California Fish and Game 97(3):130-137; 2011

Sex ratio estimates of Roosevelt elk using counts and Bowden's estimator

Sara P. Weaver* and Floyd W. Weckerly

Department of Biology, Texas State University, 601University Drive, San Marcos TX 78666, USA

**Correspondent: sw1251@txstate.edu*

Adult sex ratios were calculated with count data, and with Bowden's estimator, and results were evaluated for potential bias in a population of Roosevelt elk (*Cervus elaphus roosevelti*) surveyed from 1997 to 2011. The mean and high count sex ratio estimates were two to eight percent lower, on average, than the Bowden's sex ratio estimates. Bowden's estimator accounts for imperfect detection and is more likely to reliably estimate sex ratios of Roosevelt elk and, potentially, other ungulates.

Key words: bias, Bowden's estimator, *Cervus elaphus*, count data, imperfect detection, Roosevelt elk, sex ratio, sightability

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Wildlife managers make difficult decisions regarding bag limits and harvest seasons of game animals. These recommendations are usually based, at least in part, on estimates of population size and adult sex-ratios (Leopold 1933, Scalet et al. 1996, Lancia et al. 2005, Bender 2006). It is widely accepted, however, that results obtained using count data collected from big game surveys are biased due to animals that are in the population but are unsighted during surveys, a phenomenon also known as imperfect detection (Caughley 1977, Samuel et al. 1992, Williams et al. 2002, Royle et al. 2007). When count data are used to estimate sex ratios, bias can be complicated by the fact that two segments of the population, male and female, are determined with unknown detection rates (McCullough et al. 1994).

Roosevelt elk (*Cervus elaphus roosevelti*) are a polygynous ruminant considered in California to be most abundant in Humboldt County (Harper et al. 1967, McCullough 1969, Weckerly 1996), with populations of unhunted animals occurring in both Redwood National Park and Redwood State Park (USDI 2000). Currently, there is no direct management of these populations; only habitat management and population monitoring occur (USDI 2000). In the case of Roosevelt elk, females have the responsibility of parental care, which leads to an increase in energetic demands. Moreover, female group sizes are often large (≥30); large group size and the demands of parental care should force females to use habitat with abundant forage, such as meadows (Clutton-Brock et al. 1982, Weckerly 2007). Males, however, have to consider social rank with other males (McCullough 1979), as well as nutrition and female distribution (Clutton-Brock et al. 1982). A likely consequence of male-male social interactions is that males often occur in smaller groups (2-10) that can forage in habitat, such as forest, with less forage (Weckerly 2001, Weckerly et al. 2001). When abundant forage in habitats is positively associated with meadows (areas generally used by females where elk are easily sighted) versus forest (where elk are more difficult to sight), predictions about biases in sex ratio estimates can be made. Sex ratio (males:female) estimates should underestimate the population sex ratio when imperfect detection is not considered, because males usually are sighted less frequently than females during surveys.

Bowden's estimators were designed to accommodate heterogeneity of sighting frequencies among animals when estimating abundance and herd composition (hereafter, sex ratio) (Bowden and Kufeld 1995). The abundance estimator has been shown to provide unbiased estimates of abundances in a number of computer simulations (Bowden and Kufeld 1995, Fattorini et al. 2007, Diefenbach 2009, Weckerly and Foster 2010). Bowden's sex ratio estimator has also been shown to provide unbiased sex ratio estimates (Weckerly and Foster 2010). Sex ratio estimates obtained with Bowden's estimator may provide less biased estimates than those obtained from count data.

Our study objectives were to (1) estimate adult sex ratios (males:female) of a Roosevelt elk population in Redwood National Park and Redwood State Park, California, USA; and, (2) determine if the estimates based on the mean and high counts of the sexes were biased low in comparison to sex ratios obtained using Bowden's estimator. These estimates were obtained from surveys conducted over a fifteen year period during 1997 to 2011.

