POPULATION DENSITY OF THE ENDANGERED FLORIDA KEY DEER

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Abstract: With decreased illegal hunting and better habitat conservation, the Florida Key deer (*Odocoileus virginianus clavium*) population grew from an estimated 25–50 animals in the late 1940s to approximately 200 animals on Big Pine and No Name keys, Florida, USA, by 1971, the last official survey. U.S. Fish and Wildlife Service (USFWS) trend data indicate that the deer population continued to increase after 1971; however, current deer density estimates are necessary for the proposed reclassification of the Key deer from endangered to threatened. Our study objectives were to (1) obtain current population estimates of Florida Key deer and compare these to historical estimates, (2) evaluate survey methods (USFWS mortality and deer counts) in detecting changes in population trends, and (3) outline a protocol for future monitoring. Road counts (n = 889) were conducted from January 1971 to December 1971 and January 1976 to December 2001 on Big Pine and No Name keys. From mark–recapture data, we estimated that the Key deer population on these 2 islands increased by 240% between 1971 and 2001 (2001 estimate: 453–517 deer). Trend data indicated that annual deer mortality was a function of deer density or population size (r_s = 0.743). We compared the annual finite rate of increase (R) from USFWS annual deer counts and mortality data (R = 1.053–1.065) to mark–recapture studies (R = 1.038) and found them to be similar (P = 0.66–0.67). This similarity suggests that all 3 methods (USFWS deer counts and mortality data, and mark–recapture data) can be used to monitor changes in Key deer density.

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The endangered Florida Key deer, the smallest subspecies of white-tailed deer in the United States, is endemic to the Florida Keys on the southern end of peninsular Florida (Hardin et al. 1984). Key deer occupy 20–25 islands within the boundaries of the National Key Deer Refuge (NKDR), with approximately 75% of the overall Key deer population on Big Pine and No Name keys (Lopez 2001). Intense hunting pressure and habitat loss resulted in a decline in the Key deer population to an estimated 25–50 animals by the late 1940s (Dickson 1955, USFWS 1999). With a reduction in illegal hunting and the conservation of Key deer habitat through the establishment of the NKDR in 1957, the Key deer population grew to an estimated 200 animals on Big Pine and No Name keys by 1971, the last official survey (Silvy 1975). In 1998, Texas A&M University (TAMU) and USFWS began studies to estimate the population density of this federally protected subspecies. Trend data collected by USFWS biologists indicated that the deer population had increased; however, current deer density estimates, necessary in the proposed reclassification of the Key deer from endangered to threatened, are lacking (USFWS 1999).

Key deer were marked as part of 2 separate field studies (1968–1972, hereafter, historical study; and 1998–2001, hereafter, current study). In addition, USFWS biologists have collected deer mortality and trend survey data since 1968. Collectively, we used these data to (1) obtain current population estimates and compare these to historical estimates, (2) evaluate survey methods in detecting changes in population trends, and (3) outline a protocol for future monitoring.

STUDY AREA

The Florida Keys are a chain of small islands approximately 200 km in length extending southwest from peninsular Florida, USA. Big Pine Key (2,548 ha) and No Name Key (461 ha) are within the boundaries of the NKDR and Monroe County, and they support approximately 75% of the Key deer population (Lopez 2001). Soils vary from marl deposits to bare rock of the oolitic limestone formation (Dickson 1955). Typically, island areas near sea level (maritime zones) are comprised of red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and button-

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wood (*Conocarpus erecta*) forests. With increasing elevation, maritime zones transition into hardwood (e.g., gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipula*]) and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) upland forests with vegetation intolerant of salt water (Dickson 1955, Folk 1991). Approximately 24% of native areas have been developed in the last 50 years (Lopez 2001).

