ON THE RELATIONSHIP OF ANIMALS MARKED TO COST AND ACCURACY OF LINCOLN ESTIMATES

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Abstract: The relationship between the number of individuals marked to cost and accuracy of Lincoln Index estimates for a wild population of Key deer (*Odocoileus virginianus clavium*) of known size was examined. Data indicated that when 50% of the population was marked, there was a greater chance for an accurate estimate; also the cost to trap and mark deer was lowest.

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The purpose of this paper is to compare the relationships between the number of individuals marked, marking costs, and the accuracy of Lincoln Index estimates for a wild population of known size. Such a situation existed in our work with the Florida Key deer.

Several techniques to check the accuracy of population estimates based on live trapping data have been proposed, however, these generally have involved population simulation. Robson and Regier (1964) presented formulae and graphs of the relationships between sample size, cost, accuracy, and precision estimates from mark-recapture experiments. Their method, however requires an approximation, in advance, of the unknown quantity (N) which the experiment is designed to estimate.

Due to the difficulty of determining the total number of animals in a free-ranging population, the accuracy of population estimates has seldom been tested. Although mark-recapture accuracy determinations have been made for confined (Edwards and Eberhardt 1967) or artificial populations (Robinette et al. 1954, 1956 and 1975), the absence or suppression of normal animal behavioral patterns may have reduced the general applicability of the results.

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STUDY AREA AND METHODS

Data were gathered in conjunction with an ecological study of the Key deer on Big Pine Key, Monroe County, Florida. Deer were live-trapped using trail traps, drugs, and hand and portable drive nets (Silvy et al. 1975) throughout the study and marked with ear tags, ear streamers, collars, and radio transmitters; however for this paper, deer were considered marked only when they wore collars bearing individually identifiable reflective symbols.

A weekly 10 mile road census was conducted at 2300 hours over a predetermined route within the refuge on Big Pine Key from June 1968 through June 1972. Generally, censuses were completed in 1-1.5 hours. Two persons, spotlighting from opposite sides of a vehicle, observed and recorded deer by age and sex and whether or not they wore collars; those not so classified were recorded as unidentified. In most cases marked deer were individually identified. Fawns were not included in population estimates until October of their first year because few were active at night prior to this time. Application of the Lincoln Index to weekly data from the road censuses provided estimates of population size.

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To evaluate the relationship between the number of individuals marked in the population to the cost and accuracy of the Lincoln Index estimates, data for 1971 were used. An average of 77 of an estimated 121 deer for the area wore collars during any 1 week (Silvy 1975). Determination of a "known" population was accomplished by using all collar-marked deer as the "total" population. The marked population was subsampled at 10, 25, 50, 75, and 90 percent for a given week. These subsamples of the marked population were considered the only "marked" animals; other animals wearing collars were considered "non-marked". Selection of the "marked" animals to use in each subsample was by date of capture. First animals captured were considered "marked" until the needed percentage was filled. The use of first animals captured to fill the "marked" proportion of the population simulated actual field conditions where the first animals captured are the only ones used to estimate population densities. The sex and age ratios of animals in the subsamples varied throughout the study as animals lost their marks, died, and/or as more individuals were captured.

Fifty road censuses were used to provide the number of collared animals observed (438 collared of 686 total sightings). The ratio of "marked" collared animals to "non-marked" collared animals then served as the basis for our Lincoln Index estimates of the known marked population.

Estimated costs to trap and tag Key deer were provided by R. E. Hawkins, President, Wildlife Materials Inc. He provided costs for trapping and tagging from 1 to 77 deer at 1-deer increments. Estimated costs to trap and tag deer were developed empirically from this study.

