Improvement of a Catch-per-unit-effort Estimator for White-tailed Deer Populations

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Abstract: Catch-per-unit-effort (CPUE) is a useful index of population density that is often applied to harvested populations. Because CPUE is an economical index and data collection is simple, we wanted to enhance the user-friendliness and accessibility of a tool for tracking deer population abundance by recoding an existing FORTRAN estimator to JMP scripting language (JSL). Using the revised CPUE-JMP method, we estimated an antlered white-tailed deer (*Odocoileus virginianus*) population on Chesapeake Farms, Maryland, from 1981–2006 to compare the performance of CPUE techniques in a short (one-week) non-selective hunting season versus a longer (two-week) hunting season with selective harvest criteria. For reference, we compared CPUE estimates to a population reconstruction generated from harvest and natural mortality records. With compact hunting seasons and non-selective antlered male harvest, this easy-to-use, low cost method produced annual indices sufficient to see general trends within the white-tailed deer population.

Key words: catch-per-unit-effort, *Odocoileus virginianus*, white-tailed deer, population estimation, population index

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An estimate of relative population density is critical to understanding rates of increase and decrease, analyzing dispersal mechanisms, and determining a population's response to a management or harvest strategy (Caughley 1977, Novak et al. 1991, Rosenberry et al. 1999, Shaw et al. 2006). When obtaining annual estimates of absolute abundance is not feasible, indices are helpful and generate relative population estimates that can be compared across time periods. However, indices should be used with caution (Johnson 2008), and Eberhardt and Simmons (1987) raised concerns that indices do not necessarily reflect true population trends. Comparisons to known truth are not usually available, therefore indices can provide unreliable information due to their very nature (Fryxell et al. 1988). Gibbs (2000) stated that indices depend upon the assumption that true population trends are mirrored and the effects of observer, environment, and species behavior are minimal and consistent (Anderson 2001).

Because researchers rarely have the luxury of comparing indices to true population parameters, collecting and comparing additional, independent indices has been recommended (McKelvey and Pearson 2001). Uno et al. (2006) estimated population of sika deer (*Cervus nippon*) using five separate indices and concluded that spotlight survey was the least biased index. Further, Fryxell et al. (1988) suggested that a cohort analysis provided a useful reference to judge and calibrate abundance indices over time.

With a methodological breadth of indices to choose from, catch-per-unit-effort (CPUE) offers a relatively simple and inexpensive method for conducting population trend analysis and investigators do not have to capture any animals if a population is already harvested. CPUE as a proxy for true abundance is an approach commonly used to assess commercially-exploited fish populations where the fishery catch and effort is used to infer trends in population (Ricker 1958), but the use of CPUE may be effectively employed in wildlife management. CPUE techniques can be readily applied to terrestrial or aquatic populations under the following conditions: 1) the rate of catch is proportional to the level of effort expended and 2) a known decrease (or increase) occurs in the population (Lancia et al. 1996).

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Providing the two conditions are met, there are two basic assumptions of CPUE population estimations including 1) the population must be closed (except for known removals or additions) and 2) there must be equal catchability for all individuals within the population (Lancia et al. 1996). Short sampling periods minimize concerns over the closed population assumption (Lancia et al. 1996), but environmental fluctuations, varying hunter selectivity, behavioral responses of game to hunting pressure, and heterogeneity due to inherent individual characteristics may violate the equal catchability assumption (Lewis and Farrar 1968, Miller and Mohn 1993, Matsuda et al. 2002). Short, closely-controlled hunting seasons, in which hunters provide accurate effort and catch data, likely lend themselves to CPUE estimation. Also, a short hunting season decreases the likelihood of heterogeneous catchability attributable to behavioral response of game to hunting pressure and lessens the occurrence of unknown natural mortality, births, immigration, and emigration during the time interval (Lancia et al. 1988, Bishir and Lancia 1996).