Study Area

We studied elk within a 10 km^2 area of meadows and forest in the Prairie Creek drainage (41° 17' N, 124° 03' W) in Redwood National Park and Redwood State Park, Humboldt County, California, USA. The climate was maritime, consisting of wet and cool winters and dry and cool summers. Daytime temperatures in winter and summer were often less than 18° C. Precipitation consisted of fog in the summer and rain in the winter. Mean annual precipitation was >150 cm, most of which fell between October and May. Meadows had flat terrain and ranged in size from 13 ha to 51 ha, and were dominated by perennial and annual grasses (Harper et al. 1967). Parts of the drainage area consisted of riparian or riparian-meadow habitat that was dominated by a red alder (*Alnus rubra*) overstory. Meadows were surrounded by thickly canopied forests dominated by coastal redwood (*Sequoia sempervirens*), fir (*Abies* spp.), and Douglas fir (*Pseudotsuga menziesii*) (Weckerly 1998, 2007).

Materials and Methods

Surveys were conducted from a vehicle during January and February from 1997 to 2011. The route was established based on comprehensive observations of elk in the area from 1995 to 1997, and encompassed forests and meadows used by the elk population (Weckerly 1996, 1999). Within 30 days before each survey season all meadows and forests along the survey area were repeatedly searched and unique elk were identified from natural marks (Weckerly 2007). These marks were due to scars, notches and slits in ears, anomalous morphology, and antler dimensions (Weckerly 1996). The route was driven at dawn in a vehicle for 1.75 hours (Weckerly et al. 2004). When elk were spotted, unobstructed views were obtained and group size, age and sex, and a tally of marked elk were recorded. Elk were viewed for an adequate time (up to 15 minutes) and at distances (20-200 m) that decreased the chances of non-detection or misidentifying marked individuals. Data from animals suspected of being tallied multiple times during a survey were discarded (Weckerly 2007). Five surveys were conducted in 1998 and 1999, and 10 surveys were conducted in all other years.

Sex ratios were calculated based on males ≥2 years old and females that were ≥1 year old. Yearling males could be identified by their unbranched antlers, but yearling females could not be distinguished from older females. Yearling males were not used in the calculations because we were concerned with obtaining adult sex ratios. We estimated sex ratios and 95% confidence intervals using the Bowden estimator for herd composition ratios (Bowden and Kufeld 1995, Weckerly and Foster 2010). We used EXCEL to calculate estimates and associated 95% confidence intervals. We also estimated sex ratios using the mean and high counts of each sex. The high count was the highest count of males observed across the 5-10 surveys each year, and was the same for females. The 95% confidence intervals for the mean count were calculated according to Manly et al. (1993) and Weckerly (1993). A paired *t*-test was used to determine if there were differences between sex ratio estimates from Bowden's estimator and mean or high counts. We used an alpha of 0.10 to determine statistical significance.

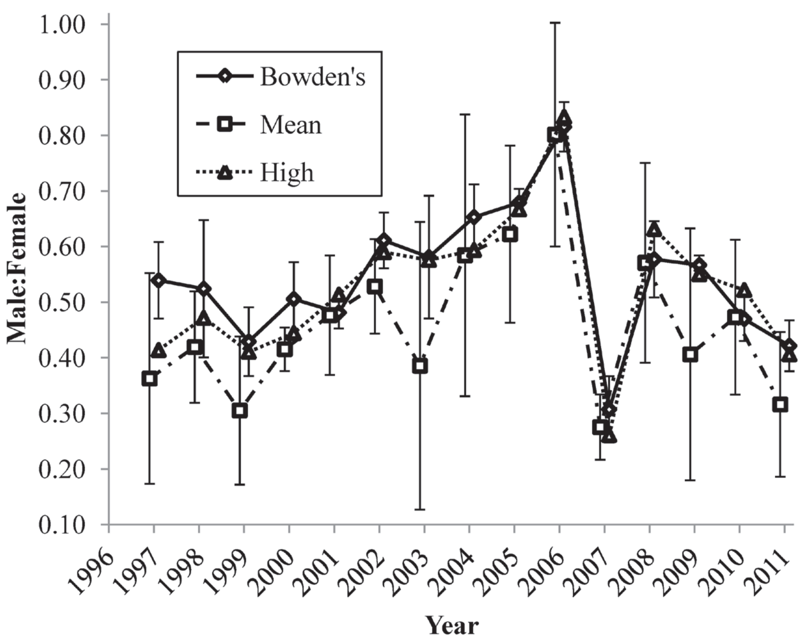

Figure 1.—Sex ratio estimates and 95% confidence intervals of Roosevelt elk derived from Bowden's estimator, the mean count data, and high count data, Prairie Creek drainage, Redwood National Park and Redwood State Park, Humboldt County, California, 1997-2011.