METHODS

Trapping and Marking

Key deer were captured as part of 2 separate research projects conducted December 1968–June 1972 (Southern Illinois University-Carbondale [SIU]; Silvy 1975) and January 1998–December 2001 (TAMU; Lopez 2001) on Big Pine and No Name keys. Deer were captured with either portable drive nets (Silvy et al. 1975), drop nets (Lopez et al. 1998), and/or by hand (Silvy 1975). Deer were physically restrained after capture with an average holding time of 10–15 min (no drugs were used). Sex, age, capture location, body weight, radio frequency (if applicable), and body condition were recorded for each deer prior to release. In addition, each animal captured was tattooed in an ear (Silvy 1975).

Deer were marked in a variety of ways depending on sex and age (Silvy 1975, Lopez 2001). We used plastic neck collars (8-cm wide) primarily for females of all age classes, leather antler collars (0.25-cm wide) for yearling and adult males only, and elastic expandable neck collars (3-cm wide) primarily for male fawns/yearlings. A battery-powered, mortality-sensitive radiotransmitter (<450 g, AVM Electronics Corporation, Champaign, Illinois, USA, 1968–1972; <110 g, Advanced Telemetry Systems, Isanti, Minnesota, USA, 1998–2000) was attached to approximately 67–75% of collars during both studies (Lopez et al. 2003). Collars on Key deer served as visual markers used in determining population estimates for Big Pine and No Name keys. The number of marked animals available during a survey (Krebs 1999) was determined from daily radiotelemetry observations and/or weekly road-count surveys.

Density Estimates

Road counts were conducted by SIU researchers from January 1971 to December 1971 and by TAMU researchers from January 1976 to December 2001 on Big Pine and No Name keys (Lopez 2001). We obtained survey data from 3 sources: (1) SIU: January 1971–December 1971, Big Pine Key (71-km route; Silvy 1975), (2) TAMU: March 1998–2001, Big Pine Key (71-km route, identical to SIU route; Lopez 2001) and No Name Key (4-km route; Lopez 2001), and (3) USFWS: January 1976–December 2000, Big Pine Key (56-km route; USFWS 1999). Historical survey data for No Name Key were unavailable for analyses; however, Silvy (1975) reported a population estimate of 34 deer from mark–recapture efforts for this island in 1973, and we used this estimate in our comparison. Both the SIU and TAMU weekly surveys were designed to estimate deer density on the islands using mark–recapture methods (White and Garrott 1990, Krebs 1999). The SIU/TAMU surveys began 0.5 hr before official sunrise and 1.5 hr before official sunset (Lopez 2001). In addition, a night spotlight survey was conducted between 2000 and 2100 hr on No Name Key during the current study (Lopez 2001). For the SIU and TAMU surveys, 2 observers in a vehicle (average travel speed 16–24 km/hr) recorded the number of deer observed along the survey route in addition to sex (male, female, or unknown), age (fawn, yearling, adult, or unknown), and whether the deer observed was marked or unmarked (Silvy 1975, Humphrey and Bell 1986, Lopez 2001). The starting and ending points for the SIU and TAMU surveys were alternated each week (e.g., north to south, south to north).

Population Trends

The USFWS monthly survey, modified from the original 71-km SIU/TAMU route, has served as the official survey route for NKDR since 1976 and has provided refuge biologists with an index to population size (Humphrey and Bell 1986, USFWS 1999). The USFWS spotlight survey began at 2000–2100 hr (Humphrey and Bell 1986). Similar to the SIU/TAMU surveys, 2 observers in a vehicle (average travel speed 16–24 km/hr) recorded the number of deer observed along the survey route in addition to sex (male, female, or unknown), and age (fawn, yearling, adult, or unknown; Silvy 1975, Humphrey and Bell 1986, Lopez 2001). Spotlights were used during the USFWS surveys. The starting and ending points for the USFWS survey were identical each time.

Since 1966, NKDR staff has recorded Key deer mortality as part of recovery efforts. Direct sightings, citizen reports, or observation of turkey vultures (*Cathartes aura*) helped locate most dead animals. Animals collected were either frozen

prior to necropsy or necropsied immediately. Carcass quality or ability to determine cause of death ranged from good to marginal (Nettles 1981, Nettles et al. 2002). Age, sex, body weight, and cause of death were recorded for each animal using procedures described by Nettles (1981).