Within the context of harvested populations and CPUE estimators, catch has traditionally been defined as the number of animals killed. However, Bishir and Lancia (1996) suggested that catch could be defined as sightings and harvests and described a joint sightings and harvest CPUE estimator developed in FORTRAN (IBM, Armonk, New York). Using sightings/harvest data from 1981–1991, Lancia et al. (1996) employed the CPUE-FORTRAN technique developed by Bishir and Lancia (1996) to estimate the antlered white-tailed deer (*Odocoileus virginianus*) population at Chesapeake Farms, Maryland. Their approach employed iteratively reweighted least squares in a generalized linear model, and estimates were compared to a population reconstruction derived from hunter harvest data from Maryland's shotgun season (late November–early December). Albeit lower, the 1981–1991 CPUE-FORTRAN estimates closely followed the reconstructed population, and assumptions of equal observability and known changes in the populations were likely minimized due to the short duration (one-week) of firearms hunting seasons (Lancia et al. 1996). Nevertheless, their CPUE estimates for the antlered white-tailed deer population closely mirrored reconstruction trends within the male population and were deemed sufficient for most management applications (Lancia et al. 1996, Tilton 2005). Unfortunately, the CPUE-FORTRAN estimator was not widely used by biologists, managers, and laypersons possibly due to the cumbersome nature of FORTRAN coding, complicated data input, slow computation speed, and lack of user help resources.

Our objectives were to: 1) make the joint sightings/kill CPUE index more accessible to potential users by converting the FORTRAN code to JMP scripting language (JSL) and 2) compare CPUE-JMP estimates for a short one-week hunting season with no antler restrictions to a longer two-week hunting season with quality deer management (QDM) antler restrictions.

Study Area

Chesapeake Farms was located on the Eastern Shore of Chesapeake Bay, 10 km southwest of Chestertown, in Kent County, Maryland. Owned by DuPont and operated by DuPont Crop Protection, Chesapeake Farms was a 1,300-ha wildlife management and agricultural research demonstration area. From 1981–1984, regulations allowed one antlered male per hunter, and starting in 1985 hunters were encouraged to harvest at least one antlerless deer in addition to an antlered male (Lancia et al. 1996). After 1991, the deer population and management program at Chesapeake Farms changed dramatically (Shaw 2005). In 1993, the one-week shotgun season was permanently extended to two weeks, and in 1994, management shifted to a QDM paradigm with a 7-point restriction placed on all antlered deer harvested. Essentially, QDM seeks to create an age structure with a greater proportion of older males through hunter restraint and harvest of an appropriate number of females. This results in a more balanced sex ratio and equilibrates the overall population with the available habitat (Miller and Marchinton 1995). In 1997, the harvest restriction was changed to protect antlered males with outside spreads less than 40 cm. Throughout the late 1990s and early 2000s, antlerless harvests increased to reduce crop damage. Because added harvest pressure was placed on females, the male:female ratio became increasingly balanced from the late 1990s (1:2.8) to 2006 (1:1.5; M. Conner, Chesapeake Farms, Chestertown, Maryland, personal communication) (Rosenberry et al. 2001).

Methods

To generate CPUE estimates, we used daily sightings, harvest, and effort data collected by hunters at Chesapeake Farms. Hunting was conducted from the same permanent stands every year, so sampling was spatially consistent and was not a potential bias. All hunters were required to collect these data and annual datasets were compiled by Chesapeake Farms staff.

We modified the original FORTRAN code into JSL using JMP 7 software (SAS Institute, Cary, North Carolina). The JMP iterative least squares uses the Gauss-Newton algorithm (described in Monahan 2001) to minimize the sum of squared errors for the CPUE model; additional changes included placing minimum and/or maximum bounds on starting parameters (e.g., the CPUE population estimate must be greater than or equal to the total number of known removals). We used default starting values (population size [N], probability that a sighting results in a harvest [p], and number of animals sighted per animal in the population per effort [*b*]) to generate all CPUE-JMP estimates.

