently, Gast et al. (2013) employed independent mark-recapture estimates of total population size to calibrate an SPR model for elk (*Cervus elaphus*) in Michigan. Another recent example of SPR in the contest of a harvested deer herd management is given in Skalski et al. (2007), where they analyzed long-term trend in black-tailed deer (*Odocoileus hemionus*) population in Washington, USA. A simulation and sensitivity analyses by Clawson et al. (2013) further showed that utilizing auxiliary information in reconstruction models for black-tailed deer population in Washington greatly improved and stabilized population estimates even when historical age-at-harvest data was reduced.

Population Dynamics Modeling

Traditional population reconstruction methods only focus on estimating vital characteristics of a population with no or limited ability to predict future abundance. Population dynamics models, on the other hand, assume a specific growth model, such as the density-independent exponential growth model (Dennis et al. 1991, Holmes 2004), to study long-term dynamics of wildlife populations. A fundamental feature of wildlife populations, including the harvested ungulate herds, is density regulation, i.e. growth rate is negatively density dependent (Sibly and Hone 2002, Brooks and Bradshaw 2006). A suite of stochastic population growth models, such as theta-logistic and Beverton-Holt models (Beverton and Holt 1957, Gilpin and Ayala 1973) together with well-developed statistical techniques are available to model and test the presence of density dependence (Dennis and Taper 1994, Ponciano et al. 2009, Nadeem and Lele 2012). Time series of abundance estimates, such as those arising from mark-recapture or point count surveys, are frequently used to fit these models to study population dynamics and to predict future viability (Dennis and Otten 2000, Nadeem and Lele 2012).

Table 1. Population Reconstruction Techniques

Method	Assumptions	Data Requirement	Output	Criticism
Virtual Population Reconstruction (Fry 1949)	1. The ratio of harvest mortality rates to total mortality is constant over time 2. Age determination is unbiased	Harvest-by-Age counts	Estimates of 1. individual cohort size 2. minimum population size	The method ignores variability in natural mortality over time. This can result in markedly biased abundance estimates (Davis et al. 2007).
Downing's Reconstruction (Downing 1980)	Same as virtual reconstruction and: 3. Mortality rates are uniform in the oldest two age classes	1. Total harvest by year 2. A random subsample of Harvest-by-Age counts	Estimates of 1. individual cohort size 2. minimum population size 3. age-specific harvest rates 4. fawn/doe ratios 5. adult sex ratios	Same as above, plus estimates of population trend can be misleading if annual harvest rates and survival rates are highly variable over time (Davis et al. 2007).
Sex-age-kill (SAK) (Creed et al. 1984)	Same as virtual reconstruction and: 3. Estimates of adult sex ratio and female/offspring ratios are precise	1. Harvest-by-Age counts 2. Estimates of (a) total male harvest (b) proportion of total mortality associated with harvest (c) adult sex ratio and (d) female/offspring ratio	Estimates of 1. total population size 2. population sex ratio 3. Juvenile population size	Output estimates are highly sensitive to the precision of input estimates. Increasing precision of input estimates requires extensive field data which are usually very expensive to collect. (Skalski et al. 2002).
Virtual Reconstruction with catch-per-unit Effort (Fryxell et al. 1988)	Same as virtual reconstruction and: 3. Harvest rate is linear as a function of catch-effort and vulnerability	1. Harvest-by-Age counts 2. Estimates of age-specific survival rates 3. Index of hunting effort	Estimates of 1. individual cohort size 2. minimum population size	Accurate indices of hunting effort may not always be available. Furthermore, the method only works if considerable variation in catch effort over time is present (Roseberry and Woolf, 1991).
Statistical Population Reconstruction (Gove et al. 2002)	1. The fate of every animal is independent of every other animal 2. Auxiliary data are reported unbiasedly	1. Harvest-by-Age counts 2. At least one auxiliary source of information is available. Examples of auxiliary datasets are: (a) an independent telemetry study to estimate natural and hunting mortalities and (b) estimates of population abundance of in 1 year.	Estimates of 1. Total population abundance 2. Age-specific abundance estimates 3. Age-specific survival and harvest mortality rates 4. recruitment rate	In addition to age-at-harvest data, an auxiliary source of data must be available. However, these methods provide superior estimates of population quantities. Furthermore, they allow synthesis of various sources of information such as hunter-effort and independent abundance estimates (Gove et al. 2002, Skalski et al. 2007, Clawson et al. 2013).

Source: Roseberry and Woolf (1991) and Tilton (2005).

Age-structured models – Population dynamics models assume that all individuals in the population are equal with respect to various demographic characteristics, e.g. survival and fecundity and sex-ratio (Akcakaya et a. 1999). Consequently, the only requirement to fit these models is the availability of reliable estimates of total population abundance. In contrast, age-structured or stage-structured models attempt to explain variation in demographic characteristics at the level of age class or that of a particular stage in the life cycle (Akcakaya et a. 1999). A dynamical structure involving density-dependent growth can also be incorporated in age-structured models using the Leslie matrix formulation (Caswell 2001). One application of these models in harvested populations is to consistently maintain the population below its natural carrying capacity. For instance, Hauser et al. (2006) employed age-structured models to devise optimal harvest strategies that account for differences among age- or stage-classes of individuals. Although age-structured models capture demographic features of a population in considerable detail, estimation of these models require population abundance counts by age-structure, which can be economically prohibitive to maintain over several years.