Data Analysis

We estimated density for Big Pine and No Name keys from SIU and TAMU survey data using Lincoln-Petersen (Seber's modification) and Schnabel estimators (White et al. 1982, Krebs 1999). These survey routes met the requirements for both estimators because each survey adequately covered what was considered a closed population (both areas are islands, with limited dispersal between islands and small population growth), and a segment of the population was radiomarked when surveys were conducted.

We compared population estimates between islands and time of day (sunrise, sunset) using repeated-measures analysis of variance (ANOVA; Tzilkowski and Storm 1993, SPSS 2001, von Ende 2001). Repeated-measures ANOVA accounts for lack of independence when repeated observations are obtained from the same experimental units (Zar 1996). We log transformed density estimates and selected random samples within years to obtain a balanced design. Critical assumptions, such as normality and circularity within the variance–covariance matrix, were assessed prior to hypothesis testing. We tested for equality of error variances using Levene's test, and we examined trends among years (within-subject factor) using polynomial transformations (orthagonal contrast; von Ende 2001). Following Lomax (2001), we reported conservative Greenhouse-Geisser probabilities along with the standard F-statistic (Greenhouse and Geisser 1959). Last, we calculated an overall Schnabel estimate (Krebs 1999) between islands and study (historical, current), and we compared these estimates to averaged Lincoln-Petersen estimates.

To evaluate Key deer population trends from USFWS survey and mortality data (1976–2000), we compared the average number of deer seen annually to annual deer mortality using a Spearman's rank correlation coefficient (Ott 1993). We calculated the annual finite rate of increase (R; Caughley 1977) for successive years for USFWS survey and mortality data, and we compared the average of these estimates to estimates of R from SIU and TAMU survey data using a Student's t-test (Ott 1993, Minitab 1998).

RESULTS

Trapping and Marking

During December 1968–June 1972 and January 1998–December 2001, we captured and marked 434 Key deer (historical = 179, current = 255; fawn female = 41, yearling female = 43, adult female = 147, fawn male = 66, yearling male = 54, adult male = 83). The average number of marked animals available on a weekly basis by island and study was 76 (range = 62–90) for Big Pine historical, 48 (range = 34–64) for Big Pine current, and 22 (range = 18–35) for No Name current. Approximately 67–75% of animals captured were radiomarked during both studies (SIU = 120/179, TAMU = 191/255).

Density Estimates

We conducted 889 roadside surveys (USFWS = 266, SIU = 54, TAMU = 569; Table 1). From historical weekly surveys (1971), we estimated 167 (95% CI: 149 to 185) and 34 (95% CI could not be calculated; Silvy 1975) Key deer on Big Pine and No Name keys, respectively (Table 1). From current weekly surveys (1998–2001), we estimated 406 (95% CI: 378 to 433) and 76 (95% CI: 72 to 80) Key deer on Big Pine and No Name keys, respectively (Table 1). Conversely, Schnabel estimates indicated 170 (95% CI: 154 to 191) Key deer on Big Pine Key from historical surveys, and 390 (95% CI: 371 to 411) and 79 (95% CI: 75 to 84) Key deer on Big Pine and No Name keys, respectively, from current surveys (Table 1). Schnabel and weekly Lincoln-Petersen population estimates were similar ($P >$ 0.05; Table 1). Density estimates indicated the Key deer population on these 2 islands increased by 240% (482/201) between 1971 and 2001.

The repeated-measures ANOVA was conducted using a balanced design that maximized the number of surveys within each island × year × survey period combination. One data point (BPK sunset; estimate = 6.5 deer) was considered an outlier and removed from consideration. Because no other data were available, the 1971 population estimate of 34 (Silvy 1975) was used for No Name Key and resulted in a loss of homogeneity for that year (Levene's test; P = 0.004). All other years demonstrated equality of error variances by Levene's test ($P > 0.132$ for all remaining years). The repeated-measures ANOVA results indicated no year × survey (P = 0.743), year × island (P = 0.294), or year × survey × island (P = 0.304) interactions; therefore, population estimates among years were not influenced by either time of survey

Table 1. Florida Key deer density estimates for Big Pine and No Name keys, Florida, USA, 1971 and 1998–2001.