We generated estimates of the antlered male population at Chesapeake Farms from 1981–2006. Only harvest data were used to generate CPUE-FORTRAN estimates in 1986 and 1991 (Lancia et al. 1996); hence, for comparison, we generated CPUE-JMP estimates similarly for the same years. We compared the CPUE-FORTRAN (Lancia et al. 1996) and CPUE-JMP estimates from 1981–1991 to reconstructed values (minimum-number-alive estimate) of the antlered white-tailed deer population at Chesapeake Farms (McCullough et al. 1990, Gove et al. 2002). The reconstruction was based on harvest and natural mortality records. Because some individuals are likely to be unaccounted for, even under the most controlled conditions (i.e., Chesapeake Farms), reconstruction estimates are slightly negatively biased. All harvested deer were aged using tooth wear and replacement characteristics (Severinghaus 1949) and comparison to known-age deer jaws from Chesapeake Farms. To reconstruct the antlered population from 1981–2006, we appended the existing (1981–1991) antlered reconstruction with 1992–2007 harvest data using the standard reconstruction method (Fry 1949, McCullough 1979, Roseberry and Woolf 1991, Lancia et al. 1996). Complete reconstructions lag several years behind harvest data because not all individuals have died in the recent cohorts (Fryxell et al. 1988, Pocock et al. 2004). Thus, we omitted 2005 and 2006 reconstruction and CPUE-JMP estimates from comparisons (Roseberry and Woolf 1991).

To make the 1994–2004 CPUE-JMP and reconstruction comparison equivalent to 1981–1993, we constrained the reconstruction to males that were vulnerable to harvest (i.e., males whose antlers met the minimum requirement). Pre-1994, any antlered male was eligible for harvest; afterwards, a proportion of antlered males were protected under selective harvest criteria and those males only graduated into the reconstruction when they met minimum antler requirements. We used data from hunter harvests in 1991–1993 to estimate the proportion of each male age class that had ≥7 points and would be vulnerable to harvest under the 1994–1996 7-point minimum antler restrictions. Twenty-one percent of 1.5-year-old males ($n = 39$), 44% of 2.5-year-old males ($n = 16$), 69% of 3.5-year-old males ($n = 16$), and 100% of ≥4.5-year old males ($n = 7$) possessed ≥7 points from 1991–1993. We applied the correction factors to the 1994–1996 antlered population reconstruction. Because Chesapeake Farms did not measure outside spread on harvested white-tailed deer, we were unable to calculate an outside antler spread correction factor based directly on hunter harvests. No known yearling male has ever met the 40-cm minimum outside spread requirement at Chesapeake Farms (M. C. Conner, Chesapeake Farms, personal communication). Using data collected from live deer captures in a GPS collar study (Karns et al. 2011), we estimated 25% of the 2.5-year-old males ($n = 8$) would fall short of the 40-cm minimum outside spread restriction. We applied these proportions to the 2.5-year-old male cohorts from 1997–2004. From 1997–present, hunters were permitted to harvest mature (≥3.5-year-old) males regardless of points/spread.

We used Pearson's correlation coefficient (r) to examine the relationship between 1981–1991 CPUE-JMP and 1981–1991 reconstruction, 1981–1991 CPUE-FORTRAN and 1981–1991 reconstruction, 1981–1992 (one-week hunting season) CPUE-JMP and 1981–1992 reconstruction, and 1995–2004 (two-week hunting season) CPUE-JMP and 1995–2004 reconstruction. Using a Fisher r-to-z transformation, we tested for significant difference between correlation coefficients of the 1981–1991 CPUE-FORTRAN and CPUE-JMP estimates to reconstruction using a two-tailed t-test. Also, the same statistical test was used to compare correlation coefficients of 1981–1992 CPUE-JMP and 1995–2004 CPUE-JMP estimates to corresponding reconstructions. We omitted 1993 from comparisons because it was the only two-week hunting season without antler restrictions. Additionally, due to relatively low and abnormally distributed harvests during the 1994 hunting season, estimates for 1994 were omitted from analyses. Alpha was set at 0.05.