Results

Each year the number of marked animals ranged from 9 to 14 for males and from 6 to 17 for females (Appendix I). Bowden's sex ratio estimates fluctuated greatly throughout the 15 year period (Figure 1), ranging from 0.82 to 0.31. Sex ratio estimates from the mean count ranged from 0.80 to 0.28, and sex ratio estimates from the high count ranged from 0.83 to 0.28. In all years the mean count sex ratios were lower than Bowden's sex ratios. With the exceptions of 2001 and 2010, the sex ratio estimates from the high counts were lower than those derived using Bowden's sex ratio estimator. The results from the paired *t*-test showed a significant difference between Bowden's sex ratio estimates and the mean count (t_{14}=3.19; P=0.003) and high count estimates (t_{14}=1.51; P=0.077). The mean sex ratio estimates of Bowden's, mean, and high estimates were 0.544, 0.463, and 0.526, respectively.

Discussion

Our expectation that count data sex ratio estimates would be biased low in comparison to Bowden's sex ratio estimates was supported; the paired *t*-test revealed that both the mean and high count estimates were lower. When count data such as the mean and high count are used to estimate sex ratios, detection differences between the sexes can lead to biased estimates (Downing et al. 1977, McCullough 1982, Samuel et al. 1992, McCullough et al. 1994, Bender 2006). In the case of polygynous ruminants, such as the Roosevelt elk and other big game animals, males tend to be more affected by imperfect detection for many reasons, including group size, which may influence habitat use and sightability (McCullough et al. 1994, Berger and Gompper 1999). In landscapes containing meadows in a matrix of forests, as is the case in Redwood National Park and Redwood State Park, females use meadows where they are readily sighted, whereas males use forests more often and, as a result, they are difficult to see (Clutton-Brock et al. 1982, Weckerly 2001, Weckerly et al. 2001, Weckerly 2007). As our study indicates, this leads to biased sex ratio estimates using count data.

Imperfect detection seems to be common in surveys of ungulates (McCullough et al. 1994, Berger and Gompper 1999, White et al. 2001). A study conducted on black-tailed deer found that detectability of males and females differed, as did habitat use and behavior (McCullough et al. 1994). These differences led to biased sex ratios, age ratios, and abundance estimates (McCullough et al. 1994). Berger and Gompper (1999) conducted a meta-analysis on sex ratios in ungulates that found large variation in adult sex ratio (ASR) estimates. They suggested that ASR counts are overall biased towards females and can be caused by behavioral differences between the sexes, predation pressure, or errors in survey methodology to name a few. Berger and Gompper (1999) recommend that reducing sources of variation, such as errors in survey methods, is important when calculating sex ratios. White et al. (2001) suggested that imperfect detection will lead to bias in sex ratio estimates and, when detection probabilities change from year to year, this "noise" can be an additional source of variation.

Our sex ratio estimates were similar to sex ratio estimates for other populations of *C. elaphus* (Eberhardt et al. 1996, Howell et al. 2002). Eberhardt et al. (1996) reported herd composition data for an isolated population of Rocky Mountain elk (*C. e. nelsoni*). Their sex ratio estimates from count data over an 11-year period ranged from 0.24 to 0.62, which is similar to our range in estimates (0.31 to 0.82) calculated with Bowden's estimator. A study of Tule elk (*C. e. nannodes*) at Point Reyes National Seashore, California reported sex ratios from herd counts that ranged from 0.40 to 0.88 over a 13-year period (Howell et al. 2002). A long term study on *C. elaphus* in Scotland showed large variation (0.48 to 2.14) in sex ratio estimates using count data (Clutton-Brock et al. 1982). While this range of estimates is much larger than those we derived using Bowden's sex ratio estimator, that result could, in part, be due to the longer study period (22 years) and because management culled females, but not males, during some years of the investigation (Clutton-Brock et al. 1982). It appears that our range in sex ratios obtained with Bowden's estimator is similar to populations of *C. elaphus* based on results of other studies.