Year	Time			95% CI
Petersen estimates				
Big Pine Key				
1971	sunrise	26	141	123 to 158
1971	sunset	28	192	164 to 219
1998	sunrise	36	447	364 to 530
1998	sunset	36	366	322 to 410
1999	sunrise	48	400	350 to 449
1999	sunset	48	332	289 to 376
2000	sunrise	32	498	415 to 580
2000	sunset	33	408	331 to 486
2001	sunrise	7	571	159 to 983
2001	sunset	7	342	212 to 473
historical	sunrise	26	141	123 to 158
	sunset	28	192	164 to 219
	combined	54	167	149 to 185
current	sunrise	123	449	405 to 493
	sunset	124	363	332 to 393
	combined	247	406	378 to 433
No Name Key				
1998	sunrise	36	105	94 to 116
1998	sunset	36	81	73 to 89
1999	night	43	63	52 to 73
1999	sunrise	48	82	68 to 96
1999	sunset	48	74	60 to 88
2000	night	29	72	57 to 86
2000	sunrise	31	63	53 to 74
2000	sunset	34	69	59 to 78
2001	night	2	46	38 to 54
2001	sunrise	7	97	51 to 143
2001	sunset	8	77	52 to 101
historical[a]	combined	34		
current	sunrise	122	85	57 to 93
	sunset	126	75	68 to 81
	night	74	66	57 to 74
	combined	322	76	72 to 80
Schnabel Estimates				
Big Pine Key				
historical	combined	54	170	154 to 191
current	combined	247	390	371 to 411
No Name Key				
historical	combined	34		
current	combined	322	79	75 to 84

[a] Raw data from historical surveys for No Name Key were unavailable for analyses; however, Silvy (1975) reported an estimate of 34 deer from mark–recapture efforts for this island in 1973, and we used this estimate in our comparison when appropriate.

or island. The main effect for year was significant ($P < 0.001$), indicating that population estimates were different for at least 1 year. Pairwise comparisons among years (Fisher's least-squares difference) indicated that 1971 was significantly ($P < 0.001$ for all comparisons) different from all other years with all other years being more similar ($P > 0.05$). The main effect for survey indicated no difference ($P = 0.729$) between population estimates generated during the sunrise- and sunset-survey

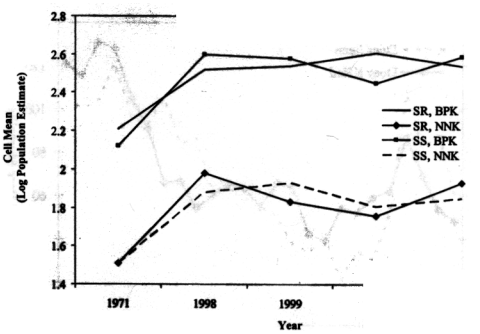

Fig. 1. Interaction line plot for Florida Key deer density estimates by year (1971, 1998–2001), island (Big Pine Key [BPK], No Name Key [NNK]), and survey time (sunset = SS, sunrise = SR) in Florida, USA.

periods. The main effect for island is a trivial hypothesis, but confirmed a significant ($P < 0.001$) difference between the population estimates. Polynomial contrast indicated a significant ($P < 0.001$) quadratic trend for the population estimates from 1971 to 2001 (Fig. 1).

Population Trends

Data indicated that annual deer mortality was a function of deer density or population size; a correlation ($r_s = 0.743$, Fig. 2) between annual deer mortality and monthly road-count data was found. We also found averaged annual R estimates from the USFWS survey ($R = 1.053$, 95% CI: 0.936 to 1.195) and mortality data ($R = 1.065$, 95% CI: 0.970 to 1.136) were similar ($t = 0.42$–0.44, $P = 0.66$–0.67) to R estimates from the SIU and TAMU studies ($R = 1.038$).