Results

1981–1991 CPUE-JMP estimates were correlated to the 1981–1991 reconstruction values by $r = 0.805$ (df = 9, $P = 0.003$). Also, 1981–1991 CPUE-FORTRAN estimates were nearly significantly correlated to the corresponding reconstruction by $r = 0.597$ (df = 9, $P = 0.053$). Although we failed to detect significant difference between the correlation coefficients ($Z = 0.85$, df = 9, $P = 0.395$), the JMP estimates were consistently closer to reconstruction values than FORTRAN estimates (8 of 11 years; Figure 1). During one-

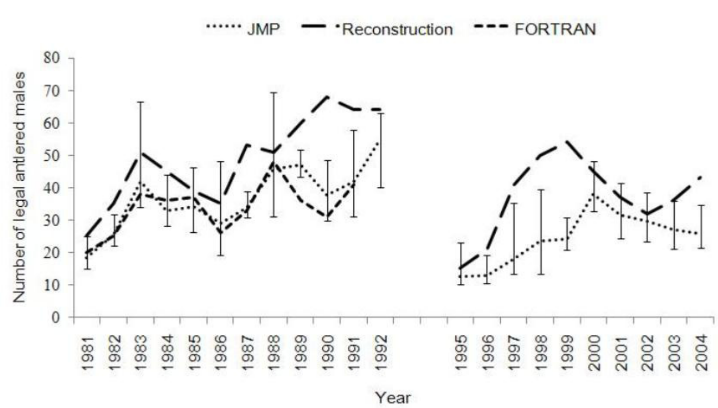

Figure 1. CPUE-JMP, CPUE-FORTRAN, and reconstruction estimates for the antlered male white-tailed deer population at Chesapeake Farms, Maryland, 1981–1992 and 1995–2004. The 95% confidence intervals pertain to CPUE-JMP estimates (dotted line).

week hunting seasons with non-selective antlered male harvest (1981–1992), CPUE-JMP estimates and reconstruction values were correlated ($r = 0.828$, df = 10, $P = 0.001$). Following the implementation of two-week hunting seasons and mandatory antler restrictions (1995–2004), CPUE-JMP and reconstruction estimates were not significantly correlated ($r = 0.576$, df = 8, $P = 0.082$). Again, the difference between correlation coefficients was not statistically significant ($Z = 0.94$, df = 8, $P = 0.347$). The 1992 CPUE-JMP estimate was based only on harvest data because the 95% confidence interval was unrealistically large (similar to 1986 and 1991) (Lancia et al. 1996).

Discussion

During the 22 years of study, the CPUE-JMP estimator tracked trends in population that suggested increases and decreases such as the drop in harvestable antlered males immediately following the implementation of antler restrictions and subsequent rise in harvestable animals as younger males were allowed to reach older age-classes. This suggests that 1) the use of CPUE methods can track and detect population responses to a management action and 2) implementation of selective harvest criterion had a large effect on the population. Though our results lacked statistical significance (possibly due to low sample sizes), CPUE-JMP performance during non-selective, short duration hunting seasons appeared better than longer hunting seasons with mandatory harvest restrictions.

As expected, our CPUE estimator performed better when a larger proportion of the population was removed (Gould and Pollock 1997). Novak et al. (1991) stated that increasing the number of sampling periods for CPUE techniques generally improved the accuracy of estimates. However, our two-week, QDM hunting season estimates deviated further from reconstruction values than one-week, traditional hunting season estimates probably because total removal did not increase proportionally to the amount of time available to hunt (e.g., 29 average male harvests 1981–1992 and 18 average male harvests 1995–2004). Because too few antlered deer were harvested on most individual days during the two-week hunting seasons, the linear relationship between catch and effort weakened, and estimates were more negatively biased.