RESULTS AND DISCUSSION

Relationship of Accuracy to Number of Animals Marked

Our data (Fig. 1) showed that the probability of underestimation was inversely

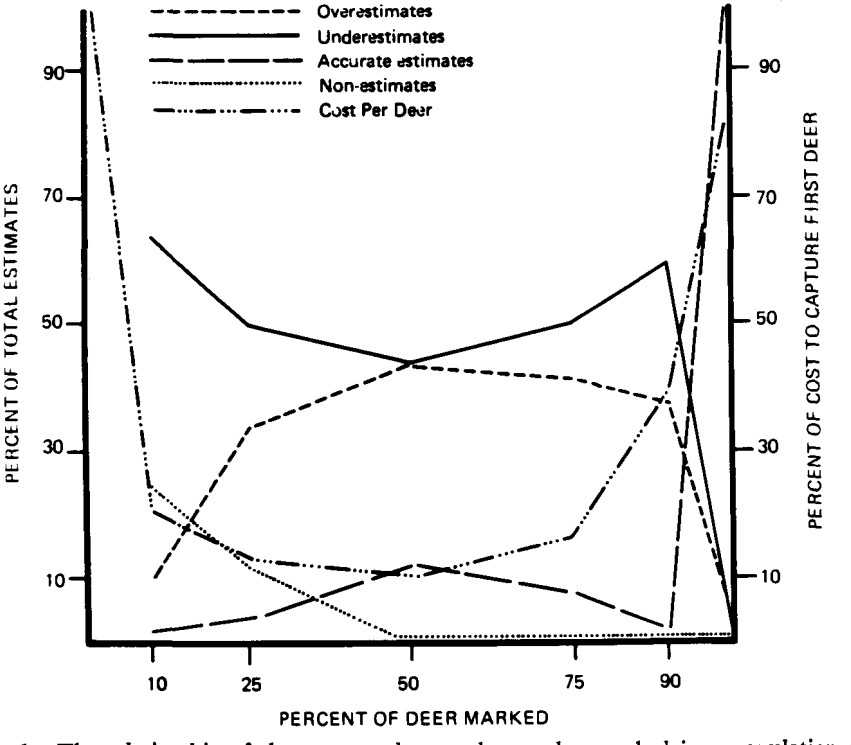

Fig. 1. The relationship of the cost per deer to the number marked in a population to the percent overestimates, underestimates, accurate estimates (100%), and non-estimates as determined by Lincoln estimates.

related to how few deer were in either the marked or unmarked categories. Most underestimates occurred when 10 percent or 90 percent of the deer were "marked". However, these latter underestimates were usually not as severe (average 8% less than actual) as those that occurred when few animals were "marked" (average 50% less than actual). When the number of animals "marked" approximated 50 percent of the population, there were equal probabilities of underestimating and overestimating the population, and a greater probability of obtaining an accurate estimate (100%).

Population estimates could not be made 24 percent of the time when 10 percent of the population was "marked", and 12 percent of the time when 25 percent of the population was "marked", due to the lack of "marked" deer seen on census. When a greater number of animals was "marked" the probability of obtaining a sample with no "marked" animals was less; however, when most of the animals were "marked" animals the chance of sighting a "non-marked" animal became less. Estimates made from a recapture sample in which all animals seen were "marked" gave an estimate equal to the total "marked" in the population at the time. In this situation, the population was always underestimated unless all animals in the population were "marked". Therefore, when a large percentage of the population is marked, an underestimation is likely.

When weekly population estimates were averaged for the year, estimates with 25 percent or more of the population "marked" provided close estimates of the 77 animals in the population (Table 1). Monthly estimates when averaged for the year produced

Table 1. The mean weekly Lincoln Index estimates and number of weekly underestimates, overestimates, accurate estimates and non-estimates of Key deer as determined by difference in the total number of marked animals in the population during 1971, Key Deer National Wildlife Refuge, Big Pine Key, Florida.

Percent marked	*Mean weekly estimate*	*Number of weekly underestimates*	*Number of weekly overestimates*	*Number of weekly accurate estimates*	*Number of weekly non-estimates*
10	46 ± 3.97[a]	32	5	1	12
25	83 ± 7.43	25	17	2	6
50	76 ± 3.36	22	22	6	0
75	80 ± 3.29	25	21	4	0
90	77 ± 1.95	30	19	1	0
100	77 ± 1.05	0	0	50	0

[a]Standard error.

similar results (i.e. samples with 10, 25, 50, 75, and 90% animals "marked" gave estimates of 55, 82, 74, 69, and 78, animals, respectively). With only 10 percent of the population "marked" the yearly average underestimated the population.

According to Eberhardt (1969), the usual capture-recapture methods may seriously underestimate population density. Robson and Regier (1964) have shown the Lincoln Index to be biased and that the extent of the bias was a function of sample sizes. Three inherent factors can affect the accuracy of Lincoln Index estimates. Robson and Regier (1964) noted that the number of animals marked (M) in the population and the recaptured sample size (C) both affected the accuracy of the Lincoln Index estimate. In addition, the assumption that all individuals in the population are equally likely to be recaptured at any time must be met. Therefore, results from our analyses could have been due to any of these or a combination of these 3 factors.