DISCUSSION

Density Estimates

As expected, we found differences in year (historical vs. current) and island (Big Pine vs. No Name), and we found no difference in density estimates for survey time (sunrise vs. sunset). Since 1971, the Key deer population on Big Pine and No Name keys has increased to an estimated 453–517 deer (1998–2001), the highest recorded population number. The noted quadratic trend for the population estimates from 1971 to 2001 suggests the population may be at or near carrying capacity for the current state of land use. The interaction plot (Fig. 1) illustrates this quadratic trend but caution is indicated due to the large number of intervening years with no data. We attribute habitat protection and a reduction in

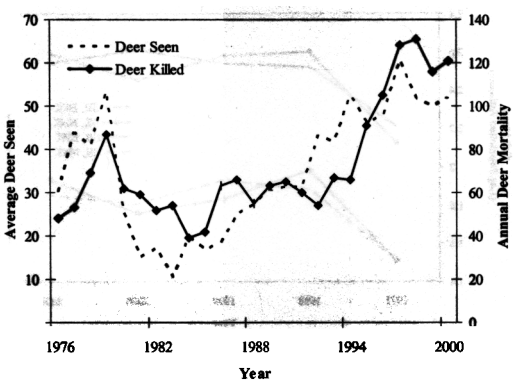

Fig. 2. Average number of deer seen on U.S. Fish and Wildlife Service monthly road counts and annual deer mortality on Big Pine Key, Florida, USA, 1976–2000.

illegal hunting as the primary reasons for the increase (Lopez 2001). For example, in the last 30 years, NKDR and other natural resource agencies have purchased and managed nearly 64% of these 2 islands for Key deer conservation (Lopez 2001). Furthermore, documented Key deer poaching has decreased nearly 10-fold since the 1970s (USFWS, unpublished data). We propose that urban development also might be responsible for the increase in Key deer numbers. For example, since the establishment of NKDR in 1957, approximately 717 ha (24%) of native habitats on Big Pine and No Name keys were developed (Lopez 2001) in concert with the Key deer population increase. The results of early development (prior to mid-1980s) probably benefited Key deer by the conversion of tidal areas such as mangrove and buttonwood forests into "uplands" (Gallagher 1991). Initially, the conversion and filling of these habitats provided Key deer with both native and ornamental vegetation (Lopez 2001). For these reasons, we propose that urban development in the form of land clearing increased the overall carrying capacity for Key deer on these 2 islands. Continued development in the form of houses and/or businesses, however, might not provide the same benefits as increases in secondary impacts (i.e., road mortality, habitat loss, fence entanglement) also would be expected (Lopez et al. 2003).

Population Trends

In comparing annual R estimates for the Key deer population, we found USFWS trend data were similar to and validated SIU/TAMU estimates. Since 1971, we estimate that the Key deer population has grown approximately 5% annually. The similarity in results between the mark–recapture estimates ($R = 1.038$), USFWS road-survey data ($R = 1.053$), and mortality data ($R = 1.065$) suggest that all 3 methods can be used to monitor changes in Key deer trends. In particular, the USFWS road-survey and mortality data are useful in monitoring population changes of this federally protected subspecies because data are collected each year by USFWS biologists. We recommend the continuation of both of these 25-plus year data sources.

MANAGEMENT IMPLICATIONS

The decision to consider downlisting the Key deer is based on current deer density estimates and recovery criteria that state an $R \geq 1.0$ for a 14-year period would warrant reclassification (USFWS 1999). As a result of our study, the reclassification of the Key deer from endangered to threatened has been proposed and currently is being considered by USFWS (Jay Slack, Ecological Services Field Supervisor, USFWS, personal communication). Other recovery criteria that should be addressed in the next several years include the establishment of other local populations of Key deer on outer islands. Overall, efforts by USFWS, state agencies, and conservation organizations have been instrumental in the first step toward Key deer recovery.

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