State-space models (SSMs) – An important issue in fitting population dynamics models is to account for the fact that population time series counts are merely estimates of the underlying true abundances, and therefore, contain measurement error. A state-space model consists of two component: (i) a process (state) model describing population dynamics, and (ii) a measurement error model linking the error prone observed abundance to the true population counts. It is well-established in the recent ecological literature that unaccounted for measurement error can lead to biased estimates of key dynamical parameters and may even mask the form of the underlying growth model (Freckleton et al. 2006, Barker and Sibly 2008, Nadeem and Lele 2012). SSMs provide an effective framework for linking the stochastic observation error process to the stochastic population dynamics process (Pederson et al. 2011). Analysis of SSMs only entail time series of abundance estimates while valid statistical inferences can be drawn for the biological state process. Recent examples of application of SSMs in harvested wildlife population are provided in Chaloupka et al. (2007) and Fakusava et al. (2013).

Adequacy of PGIs for Determining Deer Density and Population Estimates

Deer population reconstruction in Nova Scotia can be based on age-at-harvest data collected through hunting reports. However, as discussed earlier, statistically defensible application of reconstruction methods require independent auxiliary information, e.g. total abundance, mortality, recruitment and catch-effort. These auxiliary data are usually collected through tagging studies, such as mark–recapture experiments over several consecutive years and can be further augmented by other sources such as aerial surveys and abundance rankings. Unfortunately, no auxiliary data source currently exists in Nova Scotia to partition white-tailed deer mortality in constituent factors; namely, natural, road–kill and hunting mortality. Furthermore, collection of catch–effort data (typically time invested by hunters in taking the deer) has only commenced as of year 2011.

The alternative strategy is therefore to use PGI data in tandem with transect–sampling based abundance estimation approach (Buckland et al. 2004). Nova Scotia DNR has been consistently conducting PGI surveys since 1982 on randomly located transect strips throughout the province. The department has also used these surveys to produce population indices and consequently suggest changes in deer harvest management. Currently, we have developed a time series population dynamics modeling approach to reconstruct deer densities and to predict future herd size. The modeling approach involves two main components (i) a density–dependent population dynamics model (Dennis and Taper 1994) to estimate intrinsic deer population growth rate, carrying capacity and magnitude of year–to–year environmental variation in density, and (ii) a transect–sampling model that utilizes PGI data to reconstruct deer abundance in conjunction with the first component. We also plan to augment harvest and road–kill data within our transect–sampling model to improve accuracy and precision of abundance estimates. Amount and duration of snowfall is an important limiting factor in deer survival in winter (Patterson et al. 2002). We intend to include snowfall data in our transect–sampling model as a predictor variable for deer mortality over the wintering months.

Our transect–sampling based modeling approach also has implications for a general transect–sampling method known as distance–sampling (Buckland et al. 2004). Unlike PGI surveys where detection of pellet groups over the transect strip is nearly perfect (i.e. probability of missing the pellets is very small), distance–sampling methods allow imperfect detection of objects over the surveys strips or plots. Imperfect detection is a common phenomenon when observing birds, reptiles, insects or fish which can go undetected during the survey effort owing to various habitat related factors. If unaccounted for, imperfect detection of animals can lead to severely biased density estimates. There exist sophisticated methods to account for imperfect detection, yielding reliable density estimates over the entire study region (Royle 2004, Royle et al. 2004). Since distance–sampling data are often collected over a number of years, population trend can be estimated from these data (Moore and Barlow 2011). Building on the model developments in our deer project, we have extended this simple trend estimation approach to fitting a full time series population dynamics model that allows abundance prediction in both space and time.

Deer Data Collection and Management Policy in Nova Scotia

In addition to being an important part of the ecosystem, white-tailed deer populations across North America provide a valuable recreational and aesthetic resource for humans. Overabundance of deer population can adversely affect diversity of local flora. This, in turn, influences the viability of animals that also forage on vegetation (Fuller and Gill 2001, Cote´ et al. 2004, Scheffer et al. 2001). Sustained harvest serves as a means to regulate deer densities, but uncontrolled hunting can endanger viability of the species. The Nova Scotia Department of Natural Resources is responsible for management of white-tailed deer population in the province which includes (i) to regulate and oversee harvest policy to maintain herd size at a sustainable level, and (ii) to collect deer related data for assessing population size and health quality of the herd.

Efficient management of wildlife requires continual development and maintenance of policies and regulations pertaining to the methodologies governing population goals, e.g. decreasing, stabilizing or increasing population density. Most US states, where white-tailed deer are naturally abundant, follow a rigorous deer management plan, which is periodically revised in order to adapt to the existing state-of-the-art and to address needs of various stakeholders (see, for instance, Rosenberry et al. 2009, Kroll et al. 2012). However, DNR does not currently have a written deer-specific plan detailing goals, guidelines and procedures to manage the population. Given that white-tailed deer is a keystone herbivorous species (Waller and Elverson 1997), this report strongly recommends development of a comprehensively written plan to streamline various aspects of white-tailed deer population management in Nova Scotia.

In Nova Scotia, the Department of Natural Resources (DNR) has traditionally collected deer data from several sources including (i) hunter harvest reports on sex, age, county, deer management zone and method of kill (and as of year 2011, abundance ranking and hunter effort), (ii) voluntary deer jaw returns (returned for an incentive crest) with age, sex, antler circumference and points (if male), county of kill and deer management zone, and (iii) line transect surveys of deer pellet group inventories (PGIs), completed across the province by provincial staff every spring, before green up. There are 458 such transects placed throughout the province that have been variously surveyed since 1982. Road–killed deer are also reported and assessed for age, health, and reproductive status during the critical period, Feb.1–May 15th each year. Mostly, PGIs have been used as the main data source producing deer density estimates – albeit without involving predictive modeling approaches.

Currently, not all these data are available for analysis in a digitized format. Rather, most of these data are scattered in various paper and digital formats. We strongly recommend creating a computer database to store all deer related data at one place, in a digitized format. This will ensure easy retrieval of information within the ongoing project and would facilitate accessibility for basic scientific research on white-tailed deer biology.

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