Using a CPUE technique in a QDM setting with longer hunting seasons could introduce some confounding factors negatively biasing index values. Resulting from selective harvest restrictions, an increase in older age-class males increases the likelihood of heterogeneous observability – the single biggest factor in the negative bias of CPUE estimates (Lancia et al. 1996, White et al. 1982). Following antler restrictions, male age structure and harvest shifted from younger males (mostly 1.5-year-old males) to predominantly 2.5- and 3.5-year-old and older males (Shaw 2005). At Chesapeake Farms, previous studies have shown that a heterogeneity mark-recapture model best matched observations of marked deer, and heterogeneous observability was detected in radiocollared females (Conner 1986, Lancia et al. 1995). Yearling males display higher observability than older age-class males (McCullough 1979), and it is likely that overall observability decreased as the population moved to an older age structure and variation between individual observability increased (Roseberry and Klimstra 1974). Lancia et al. (1996) and White et al. (1982) assert that heterogeneous observability likely accounted for most of the negative bias in CPUE estimates. Again, acknowledging that CPUE estimates are not compared to truth but rather to a population reconstruction, increasing the hunting season to two weeks decreased the correlation between the 1995–2004 CPUE-JMP and reconstructed population estimates. Longer hunting seasons increase the heterogeneity of individual animal sightability because deer are more likely to be affected by hunting pressure and become less observable as the season progresses. Also, an additional week of hunting season increases the risk of unknown changes within the population (Lancia et al. 1996). Furthermore, hunter selectivity often increases beyond the required antlered restriction and could introduce an additional source of heterogeneity (Roseberry and Klimstra 1974, Coe et al. 1980, Novak et al. 1991).

The CPUE-JMP estimator is more user-friendly than its complicated FORTRAN predecessor and provides an effective method of attaining CPUE indices. Previously, users had to manually input harvest, sightings, and effort data into FORTRAN code and run the program through a compiler. CPUE-JMP users select appropriate data by clicking on data worksheet column headings and input into the code is automatic; and the estimator is versatile with a graphical user interface (GUI) allowing the client to generate population estimates based on sightings only, harvest only, or combined sightings/harvest data. Outputs include parameter estimates and their standard errors and 95% confidence limits, a fitted line graph, and a correlation matrix. Intuitive interfacing and text/graphic results available through JMP 7 enhanced ease of use, visualization of the data and outputs, flexibility of analysis options, and computation speed. The CPUE-JMP estimator is available to the public at the online JMP user community file exchange (http://www.jmp.com/community/). The JMP operating platform (JMP 7 or current version) is required for using the estimator, and a non-commercial individual user copy may be attained for a minimal charge. A README help file is located at the online JMP user community file exchange.

From 1981–1991, the CPUE-JMP estimates differed and were consistently closer to the reconstructed values than were the previous CPUE-FORTRAN estimates because JMP employs different algorithms and has stricter convergence criteria than the CPUE-FORTRAN program (Monahan 2001). When researchers have knowledge of the population, the CPUE-JMP index provides flexibility to allow the user to input custom starting values and override the default starting values calculated from the input data by JSL. Because starting values provide an initial value from which the convergence procedure begins, user-defined starting values that lie closer to the parameter estimate than JSL-computed values may result in more efficient convergence.

In conclusion, while we acknowledge the limitations of using indices solely to make management decisions, catch-per-unit-effort (CPUE) can be a useful index of population density that is often applied to harvested populations. This technique is most applicable to closely controlled hunts where hunters may easily collect accurate catch and effort data to use in the joint CPUE-JMP estimator. We produced a user-friendly JMP tool that is an improvement over the formerly available FORTRAN program. Based on increased heterogeneous observability, increased occurrence of unknown removals, and insufficient harvest levels, it appears that longer hunting seasons coupled with selective harvest antler restrictions reduces the index's effectiveness. As with any indirect estimate of abundance, discretion and rigor should be exercised to minimize assumption violations. The CPUE-JMP estimator is most appropriate to analyze trends in populations managed for maximum yield, with short hunting seasons, and non-selective harvest. If more accurate population estimates are required, other methods should be considered.

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