In 2001and 2010 the high count sex ratio estimates were greater than the Bowden's sex ratio estimates. Roosevelt elk show great variation in behavior from year to year (Weckerly et al. 2001, 2004; Weckerly 2007) and in some years the male segment of the population was found more often in meadows, which could be due to changes in food availability (Weckerly 2007). However, the results from the paired *t*-test show that, across the entire survey period, both the mean and high count sex ratios were lower than the Bowden's estimates. Another important result was the difference in precision between the mean count and Bowden's estimates. The confidence intervals of the mean count sex ratios were much larger than those of Bowden's. Sex ratio estimates from Bowden's estimator appear to be less biased and more precise when compared to estimates from mean counts; nevertheless, since the sex ratio of the population is unknown, it is possible that sex ratio estimates using Bowden's estimator also were biased.

Biased estimates are less likely, however, if the assumptions of Bowden's estimator (Bowden and Kufled 1995) are met. Weckerly (2007) discussed these assumptions; they are probably met because of the short survey season, habituation of elk to anthropogenic activity, the strong fidelity of females and males to particular meadows and forests near meadows, and the availability of naturally marked elk. Closure of the population is likely due to social bonding of females and because groups of females used meadows that were unoccupied by other socially bonded female groups (Harper et al. 1967, Franklin and Lieb 1979, Weckerly 1998). Males when in forests also showed high association with areas near particular meadows and generally were observed to occupy the same areas throughout the study period (Weckerly 1998, 2007). Also, over the short survey season animals are unlikely to die or disperse from the survey area. Further, animals can be viewed long enough to identify marked elk and uniquely identify them so errors from misidentification are unlikely. Finally, it is improbable that a naturally marked elk can be confused with other such animals (Weckerly 2007).

Assuming the aforementioned assumptions were not violated, these conclusions support our expectation. When sex ratios are estimated using count data, two segments of the population are counted, thereby leading to a greater opportunity for imperfect detection and biased estimates. Mason et al. (2006) suggest that correcting for bias using statistical aspects is imperative to obtain accurate surveys of ungulate populations. If there are issues with imperfect detection of either sex, using Bowden's estimator will help adjust for this bias and give a more precise estimate of the sex ratio. Furthermore, Bowden's estimator uses mark-resight survey methods that are practical for wildlife managers (Weckerly 1996). The only cost associated with these methods are the use of a vehicle, salary for one technician to observe elk and conduct surveys, and a high-powered spotting scope; there is no cost associated with capturing and marking elk or conducting aerial surveys (Weckerly 1996). Bowden's estimator has been used to determine herd composition data of white-tailed deer

(*Odocoileus virginianus*) in blind count surveys (Weckerly and Foster 2010), and a Colorado moose population (Bowden and Kufeld 1995). It is our recommendation that Bowden's estimator be used for estimating sex ratios of Roosevelt elk in Redwood National Park and Redwood State Park to better understand the status of the population. This methodology could also be of use with other closed populations of ungulates that are habituated to people, such as found on many game ranches and in other national and state parks.

Acknowledgments

Redwood National Park and Redwood State Park provided support and financial assistance. Partial funding was provided by the Elk Management Program of the California Department of Fish and Game, Rocky Mountain Elk Foundation, Redwood National Park and Redwood State Park, Alamo Safari Club, Granite Bay Safari Club, and Houston Safari Club. We thank A. Duarte and R. Luna for comments on earlier drafts of the manuscript.

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Submitted 14 June 2011
Accepted 24 June 2011
Associate Editor was V. Bleich

Appendix: Count Data for Roosevelt Elk Surveyed From 1997 to 2011

Summary of count data, by sex, for a Roosevelt elk population in Prairie Creek drainage, Redwood National Park and Redwood State Park, California, 1997-2011. Males counted were ≥2 years old and females counted were ≥1 year old. Total males and females are the sum of all the males and females counted during the survey year.

Year	Number of surveys	Total males	Number of marked males	Total females	Number of marked females
1997	10	202	11	557	8
1998	5	109	9	260	6
1999	5	83	11	272	7
2000	10	174	12	419	9
2001	10	171	9	359	7
2002	10	206	14	390	8
2003	10	123	12	319	12
2004	10	177	12	303	8
2005	10	168	12	270	6
2006	10	141	10	176	6
2007	10	109	13	396	17
2008	10	101	10	177	17
2009	10	78	11	192	11
2010	10	105	12	222	13
2011	10	101	14	320	9