Because sample size was similar throughout our study ($\bar{X}$ = 8.76), it was considered to have a similar effect at all levels of subsampling. To test the assumption that animals captured first in the study did not differ in behavior from those caught later, the probability of observing individual Key deer along the census route was determined. Comparisons were made of the probabilities of observing along the census route those animals "marked" in the population with those "non-marked" (Table 2). These data indicated that the first 10 percent of the animals marked had a significantly greater probability of being observed along the census route than did the remaining 90 percent

of the total marked population. All other comparisons were nonsignificant. Because the first 10 percent of the marked population was more likely to be observed than the remaining 90 percent, a bias for underestimation of the population existed. This bias contributed to the large number of underestimations when only 10 percent of the population was "marked"; however, because no significant bias existed at the other levels (when 25, 50, 75, and 90% of the population was "marked"), the large number of underestimtaions at these other levels was more likely caused either by the small sample size, or the number of animals "marked" in the population. Although sample size may have an effect, as noted earlier, the number of marked animals in the population can also add bias to the Lincoln Index estimate.

Because of the close relationship between sample size and the number of animals marked in the population, accuracy can be increased when using the Lincoln Index if either or both of these variables are increased. The sample size of our study was set by the length of the census route. Because our data suggested that when 50 percent of the population is marked estimates are more likely to be accurate, it seemed reasonable to increase the number of animals marked in the population if we wished to increase accuracy of our Lincoln Index estimates. However, an additional question to be asked is "are such increases economical?"

Table 2. Average probability of observing individual "marked" and "non-marked" Key deer when different percent of the population is marked along 10-mile census route during 1971, Key Deer National Wildlife Refuge, Big Pine Key, Florida.

Percent marked	*Probability of observing*[a] *"marked deer"*	*Probability of observing "non-marked" deer*
10	0.16	0.09[b]
25[c]	0.10	0.10
50	0.11	0.10
75	0.10	0.11
90	0.10	0.11

[a]Probability of observing an animal at each opportunity equals 1.00.

[b]Differs significantly ($P < 0.05$) from probability of observing "marked" deer.

[c]Calculation of the probability of observing individual deer is cumulative, that is, the 25 percent marked includes animals in the 10 percent marked, etc.

Relationship of Accuracy to Cost

Estimates of costs to trap and tag from 1 to 77 Key deer at 1-deer increments (Fig. 1) indicated that such costs per deer are not in direct proportion to the number of deer marked. Contrarily, the cost to capture the first deer or the last deer of a population is much higher than the cost to catch deer when approximately half of the population is marked. The cost to trap the first deer must bear all the initial cost of trapping and as more deer are trapped, the cost per deer declines. However, the cost to capture a deer increases when there are few unmarked deer left because the chance of finding an unmarked animal decreases as more are captured. After 50 percent of the population is marked, the probability of capturing a non-marked deer declines to less than 50 percent. Prior to this the probability is always greater than 50 percent. As a greater number of deer are caught, up to 50 percent of the population, the cost per deer decreases; after this point cost increases because the probability of capturing a non-marked deer decreases.

Robson and Regier (1964) noted that the total cost of mark-recapture study consisted of fixed plus variable costs. Fixed or overhead costs were independent of sample size while variable costs depended on sample size. They assumed that variable costs increased in direct proportion to sample size; however, the difficulty of trapping fewer non-marked animals makes this an invalid assumption. Our data suggest that the best cost per deer to accuracy ratio of the Lincoln Index estimate occurred when 50 percent of the population is marked.

CONCLUSIONS

Because the cost per animal is lowest and the probability of obtaining an accurate estimate is highest when 50 percent of the population is marked, we suggest that mark-

recapture studies try to approach an equal ratio of marked to non-marked animals. By averaging estimates taken when 50 percent of the population is marked a more accurate estimate can be obtained.

Daily Lincoln Index estimates when less than 25 percent of the population is marked will usually lead to underestimations of the true population density. If greater than 50 percent of the population is marked, more of the estimates will also be underestimations. Unnecessary costs can be eliminated once 50 percent of the population is marked; further trapping not only increases total cost of the project but also the cost per animal increases.

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